ICE PATCHES AND REMNANT GLACIERS: PALEONTOLOGICAL DISCOVERIES AND ARCHEOLOGICAL POSSIBILITIES IN THE COLORADO HIGH COUNTRY

By Craig M. Lee, James B. Benedict, and Jennie B. Lee

ABSTRACT

In recent decades archeological and paleontological remains have melted out of glaciers and ice patches on several continents, including North America. During the summer of 2002, hikers discovered the remains of bison (Bison bison), bighorn sheep (Ovis canadensis), mule deer (Odocoileus hemionus), and elk (Cervus elaphus) in association with three high-altitude ice patches in the Rocky Mountains west of Boulder, Colorado. Bison have been extinct in the region since the late 1870s. Radiocarbon dates for the bison specimens range from 2280 ± 30 B.P. to 210 ± 60 B.P. Carbon isotope ($\delta^{13}C$) values for the bison specimens range from –19.6 ± 1‰ to –13.7 ± 1‰, suggesting the animals spent time at lower elevations as well as in the high mountains. Although no definitive association between the paleontological specimens and native peoples can be demonstrated, Colorado ice patches may yet prove to contain evidence of prehistoric human activity. The possibility that humans and game animals exploited these frozen features prehistorically suggests promising new areas for archeological and paleontological research in the western United States. Survival of ancient bison remains in these environments implies that ice has existed almost continuously in these cirques for at least two millennia. Today's extreme melting is atypical.

INTRODUCTION

Snow and ice are unparalleled in their ability to preserve organic materials. By remaining at or below freezing year-round, bones, wood and herbaceous plant materials incorporated into ice patches are shielded from the natural processes of decomposition that occur in most other depositional contexts. The 1991 discovery of the "Iceman," or "Otzi," on Tisenjoch Pass in the Ötztal Alps is perhaps the most spectacular and well-known archeological discovery yet made in such environments. The Iceman's tool kit, which included a bark quiver with fletched arrows, fire-starting equipment of tinder and flint, and clothing, represents one of the most complete collections of materials dating to the European Neolithic ever recovered (Spindler 1994). Other spectacular archeological and paleontological materials recovered from melting snow and ice patches include prehistoric human remains (Beattie et al. 2000), hunting

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equipment, e.g., wooden arrows and atlatl darts with fletching and projectile points (Dixon et al. 2005; Hare et al. 2004; VanderHoek et al. 2004), as well as numerous organic objects with inferred functions ranging from storage containers to clothing (Dixon et al. 2005; Hare et al. 2004). Paleontological discoveries include *Rangifer tarandus* (caribou), *Bison* sp., and numerous species of microtines, or small rodents (Farnell et al. 2004). Examples of artifacts collected by Hare et al. (2004) and members of four southern Yukon First Nations on ice patches in the Yukon Territory of Canada are illustrated in Figure 1.

Following an unusually dry winter (2001–2002) and warm summer (2002), hikers observed and/or collected the remains of bison (*Bison bison*), bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*) at two high-altitude ice patches and one small glacier in the Front Range of the Colorado Rocky Mountains. Previous reports place bison remains in association with similar, perennially frozen locations in southern Montana in the 1890s (Fryxell 1928:138) and in Colorado as recently as 1981 (Armstrong 1987:188). Bison had become rare in this part of Colorado by the late 1860s (Kindig 1987), and were probably extinct by the mid-1870s. This paper describes the three Colorado discoveries, and explores how and why humans may have exploited ice patches prehistorically. It suggests that the archeological and paleontological discoveries in Alaska and Canada may have parallels at low latitudes in the Rocky Mountains. The paper concludes the rapid melting

FIGURE 1. From top to bottom, examples of carved antler projectile points, arrow shafts, and other culturally modified wooden artifacts found at ice patches in the Yukon Territory of Canada (Photo: Craig Lee).

now occurring in the mountains of Colorado has almost no precedent in the past 2,000 years.

ICE PATCHES AND THEIR RECENT HISTORIES

"Ice patches" are perennial ice and snow features smaller than glaciers. They show little evidence of down-valley flow and lack the characteristic crevasses of true glaciers. They exist in locations where topography and wind-driven snow work together to accumulate large drifts that resist seasonal ablation, or melt, during the warmer months. Appropriately oriented hollows are prime locations for ice-patch formation because they are shielded from the ablating effects of warm summer winds. In Colorado, many ice-patch locations are similar to the cirques that house extant glaciers. Some ice patches show evidence of past glacial activity (e.g., Little Ice Age moraines). Ice that formed under glacial conditions may be relict in these features.

Globally averaged mass-balance measurements, reflecting the ratio of accumulation to ablation over the course of a year or longer, suggest a marked increase in the rate of glacial melt since the late 1980s (Dyurgerov 2001) (Figure 2). The recent paleontological discoveries made in Colorado seem to coincide with this pronounced global climatic change. The current peak is part of a long-term trend that has been affecting glaciers in the continental interior for at least the past 100 years (Grove 1988:239–240). The current rate at which Colorado glaciers and ice patches are melting is unknown, as mass-balance data have not been revised for this region since the late 1970s (IAHS/UNESCO 1977).

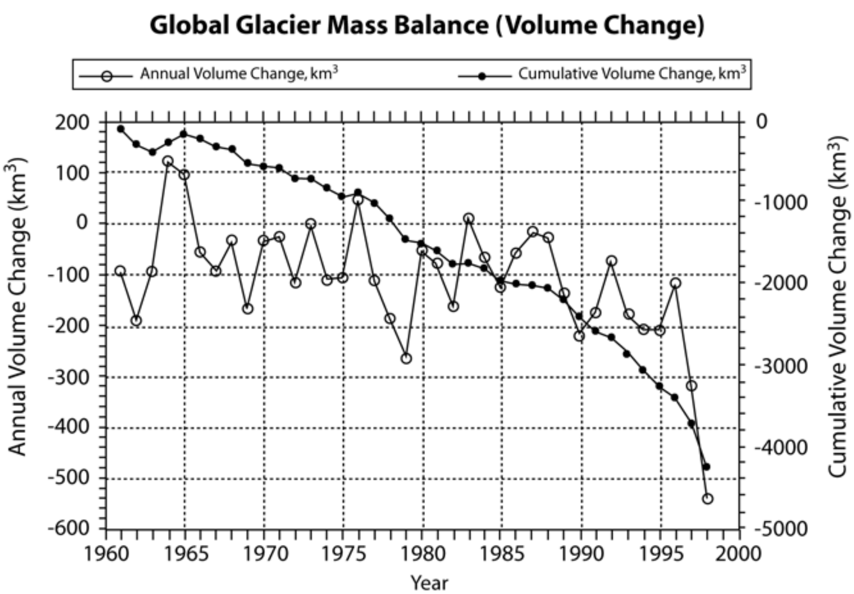

FIGURE 2. Global changes in glacier volume for the period 1961 to 1998 (reproduced from NSIDC 2004 by permission of Mark Dyurgerov).

COLORADO BISON DISCOVERIES

Buchanan Pass Glacier

In September, 2002, Jim and Bob Benedict visited the Buchanan Pass Glacier, southeast of Buchanan Pass at an altitude of about 3,600 m (11,800 ft), to replicate a photograph taken 80 years earlier. At the time of the 1922 photograph the glacier had already withdrawn from its youngest Little Ice Age moraine; however, as indicated by a distinctive crevasse, or "bergschrund," at the head of the glacier, ice was continuing to flow away from the cirque headwall. The bergschrund is visible in many historic photographs and was observed in 1990 and 2002 by one of the co-authors. During their visit to the glacier in 2002 the Benedicts found faunal remains and historic trash melting out of the ice. They collected a large-mammal humerus from the surface of the ice, and an antler tine from the foul smelling organic quagmire in the glacier forefield at the lower margin of the glacier. The remains of other large mammals, some still with flesh and hair, were also exposed at the time.

The collected humerus is complete and exceptionally well preserved, exhibiting Behrensmeyer's (1978) weathering stage 0 (Figure 3). Behrens-

FIGURE 3. *Bison bison* humerus in situ on the melting surface of Buchanan Pass Glacier. The open "Swiss Army" pocket knife is 16 cm long (Photo: Jim Benedict, September 2002).

meyer's weathering stages provide a standardized way of ranking bone decay, with 0 representing no degradation and 5 reflecting nearly complete deterioration. A weathering stage of 0 is atypical for ancient bone—a testimonial to the preservative qualities of ice. The specimen is damaged on its posterior lateral tuberosity but shows no visible toothmarks or other signs of carnivore modification. Examination of the humerus indicates it is from a bison (Balkwill and Cumbaa 1992). When compared to measurement data in Todd (1987:Table 5.18), the Buchanan Pass humerus is consistent with modern male *Bison bison* comparative specimens and archeologically recovered examples of extinct female *Bison antiquus*.

Following analysis of the humerus, nearly half of the specimen was submitted to Geochron Laboratories for conventional (non-AMS) radiocarbon dating. The assay returned an age of 210 ± 60 B.P. (GX-30359; bone collagen; δ^{13} = –17.8‰). Calibrated ages for this and other specimens appear in Table 1. Given its age, the specimen is probably from a modern male bison (*Bison bison*).

The antler tine is snapped at the base and is blackish gray in color. Its unusual coloration may stem from its association with water-saturated muck in the glacier forefield, though it could also be due to charring. The tine is tentatively identified as elk (*Cervus canadensis*). Examination under low-powered magnification showed that its tip was abraded. Though the specimen's broken base shows some similarity to the broken caribou antler tines discovered at many Canadian ice patches, its abrasion is probably consistent with the natural state of a shed antler. According to Hare et al. (2004:269), ". . . antler tine artifacts appear to have been intentionally selected and produced, but their function is uncertain . . . In all cases, they consist of a single tine removed from a palmate section of an antler beam. The tines have been snapped or cut off at a transverse angle and usually retain some portion of the palmation. Several of the tines show pitting or damage at the tip but it is not clear if this damage is cultural." Canadian archeologists have hypothesized that antler tines may have been used as pressure flakers on stone projectile points and knives and/or used as expedient skinning tools. Elk antler tines recovered by Henrikson (2003) in the "ice caves" of southeastern Idaho are thought to have been used in the excavation of frozen meat caches.

Game-drive structures occur on the tundra upland northwest of Buchanan Pass Glacier. Recorded by Benedict in 1969, the site (5GA33) was revisited by the authors in 2004, and the locations of cairns and blinds were mapped using a handheld GPS unit (Figure 4). Two trails cross the Continental Divide at Buchanan Pass. The most recent was built by the Civilian Conservation Corps (CCC) in the 1930s (Glenn Cook, personal communication 2005). The trail used prior to that time becomes snowfree earlier in summer, and is likely to have been the route followed by native people. Two drive systems are present on the tundra upland (Figure 4). The northern system consists of at least 45 low cairns, so poorly defined that to function satisfactorily as a drift fence they would have probably required the addition of brush or flagging (see Brink and Rollans 1990). Three circular and four semicircular blinds designed to conceal hunters from animals arriving from the west are associated

TABLE 1. Radiocarbon determinations from paleontological specimens associated with Colorado ice patches. All dates were calibrated using CALIB 5.0.2 (http://radiocarbon.pa.qub.ac.uk/calib/calib.html).

Site	UTM coordinates	Sample Description (and material dated)	^{14}C Age B.P.	$\delta^{13}C$‰	Calibrated Age Ranges (2-sigma) with .05 or greater relative area under probability distribution	Relative Probabilities for Age Ranges	Mean of Calibrated Age Ranges	Lab No.	Fig.
Buchanan Pass Glacier	Zone 13, 446470E 4442185N	*Bison bison* humerus (bone collagen)	210 ± 60	–17.8	A.D. 1521–1580 A.D. 1626–1892 A.D. 1908–1951	0.070 0.801 0.129	A.D. 1550 A.D. 1759 A.D. 1929	GX-30359	3
St. Vrain Ice Patch No. 1	Zone 13, 445975E 4443300N	*Bison bison* horn sheath (keratin)	2280 ± 30	–19.6	400–351 B.C. 300–230 B.C.	0.544 0.419	375 B.C. 265 B.C.	NSRL-13400	5
Horseshoe Creek Ice Patch	Zone 13, 448280E 4428440N	*Bison bison* skull (bone collagen)	2090 ± 45	–13.7	203 B.C.–A.D. 3	0.967	103 B.C.	NSRL-13455	6

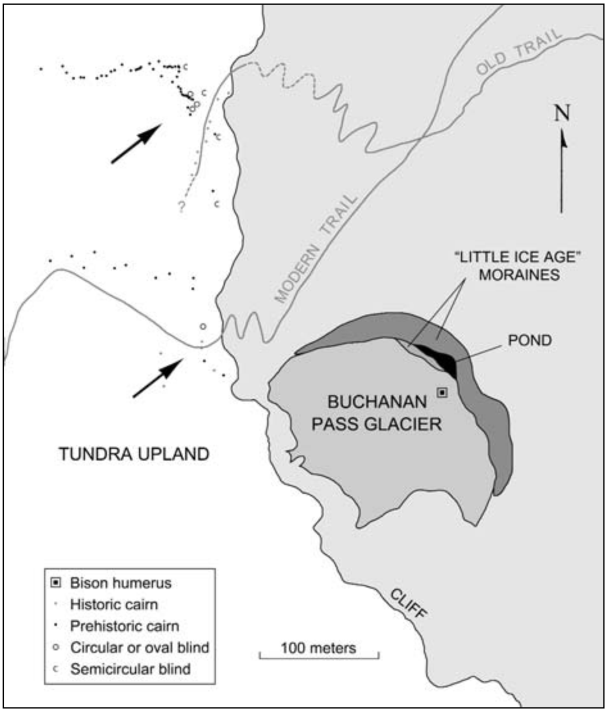

FIGURE 4. Game-drive structures on the tundra upland at archeological site 5GA33. Cairns and blinds are drafted larger than actual size. Historic and prehistoric structures were differentiated by differences in lichen cover. The Continental Divide is a short distance west of the cliff edge. Arrows show probable directions of game-animal approach.

with this system. The southern system is smaller, with only 12 cairns and a single circular blind. In 2004, several presumably discarded walking sticks were observed in the rocky cliffs directly above the Buchanan Pass Glacier. In hindsight, these sticks may have been "sewels" (Hutchinson 1990) used to support flagging associated with the drive-line systems.

St. Vrain Ice Patch No. 1

St. Vrain Ice Patch No. 1 is directly east of the Continental Divide, approximately 2 km north of Buchanan Pass, at an elevation of 3,625 m (11,900 ft). It occupies the first cirque north of Buchanan Pass and is the first permanent ice patch south of St. Vrain Glacier No. 1 (as numbered in IAHS/UNESCO 1977). Faunal materials were observed melting out of this remote ice patch in early September 2002, by Scott George, a resident of the Hygiene, Colorado, area. During his visit, Scott collected a bighorn sheep skull and bison horn sheath (Figure 5). The well-preserved horn sheath was found near the center of the ice patch, where it was embedded in "hard, clear ice" of uncertain, but possibly glacial origin. The sheep skull appeared to have recently rolled downslope onto aeolian sediments and plant detritus at the lower margin of the

FIGURE 5. Horn sheath from St. Vrain Ice Patch No. 1 with centimeter scale (Photo: Craig Lee).

ice patch. Scott noted that other bones were present and hypothesized they were related to the sheep skull.

A sample of the bison horn sheath (keratin) was submitted for AMS 14C dating to the Institute of Arctic and Alpine Research (INSTAAR) Laboratory for AMS Radiocarbon Preparation and Research (NSRL) at the University of Colorado at Boulder. The sample was prepared for dating using standard acid-base-acid macrofossil pretreatment methods. The radiocarbon assay returned a date of 2280 ± 30 B.P. (NSRL 13400; CURL-7080; keratin; δ^{13} = –19.6‰). Although the sheep skull was not submitted for radiocarbon analysis, the presence of vivianite on the skull argues for its antiquity. Vivianite is an iron oxide mineral that previously has been observed in association with animal remains buried in iron-rich damp silt (e.g., the Pleistocene fauna of Beringia; Guthrie 1990:79).

Horseshoe Creek Ice Patch

The Horseshoe Creek Ice Patch occupies a cirque at the head of an unnamed tributary to Horseshoe Creek, 2.8 km (1.7 mile) north-northwest of the historic mining camp of Caribou, Colorado. The cirque is separated from the Continental Divide by more than 4.5 km (2.8 miles) of rolling alpine tundra, a source of windblown snow in winter. Its elevation is approximately 3,325 m (10,900 ft). In late September 2002, Lee Tillotson, Bill Ikler, and Janet Roberts (residents of Nederland and Sugarloaf, Colorado) discovered bison bones scattered in a rocky area recently exposed by melting along the south lateral margin of the ice patch. Comparison of color photos taken by the hikers with black-and-white aerial photography taken in August 2001 suggests that the ice patch was unusually small in 2002.

The faunal remains recovered by the hikers were fragmentary. They included two bison horn cores and associated skull fragments (Figure 6), a vertebra, and part of a scapula. In contrast to the two locations reported above, these specimens are significantly weathered, exhibiting Behrensmeyer's (1978) weathering stage 5. Their degraded condition indicates periodic exposure by melting at this location. Because temperatures rarely drop below freezing beneath high-altitude snowbanks in Colorado, organic matter can decompose for much of the year (Holtmeier 2003:81). Thus bone will disintegrate quickly after it melts free of protective ice, even when reburied by subsequent snowfalls.

To assess the antiquity of the specimens, a relatively well-preserved portion of the bison skull was submitted to NSRL for AMS 14C analysis. The specimen was prepared using protocols established by Stafford et al. (1991:44) to produce an extract of amino acids from bone protein. The radiocarbon assay returned a date of 2090 ± 45 B.P. (NSRL-13455; CURL-7135; amino acids; δ^{13} = –13.7‰).

FIGURE 6. Two *Bison bison* horn cores from the Horseshoe Cirque Ice Patch with centimeter scale (Photo: Jennie Lee).

FAUNAL MATERIALS AND ICE PATCHES: MECHANISMS OF ASSOCIATION

The next section of the paper explores how bison, sheep, and cervid remains became incorporated into the ice patches. Possibilities include *natural mortality* (e.g., death due to old age or disease), *accidents* (e.g., death due to avalanches or entrapment in deep snow), and *human agency* (e.g., hunting of animals found on the ice patches, or storage of butchered remains for later use). Accidental death and natural mortality are discussed together, and human agency is examined separately.

Accidental Death and Natural Mortality

Historical accounts and skeletal remains show that bison made heavy use of intermontane basins and peaks in Colorado, at altitudes ranging to more than 12,000 feet (3,660 m) (Allen 1877; Fryxell 1928; Warren 1927). Although there are no historic records of bison frequenting ice patches at this latitude, woodland bison (*Bison bison athabascae*) reintroduced into southern Yukon Territory, Canada, have been observed in close proximity to ice patches (Oakley, personal communication in Farnell et al. 2004).[1] Researchers have suggested that caribou (*Rangifer tarandus*) venture onto these features to escape biting insects and/or to cool themselves (Anderson and Nilssen 1998; Ion and Kershaw 1989). Prehistoric bison in western Canada probably had similar motivations. Radiocarbon-dated bison remains from four southern Yukon ice patches range in age from 7510 ± 90 to 2840 ± 60 ^{14}C yr B.P. (Farnell et al. 2004:Table 4).

It seems possible that animals were attracted to Colorado ice patches to escape insect predation and summer heat, or for shelter from strong westerly winds; however, personal observations by the authors suggest that animals, including caribou and bighorn sheep, sometimes venture onto snowfields for the sheer novelty of a midsummer's romp in the snow. Reflected sunlight also may have played a role. Grinnell (personal communication in Fryxell 1928) postulated that one of the motivating factors for bison to move above tree line may have been the pursuit of sunshine, as mountain herds spent protracted periods of time in the trees. If bison routinely sought out ice patches, it is probable that, over time, a certain number of animals simply died there as a result of old age or poor health. Fatalities also may have resulted from natural events such as avalanches or predation from wolves and bears. In 2002, more than 140 caribou in Alaska were killed in a single snowslide (Selinger 2003). Avalanches are an important factor in bighorn sheep mortality (Paul Gilbert, personal communication 1995), and also may have impacted mountain bison.

Human Agency

Although no definitively cultural artifacts have been identified in the Colorado ice patches, there is ample evidence demonstrating that humans have utilized the surrounding mountains for at least 10,000 years (Benedict 1992, 2000, 2005; Pitblado 2000, 2003). Ice patches would have been attractive to humans for many reasons. Hunters could drive animals over cirque headwalls onto steep snowfields, or could trap them in deep springtime snow on ice-patch surfaces. If game animals tended to congregate on ice and snow, as they do in Canada and Alaska, their presence would have attracted human hunters to these locations. Further, snow and ice patches may have been used for storage of perishable food items.

As noted previously, archeological site 5GA33 is on the tundra upland northwest of Buchanan Pass Glacier. The locations and orientations of cairn lines and blinds at the site suggest that the drive systems were designed to kill animals on the Continental Divide, not to drive them over the cirque headwall onto the glacier (Figure 4). However, animals escaping between the blinds in early summer could have been intercepted by hunters in temporary blinds dug in corniced snowbanks just east of the Divide. The integration of such transient features into this type of hunting system would have been advantageous, and warrants further consideration.

No drive lines or hunting blinds are known to be associated with the St. Vrain No. 1 or Horseshoe Creek Ice Patches. It may be that formal, constructed blinds were not needed for hunting at these locations because boulders and other natural cover were readily available. In the southern Yukon Territory of Canada, about 15 percent of ice patches where artifacts have been recovered are associated with hunting blinds (Hare et al. 2004). No formal blinds have been discovered in association with Alaskan ice patches.

Native Coloradans are known to have used snow at least opportunistically to hunt bison. An ethnographic example, related to Oliver Toll in 1914 by Gun Griswold, an elderly Arapaho who had spent time in the Continental Divide region as a child, illustrates such a technique: "One winter a herd of buffalo cows in the Park climbed high on the slope of Thatchtop[2] and were caught there by the snow. The Indians climbed the mountain on snowshoes and killed many of them" (Toll 2003:11).

It seems possible that the cirque containing St. Vrain Ice Patch No. 1 could have been used as a natural trap for killing bison. Today, bighorn sheep use game trails that cross the Divide through narrow gaps in the rocks above the ice patch (Scott George, personal communication 2005). Given the right conditions, it might be possible to bog down an animal in transit to the pass in deep snow. This technique also could have been used at the Horseshoe Creek locality, where a well-worn game trail leads to the cirque from the west, descending the gentle headwall onto the ice patch. Though easily negotiable in summer, the ice patch could have served as a trap in winter or spring, when it is covered by deep, soft snow. The Buchanan Pass Cirque would probably not have been suitable for this kind of hunting, though its precipitous headwall could have been used as a jump. The only natural routes across the Continental Divide at this location were defended with drive lines and blinds, built to intercept animals as they traveled eastward (Figure 4).

All of the ice patches discussed in this paper could have been used to preserve meat for future use; however, only the antler tine from the Buchanan Pass Glacier hints at the possibility that these features were actually used in such a way. In the absence of definite human-made artifacts, it is far-fetched to associate the antler tine with human use of the glacier. In all probability the tine did not become abraded while being used for digging in the ice and snow, but represents a broken fragment of a naturally shed antler.

STABLE CARBON ISOTOPES AND BISON PALEOECOLOGY IN THE COLORADO HIGH COUNTRY

Historical accounts (Allen 1877; Fryxell 1926, 1928; Warren 1927) and archeological excavations (Kornfeld and Frison 2000; Pitblado 2003; Wilson 1981) demonstrate that bison regularly visited the parklands and mountains of Colorado. The ice-patch evidence presented thus far in this paper confirms that bison were present above timberline in Colorado during prehistoric times, but does not indicate how much of the year they spent in the alpine zone. Were the bison associated with Colorado ice patches simply crossing the Continental Divide while traveling between the mountain parks and plains, or were they long-term residents of alpine-tundra regions? Could large expanses of alpine tundra, blown free of snow in winter, enable year-round occupation? The seasonal movements of bison are important because they affected the hunting opportunities available to humans. Stable isotopes of carbon may reveal how the ice-patch bison apportioned their time geographically.

Comparison of $\delta^{13}C$ values obtained in this study with published $\delta^{13}C$ values reported for other bison of known provenance and presumed diet provides a way to evaluate the dietary histories of the ice-patch bison. All plants, including the grasses, sedges, and rushes that make up the bulk of bison diet (Fitzgerald et al. 1994), utilize predictable amounts of carbon and other elements such as nitrogen from the environment in which they live (Hobson and Welch 1992). All animals, including herbivores such as bison, concentrate the isotopes they consume into their bones, teeth, hair, and soft tissues, with predictable concentrations that reflect their diet and their trophic level in the food web (Rau et al. 1983). Herbivores possess higher concentrations of stable isotopes than the plants they eat, and carnivores possess higher concentrations of stable isotopes than the herbivores they eat.

In general, high-elevation and high-latitude grasses utilize the C_3 photosynthetic pathway, which yields $\delta^{13}C$ values averaging –26‰, whereas low-elevation and low-latitude grasses utilize the C_4 photosynthetic pathway, which produces $\delta^{13}C$ values averaging –12‰ (Koch 1998; Koch et al. 1994). Controlled tests designed to determine the carbon uptake response time in animals alternately fed C_3 and C_4 diets have demonstrated species-specific and tissue-specific differences between consumption of food and its incorporation into animal tissues (Sponheimer et al. 2003). Because bone is relatively slow growing, the carbon isotopes that it contains reflect a longer and more homogenous dietary history than do other products such as hair (Tieszen and Boutton 1988; Tieszen et al. 1983).

Compared with data compiled by Cannon (2004:Table 4), the $\delta^{13}C$ values obtained for specimens from St. Vrain Ice Patch No. 1 (–19.6 ± 1‰) and Buchanan Pass Glacier (–17.8 ± 1‰) overlap at one standard deviation with high-elevation specimens recovered in Idaho (–19.6 ± 1‰) and Utah (–18.8 ± 1‰). The two Colorado specimens have lower (more negative) isotopic signatures than specimens from Kansas (–13.8‰) and Nebraska (–15.9‰), but higher (less negative) isotopic signatures than specimens from Yellowstone National Park (–23.4‰) and Canada's Northwest Territories (–23.9‰; Cannon 2004:Table 4). The $\delta^{13}C$ value obtained for the bison horn from Horseshoe Creek Cirque (–13.7 ± 1‰) is comparable to values reported for the Kansas and Nebraska specimens. These comparisons suggest that, during their seasonal movements, all three Colorado bison consumed cold-climate (C_3) and warm-climate (C_4) plants, but that the animals whose remains were collected on Buchanan Pass Glacier and St. Vrain Ice Patch No. 1 spent a greater proportion of their time in cold environments than the bison whose remains were collected in Horseshoe Creek Cirque. The $\delta^{13}C$ value obtained from the Horseshoe Creek specimen may be skewed due to the degraded state of the bone (see Trueman et al. 2004), and consequently our interpretation should be considered tentative. A future study will assess this possibility by obtaining nitrogen-isotope values ($\delta^{15}N$), which may be less susceptible to post-depositional degradation. If the $\delta^{13}C$ and $\delta^{15}N$ values are present in appropriate proportions, it can be assumed that the $\delta^{13}C$ value accurately identifies the diet of the Horseshoe Creek bison as being rich in C_4 species.

CLIMATIC CHANGE

The discovery of ancient paleontological specimens in association with a melting glacier and two ice patches in Colorado is *at minimum* indicative of localized climatic instability and environmental change. The bison associated with Buchanan Pass Glacier almost certainly lived during the Little Ice Age glacial advances of A.D. 1600–1850 (Benedict 1985). In Arapaho Cirque, a short distance to the south, glaciers advanced at least three times during the Little Ice Age (Benedict 1973). Bison were abundant on the plains and in the mountain parks during this cold interval, probably due to improved forage. Population pressures in these areas may have encouraged increased use of the high country by bison.

Radiocarbon dates for the bison horn sheath discovered at St. Vrain Ice Patch No. 1 and the skull from the Horseshoe Creek Ice Patch suggest that ice began to accumulate at these locations at the onset of the Audubon glacial interval, around 2400 years B.P. (Benedict 1985). Their survival in an environment where exposed bone deteriorates rapidly due to low pH values, abrasion by windblown snow and sand, and gnawing by small mammals suggests they remained ice-covered and frozen throughout most, if not all, of the Medieval Warm Period (ca. A.D. 1100 to 1400) (Mann et al. 1999) and the warm interval that began at the close of the Little Ice Age.

The Horseshoe Creek Ice Patch and St. Vrain Ice Patch No.1 are an order of magnitude smaller in aerial extent than Buchanan Pass Glacier. Meltout of bison remains radiocarbon dated to 2090 ± 45 and 2280 ± 30 B.P. at these locations suggests that Audubon-age ice recently has become exposed at the surface. Such ice may contain macrobotanical remains and pollen of interest to ecologists. Both localities should be closely monitored over the next few years, as even older paleontological materials may emerge.

CONCLUSION

The presence of bison, sheep, and cervid (deer and elk) remains at three Colorado ice patches is better explained by natural mortality than human agency. It is worth noting, however, that in both Canada and Alaska, the discovery of paleontological specimens on snow and ice patches preceded the discovery of archeological materials. The possibility of human involvement at these or other locations should not be discounted. Melting of these features, as evidenced by the appearance of ancient paleontological materials that have survived for more than 2,000 years in this uniquely preservative and stable environment, implies a recent environmental change unequaled during the preceding two millennia.

Colorado, Montana, and Wyoming all possess glaciers and other perennial snow and ice features holding potential for paleontological and archeological site discovery. In *A Description of the United States' Contribution to the World Glacial Inventory*, Brown (1989) estimates that Montana has 106 glaciers covering a total area of 27 km^2, Wyoming has 81 glaciers totaling 49 km^2, and Colorado has 10 glaciers totaling over 2 km^2. Importantly, these estimates do not include the hundreds of smaller perennial snow and ice features or "ice patches" that coexist with glaciers but are not recorded by cartographers. Collectively these resources hold tremendous potential for aiding in the understanding of high-altitude human adaptation, animal ecology, and long-term climatological change. Small ice patches may be more valuable than glaciers in this regard, because ice travels through them more slowly, allowing older material to be preserved.

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REFERENCES CITED

Allen, Joel A.

1877 History of the American Bison, *Bison americanus*. In *Ninth Annual Report of the United States Geological and Geographical Survey of the Territories, Embracing Colorado and Parts of Adjacent Territories: Being a Report of Progress of the Exploration for the Year 1875*, by Ferdinand V. Hayden, pp. 445–587. U.S. Government Printing Office, Washington, D.C.

Anderson, John R., and Arne C. Nilssen

1998 Do Reindeer Aggregate on Snow Patches to Reduce Harassment by Parasitic Flies or to Thermoregulate? *Rangifer* 18(1):3–17.

Armstrong, David M.

1987 *Rocky Mountain Mammals: A Handbook of Mammals of Rocky Mountain National Park and Vicinity*. Revised ed. Colorado Associated University Press, Boulder.

Balkwill, Darlene M., and Stephen L. Cumbaa

1992 A *Guide to the Identification of Postcranial Bones of* Bos taurus *and* Bison bison. Canadian Museum of Nature Syllogeus No. 71. Ottawa.

Beattie, Owen, Brian Apland, Erik W. Blake, James A. Cosgrove, Sarah Gaunt, Sheila Greer, Alexander P. Mackie, Kjerstin E. Mackie, Dan Straathof, Valerie Thorp, and Peter M. Troffe

2000 The Kwäday Dän Ts'ínchi Discovery from a Glacier in British Columbia. *Canadian Journal of Archaeology* 24(1&2):129–147.

Behrensmeyer, Anna K.

1978 Taphonomic and Ecological Information from Bone Weathering. *Paleobiology* 4(2):150–162.

Benedict, James B.

1973 Chronology of Cirque Glaciation, Colorado Front Range. *Quaternary Research* 3(4):585–599.

1985 *Arapaho Pass. Glacial Geology and Archeology at the Crest of the Colorado Front Range*. Research Report No. 3. Center for Mountain Archeology, Ward, Colorado.

1992 Along the Great Divide: Paleoindian Archaeology of the High Colorado Front Range. In *Ice Age Hunters of the Rockies*, edited by Dennis Stanford and Jane S. Day, pp. 343–359. University of Colorado Press, Niwot.

2000 Excavations at the Fourth of July Mine Site. In *This Land of Shining Mountains. Archeological Studies in Colorado's Indian Peaks Wilderness Area*, edited by E. Steve Cassells, pp. 159–188. Research Report No. 8. Center for Mountain Archeology, Ward, Colorado.

2005 Rethinking the Fourth of July Valley Site. A Study in Glacial and Periglacial Geoarchaeology. *Geoarchaeology* 20(8):797–836.

Brink, John W., and Maureen Rollans

1990 Thoughts on the Structure and Function of Drive Lane Systems at Communal Buffalo Jumps. In *Hunters of the Recent Past*, edited by Leslie B. Davis and Barney O.K. Reeves, pp. 152–167. Unwin Hyman, London.

Brown, C. Suzanne

1989 A Description of the United States' Contribution to the World Glacial Inventory. In *Glacier Fluctuations and Climatic Change*, edited by Johannes Oerlemans, pp. 103–108. Kluwer Academic, Boston.

Cannon, Kenneth P.

2004 *The Analysis of a Late Holocene Bison Skull from the Ashley National Forest, Utah*. Midwest Archeological Center, National Park Service, Lincoln, Nebraska. Report No. AS–04–1010. USDA Forest Service, Ashley National Forest, Vernal, Utah.

Dixon, E. James, William F. Manley, and Craig M. Lee
2005 The Emerging Archaeology of Glaciers and Ice Patches: Examples From Alaska's Wrangell-St. Elias National Park and Preserve. *American Antiquity* 70(1):129–143.
Dyurgerov, Mark B.
2001 Mountain Glaciers at the End of the Twentieth Century: Global Analysis in Relation to Climate and Water Cycle. *Polar Geography* 24(4):241–336.
Farnell, Rick P., Greg Hare, Eric Blake, Vandy Bowyer, Charles Schweger, Shelia Greer, and Ruth Gotthardt
2004 Multidisciplinary Investigations of Alpine Ice Patches in Southwest Yukon, Canada: Paleoenvironmental and Paleobiological Investigations. *Arctic* 57(3): 247–259.
Fitzgerald, James P., Carron A. Meaney, and David M. Armstrong
1994 *Mammals of Colorado*. Denver Museum of Natural History and University Press of Colorado, Niwot.
Fryxell, Fritiof M.
1926 A New High Altitude Limit for the American Bison. *Journal of Mammalogy* 7(2):102–109.
1928 The Former Range of the Bison in the Rocky Mountains. *Journal of Mammalogy* 9:129–139.
Grove, Jean M.
1988 *The Little Ice Age*. Methuen, London and New York.
Guthrie, R. Dale
1990 *Frozen Fauna of the Mammoth Steppe*. University of Chicago Press, Chicago.
Hare, Greg P., Sheila Greer, Ruth Gotthardt, Rick Farnell, Vandy Bowyer, and Charles Schweger
2004 Multidisciplinary Investigations of Alpine Ice Patches in Southwest Yukon, Canada: Ethnographic and Archaeological Investigations. *Arctic* 57(3):260–272.
Henrikson, L. Suzanne
2003 Bison Freezers and Hunter-Gatherer Mobility: Archaeological Analysis of Cold Lava Tube Caves on Idaho's Snake River Plain. *Plains Anthropologist* 48(187):263–285.
Hobson, Keith A, and H. E. Welch
1992 Determination of Trophic Relationships Within a High Arctic Marine Food Web Using $\delta^{13}C$ and $\delta^{15}N$ Analysis. *Marine Ecology Progress Series* 84:9–18.
Holtmeier, Friedrich-Karl
2003 *Mountain Timberlines: Ecology, Patchiness, and Dynamics*. Kluwer Academic, Boston.
Hutchinson, Lewis A.
1990 Archaeological Investigations of High Altitude Sites near Monarch Pass, Colorado. Unpublished Master's thesis, Department of Anthropology, Colorado State University, Fort Collins.
IAHS/UNESCO
1977 *Fluctuations of Glaciers 1970–1975*, vol. III. World Glacier Monitoring Service, Paris.
Ion, Peter G., and G. Peter Kershaw
1989 The Selection of Snow Patches as Relief Habitat by Woodland Caribou (*Rangifer tarandus caribou*), MacMillan Pass, Selwyn/Mackenzie Mountains, N.W.T., Canada. *Arctic and Alpine Research* 21(2):203–211.
Kindig, Jean M.
1987 An Evaluation of an Ethnohistoric Account of a Plains Indian Communal Hunt in the Boulder Valley, 1862. *Southwestern Lore* 53(4):17–27.

Koch, Paul
1998 Isotopic Reconstruction of Past Continental Environments. *Annual Reviews of Earth and Planetary Sciences* 26:573–613.
Koch, Paul L., Marilyn L. Fogel, and Noreen Tuross
1994 Tracing the Diets of Fossil Animals Using Stable Isotopes. In *Stable Isotopes in Ecology and Environmental Science*, edited by Kate Lajtha and Robert H. Michener, pp. 63–92. Blackwell Scientific Publications, Oxford.
Kornfeld, Marcel, and George C. Frison
2000 Paleoindian Occupations of the High Country: The Case for Middle Park, Colorado. *Plains Anthropologist* 45(172):129–153.
Mann, Michael E., Raymond S. Bradley, and Malcolm K. Hughes
1999 Northern Hemisphere Temperatures during the Past Millennium: Inferences, Uncertainties, and Limitations. *Geophysical Research Letters* 26(6):759–762.
NSIDC
2004 National Snow and Ice Data Center Web Page. Electronic document, http://nsidc.org/, accessed January 1, 2005.
Pitblado, Bonnie L.
2000 Living the High Life in Colorado: Late Paleoindian Occupation of the Caribou Lake Site. In *This Land of Shining Mountains. Archeological Studies in Colorado's Indian Peaks Wilderness Area*, edited by E. Steve Cassells, pp. 124–158. Research Report No. 8. Center for Mountain Archeology, Ward, Colorado.
2003 *Late Paleoindian Occupation of the Southern Rocky Mountains: Early Holocene Projectile Points and Land Use in the High Country*. University of Colorado Press, Boulder.
Rau, Greg H., Alan J. Mearns, D. R. Young, R. J. Olson, Henry A. Schafer, and Ian R. Kaplan
1983 Animal $^{13}C/^{12}C$ Correlates with Trophic Level in Pelagic Food Webs. *Ecology* 64:1314–1318.
Selinger, Jeff
2003 Units 7 and 15 Caribou Management Report. In *Caribou Management Report of Survey and Inventory Activities 1 July 2000–30 June 2002*, edited by Carole Healy, pp. 1–33. Alaska Department of Fish and Game, Juneau.
Spindler, Konrad
1994 *The Man in the Ice. The Discovery of a 5,000-Year-Old Body Reveals the Secrets of the Stone Age*. Harmony Books, New York.
Sponheimer, Matt, Todd Robinson, Linda Ayliffe, Ben Passey, Beverly Roeder, Lisa Shipley, Elvia Lopez, Thure Cerling, Denise Dearing, and Jim Ehleringer
2003 An Experimental Study of Carbon-Isotope Fractionation Between Diet, Hair, and Feces of Mammalian Herbivores. *Canadian Journal of Zoology* 81:871–876.
Stafford, Thomas W., Jr., P. E. Hare, Lloyd Currie, A. J. T. Jull, and Douglas J. Donahue
1991 Accelerator Radiocarbon Dating at the Molecular Level. *Journal of Archaeological Science* 18(1):35–72.
Tieszen, Larry L., and Thomas W. Boutton
1988 Stable Isotopes Terrestrial Ecosystem Research. In *Stable Isotopes in Ecological Research*, edited by Phillip W. Rundel, James R. Ehleringer, and Kenneth A. Nagy, pp. 167–195. Springer-Verlag, New York.
Tieszen, Larry L., Thomas W. Boutton, K. G. Tesdahl, and N. A. Slade
1983 Fractionation and Turnover of Stable Carbon Isotopes in Animal Tissues: Implications for $\delta^{13}C$ Analysis of Diet. *Oecologia* 57:32–37.
Todd, Lawrence C.
1987 Taphonomy of the Horner II Bone Bed. In *The Horner Site: The Type Site of the Cody Cultural Complex*, edited by George C. Frison and Lawrence C. Todd, pp. 107–198. Academic Press, Orlando.

Toll, Oliver W.
2003 *Arapaho Names and Trails. A Report on a 1914 Pack Trip*. Reprinted. Rocky Mountain Nature Association, Estes Park, Colorado. Originally privately published 1962.

Trueman, Clive N. G., Anna K. Behrensmeyer, Noreen Tuross, and Steve Weiner
2004 Mineralogical and Compositional Changes in Bone Exposed on Soil Surfaces in Amboseli National Park, Kenya: Diagenetic Mechanisms and the Role of Sediment Pore Fluids. *Journal of Archaeological Science* 31(6):721–739.

VanderHoek, Richard, Charles E. Holmes, and J. David McMahan
2004 Arrow Shafts and Ice Patches: The OHA 2003 Field Season in the Denali Block, Tangle Lakes Region, Alaska. *Program and Abstracts* pg. 11. 31st Annual Conference of the Alaska Anthropological Association, Whitehorse, Yukon Territory, Canada.

Warren, Edward R.
1927 Altitude Limit of Bison. *Journal of Mamology* 8(1):60–61.

Wilson, Michael
1981 Faunal Remains and Butchering Patterns. In *The Archaeology of Vail Pass Camp: A Multi-Component Base Camp Below Treelimit in the Southern Rockies*, by John D. Gooding, pp. 111–122. Highway Salvage Report No. 35. Colorado Department of Highways, Boulder.

NOTES

[1]Oakley (personal communication in Farnell et al. 2004) notes that the reintroduced bison have been observed wallowing in ancient dung deposits that are commonly associated with ice patches in this region, or congregating near them, but not actually standing on the ice. As this behavior may be both learned and instinctual, it is possible that the reintroduced bison have yet to refine their use of the features.

[2]Given by Toll (1962:11) as hāāthāānon-tāhou hūt, the "Buffalo Climb." Thatchtop Mountain is in Rocky Mountain National Park, Colorado.