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THE SYMBIOSIS OF LICHENOMETRY AND RADIOCARBON DATING: A BAYESIAN CHRONOLOGY OF ALPINE HUNTING IN COLORADO'S SOUTHERN ROCKY MOUNTAINS, USA

Kelton A Meyer*

Department of Anthropology and Geography, Colorado State University, 1787 Campus Delivery, Fort Collins, CO, USA

ABSTRACT. Archaeologists keep a limited arsenal of methods for dating stone features at alpine sites. Radiocarbon (^{14}C) dating is rarely possible, and it is common that dates do not accurately represent the activity of interest (stone feature construction). In this paper I review a legacy set of 89 ^{14}C dates for stone driveline sites built by hunter-gatherers in Colorado's Southern Rocky Mountains. I amend the sample of dates using chronometric hygiene and focus on dates with direct association to hunting features. I then present a newly calibrated set of 29 lichenometric dates for rock features at these sites and use hygiene protocols to remove inaccurate dates. Size-frequency lichenometry, though poorly known in archaeology, provides a way to date stone features indirectly by measuring the growth of long-lived lichens that colonize rock surfaces after construction events. Bayesian modeling of the combined set of dates suggests that the tradition of alpine game driving spans over 6000 years BP, with abundant use over the last 2000 years. Archaeologists must use multiple methods for dating stone features in alpine environments. This Bayesian analysis is a formal effort to combine lichenometry and ^{14}C dating for archaeological interpretation.

KEYWORDS: alpine, Bayesian, chronometric hygiene, communal hunting, lichenometry, stone feature.

INTRODUCTION

Hunter-gatherers regularly made use of lands above timberline throughout much of North America. At times, the alpine tundra served as a simple corridor for regional migrations through mountainous terrain, but in other instances nomadic peoples established specific places to carry out tasks on a more routine basis. Evidence for site reoccupation is well-expressed in the archaeology of stone drivelines in Colorado's Southern Rocky Mountains. Native Americans built vast architectural networks of rock-walled fences, cairns, and hunting blinds along the open tundra of the Continental Divide to intercept migratory game such as bighorn sheep, elk, and deer (Benedict 1992). These sites resemble other examples of driveline architecture located throughout the world (Lemke 2021, 2022), including the *inukshuk* of Canada and Alaska as well as the "desert kite" phenomenon of the Levant, Arlo-Caspian region, and greater Arabian Peninsula (Benedict 2005a; Brink 2005; Crassard et al. 2015; Barge et al. 2016, 2022). In Colorado, there are more than 80 hunting sites with stone architecture above timberline (~3500 m asl), which range in size and complexity, but the largest contain dozens of stone features used by communal hunting groups on a seasonal basis. The tradition of game driving is a critical variable for models of seasonal transhumance in the region (Black 1991; Benedict 1992, 1999; Brunswig et al. 2014), and the high density of sites suggests a local fluorescence of driveline technologies.

The chronology of driveline hunting in Colorado has never received formal analysis, but it is generally accepted that the tradition spans several millennia (Benedict 2005a:429). Artifacts documented during surface surveys indicate use of stone drivelines may have occurred as early as the Late Paleoindian period (e.g., Benedict 2000), but continued throughout the Archaic (7500–1800 BP) and Late Prehistoric (1800–400 BP) to the mid-to-late 1800s AD (Cassells 1995; LaBelle and Pelton 2013; Whittenburg 2017; Meyer 2021). The legacy set of radiocarbon

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*Corresponding author. Email: Kelton.Meyer@colostate.edu

(^{14}C) dates mirrors this long span of use, but many of the dated samples lack clear association to game drive features. For several sites, lichenometric dating of stone walls helps to strengthen chronologies that suffer from a shortage of ^{14}C dates (Benedict 1975a; Benedict 1985; Hutchinson 1990; Cassells 1995; Benedict 1996; LaBelle and Pelton 2013; Meyer 2021). The size-frequency method of lichenometry accounts for the growth rate of *Rhizocarpon rhizocarpon* (hereafter *Rhizocarpon* sp.) that colonize stone walls following construction events (Benedict 1985; Benedict 2009; Cassells 2012).

In this paper I build a chronology of alpine hunting in the Southern Rocky Mountains from the existing sample of ^{14}C dates and lichenometric dates. I follow a basic chronometric hygiene protocol (sensu Graf 2009; Pettitt et al. 2003) to remove problematic dates that have poor association with features and insufficient numbers of thalli measurements for accurate lichenometric dating. I recalibrate new lichenometric dates for game drive walls using a recently revised version of the Colorado Front Range growth curve for *Rhizocarpon* sp. (Meyer 2021). I then use Bayesian chronological models to account for statistical uncertainty within the reliable set of dates, including samples with inbuilt age issues (Bronk Ramsey 2009a; Bronk Ramsey 2009b; Dee and Bronk Ramsey 2014). I conclude with several implications of the chronological model as well as recommendations for future research.

MATERIALS AND METHODS

Radiocarbon Dates

The complete set of ^{14}C dates includes 89 dates from 17 driveline sites (Benedict 1975a, 1975b, 1978, 1979, 1996, 2000; Hutchinson 1990; Cassells 1995; Benedict and Cassells 2000; Brunswig 2005; LaBelle and Pelton 2013; Whittenburg 2017; Meyer 2021). The drivelines cover more than 38,000 km^2 in the Southern Rockies, but the Front Range massif and the Sawatch Range contain dense concentrations of dated sites (Figure 1). The spatial distribution of drivelines with absolute dates parallels the history and intensity of game drive research in the region as well as legitimate differences in site construction methods (Benedict 1992; LaBelle and Pelton 2013). Sites with dates include more than 40 driveline features on average, whereas undated sites may contain a single wall, blind, or cairn line suggesting construction by small hunting groups. Driveline features, particularly hunting blinds, serve as potential reservoirs to capture organic materials deposited during occupation events. Higher quantities of these features within individual sites improves chances for successful ^{14}C dating. The chronology considered in this paper captures only one facet of game driving behavior in the region and potentially omits processes underlying the construction of smaller sites which are more difficult to date with absolute methods.

The archaeological context of ^{14}C dates varies widely between sites, as does the material sampled to produce dates. Dates on wood charcoal are the most abundant, consisting of bulk or single-grain samples of unidentified charred wood as well as individual burned twigs and needles identified to genus (*Abies*, *Picea*, and *Pinus*). Sample recovery methods include full or partial excavation of hunting blind pit floors (e.g., Cassells 1995), non-invasive soil coring of sediment within blinds (e.g., Benedict 1996), and excavation of external camps presumably associated with hunting features (e.g., Benedict 1978, 2000). The set of ^{14}C dates includes samples from faunal remains as well, represented by elements of *Ovis canadensis* (bighorn sheep) and *Odocoileus* sp. (deer). Bones have been recovered from site surfaces but also within the floors and walls of hunting blind pits (Benedict 1975a; Hutchinson 1990; Cassells 1995; LaBelle and Pelton 2013; Meyer 2021).

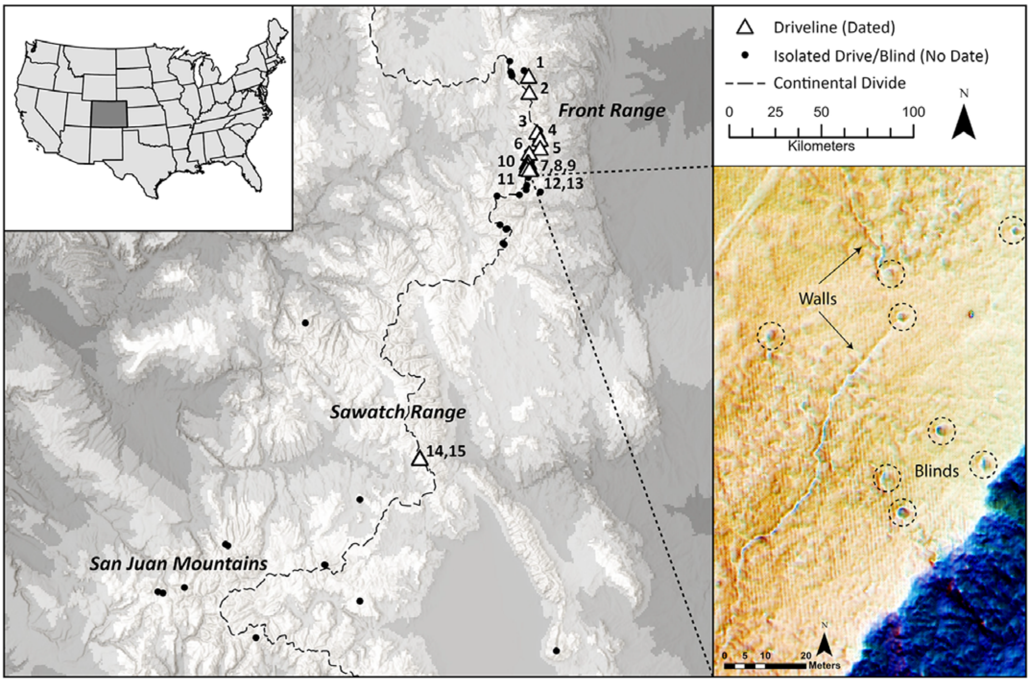

Figure 1 Distribution of hunting architecture above 3500 m asl in the Southern Rocky Mountains, Colorado. Inset LiDAR relief image (right) depicts the main intercept area at the Olson game drive, showing walls and blinds. Numbered sites include Trail Ridge (1), Flattop Mountain (2), Sawtooth (3), Blue Lake Valley (4), Murray, Hungry Whistler, 5BL68 (5), Arapaho Pass (6), Devil's Thumb Pass (7-8), Devil's Thumb Valley (9), Bob Lake (10), 5GA35 (11), High Grade (12), Olson (13), Water Dog Divide (14), 5CF499 (15).

Chronometric hygiene of the ^{14}C dataset is not as simple as removing dates on wood charcoal with large standard deviations, though this issue is a factor. Both human and non-human agents introduced charcoal into alpine archaeological sites over time. Eolian deposition of forest-fire charcoal into sedimentary matrix is well-documented for alpine environments (e.g., Novák et al. 2010; Tinner et al. 2006), and this includes peak elevations along the Continental Divide (Benedict 2002). Benedict (2002) conducted a study in which he observed that culturally derived charcoal deposits often contain wood grains larger than 3 mm in diameter, but none of the published soil core information states the actual size of grains or weight of charcoal submitted for analysis. Because of this, Benedict (2002:35) questioned the validity of many ^{14}C dates that he produced on charcoal flecks from alpine drivelines in the region, where he stated:

> The depressed centers and low peripheral walls of prehistoric hunting blinds make the blinds excellent sediment traps, vulnerable to contamination by windblown charcoal. Several AMS dates recently obtained by coring blinds at Front Range game-drive sites (Benedict 1996, 2000; Benedict and Cassells 2000) are suspect for this reason.

Periglacial mass wasting skews stratigraphic sequences when sediment is available at sites. Charcoal can migrate through site deposits quickly because of continuous surface erosion, frost-heaving, and bioturbation. Several inverted sequences of charcoal dates at game drives suggest these natural processes are common (Hutchinson 1990; Cassells 1995; Benedict 2000; Brunswig 2005), and this is a globally documented issue for alpine environments in general

Figure 2 Collapsed hunting blind at the High Grade game drive, Rollins Pass, Colorado. Native Americans constructed the blind by excavating a flat pit floor and stacking several courses of stone in the direction of the game intercept area.

(Payette and Gagnon 1985; Carcaillet 2001). The most reliable archaeological contexts for charcoal samples include thermal features identified by the cross-section of excavated hearths and related ash layers. Archaeologists have documented hearths within prepared hunting blind pit floors, which represent either pre-hunt or post-hunt use of features for non-hunting functions (Benedict 1975a; Hutchinson 1990; Cassells 1995; Benedict 2000; LaBelle and Pelton 2013). Many hunting blinds do not contain hearths and were built primarily to conceal hunters armed with arrows as well as atlatl darts (Figure 2).

The chronometric hygiene protocol that I followed is minimalistic by comparison to the standards of other studies which numerically scored individual dates (e.g., Douglass et al. 2019; Graf 2009; Napolitano et al. 2019). I simply emphasized that "clean" charcoal dates must at least have a clear association with hunting blinds and possibly represent an in situ burning event. The most reliable samples include 13 charcoal dates produced from hearths and ash layers in excavated hunting blinds (Table 1). The targeted event for charcoal dating (hearth ignition) does not directly relate to the use of stone drivelines, but the dates may at least be considered a minimum age for the hunting blinds which enclose hearth features. I also included dates made on charred materials from slotted-tube soil core samples in blinds (n=27) given the possibility that they could represent cultural burning events (Table 1). However, I emphasize here that some or all of the charcoal from soil probes could be windblown deposits or derive from some other context.

Appendices 1–4 list the remaining dates from sites and features that I excluded from the analysis based on contextual issues, sample types, and large standard lab errors. This includes

Table 1 List of 40 modeled ^{14}C dates and feature contexts from alpine driveline sites in Colorado. See Appendix 1–4 for additional information about the complete set of radiocarbon dates.

Site	Lab no.	^{14}C age BP	cal BP (2σ)	Context	Material	Reliability	$\delta^{13}C$	Reference
Sawtooth	Beta-50908	1365 ± 65	1390–1120	Blind D-6	Charred twig	Excellent (hearth fill)		Cassells 1995:89–91
Sawtooth	Beta-50909	1180 ± 55	1270–950	Blind D-6	Charred twig	Excellent (hearth fill)		Cassells 1995:89–91
Murray	M-1542	970 ± 100	1070–680	Blind 1	Bulk charcoal (*Picea*)	Excellent (hearth fill)		Benedict 1975a:169
Devil's Thumb Valley	Beta-57992	2155 ± 55	2320–1990	Blind 3	Bulk charcoal	Excellent (Hearth stain)	–20.0	Benedict 2000:Table 2.5
Devil's Thumb Valley	Beta-96541	1850 ± 50	1890–1610	Blind 5	Charcoal (*Abies*)	Good (charred layer)	–22.3	Benedict 2000:Table 2.5
Devil's Thumb Valley	Beta-67705	950 ± 40	930–740	Blind 2	Bulk charcoal	Excellent (hearth fill)	–23.2	Benedict 2000:Table 2.5
Devil's Thumb Valley	Beta-68389	765 ± 55	790–560	Blind 2	Charred needles (*Abies*)	Excellent (hearth fill)	–24.3	Benedict 2000:Table 2.5
Devil's Thumb Valley	Beta-54909	765 ± 55	790–560	Blind 2	Charred twig (*Abies*)	Excellent (hearth fill)	–23.4	Benedict 2000:Table 2.5
Olson	I-5709	2785 ± 90	3150–2740	Blind 71	Bulk charcoal	Excellent (hearth fill)		LaBelle and Pelton 2013:55
Olson	UGA-11761	140 ± 25	280–0	Blind 93	Collagen (*Ovis canadensis*)	Good (Spiral fracture)		LaBelle and Pelton 2013:55
Water Dog Divide	Beta-24185	1060 ± 60	1180–790	Blind 1	Charcoal (*Pinus aristate*)	Good (charred layer)		Hutchinson 1990:72–78
Water Dog Divide	Beta-24184	720 ± 60	740–550	Blind 1	Charcoal (*Pinus aristate*)	Excellent (hearth fill)		Hutchinson 1990:72–78
5CF499	Beta-24183	350 ± 60	510–300	Blind 1	Charred limb (*Pinus aristate*)	Good (charred layer)		Hutchinson 1990:72–78
High Grade	Beta-488944	5100 ± 30	5920–5745	Blind 15	Charcoal flecks	Unclear (soil core)	–21.8	Meyer 2021:Table 2
Trail Ridge	Beta-85363	4590 ± 50	5470–5045	Blind 5	Charcoal flecks	Unclear (soil core)	–22.3	Benedict 1996:Table 2
Trail Ridge	Beta-75998	2610 ± 60	2860–2490	Blind 3	Bulk charcoal	Unclear (soil core)	–27.1	Benedict 1996:Table 2
Flattop Mountain	Beta-79746	4310 ± 80	5280–4615	Blind 54	Charcoal flecks	Unclear (soil core)	–22.5	Benedict 1996:Table 4
Flattop Mountain	Beta-79744	2620 ± 60	2870–2495	Blind 46	Charcoal flecks	Unclear (soil core)	–20.4	Benedict 1996:Table 4
Flattop Mountain	Beta-79739	1740 ± 60	1820–1515	Blind 10	Charcoal flecks	Unclear (soil core)	–18.7	Benedict 1996:Table 4
Flattop Mountain	Beta-79737	1600 ± 60	1690–1355	Blind 3	Charcoal flecks	Unclear (soil core)	–21.6	Benedict 1996:Table 4
Flattop Mountain	Beta-79736	1570 ± 60	1570–1310	Blind 2	Charcoal flecks	Unclear (soil core)	–22.5	Benedict 1996:Table 4
Flattop Mountain	Beta-79747	1550 ± 60	1540–1310	Blind 65	Charcoal flecks	Unclear (soil core)	–20.7	Benedict 1996:Table 4
Flattop Mountain	Beta-79740	1550 ± 60	1540–1310	Blind 12	Charcoal flecks	Unclear (soil core)	–26.2	Benedict 1996:Table 4
Flattop Mountain	Beta-79741	1290 ± 60	1305-1070	Blind 23	Charcoal flecks	Unclear (soil core)	–24.9	Benedict 1996:Table 4
Flattop Mountain	Beta-79743	1240 ± 60	1295–1000	Blind 35	Charcoal flecks	Unclear (soil core)	–20.5	Benedict 1996:Table 4
Flattop Mountain	Beta-79738	1210 ± 60	1280–975	Blind 7	Charcoal flecks	Unclear (soil core)	–26.2	Benedict 1996:Table 4
Flattop Mountain	Beta-79748	1190 ± 60	955–730	Blind 76	Charcoal flecks	Unclear (soil core)	–20.8	Benedict 1996:Table 4
Flattop Mountain	Beta-79750	940 ± 60	915–885	Blind 89	Charcoal flecks	Unclear (soil core)	–19.8	Benedict 1996:Table 4
Flattop Mountain	Beta-79742	880 ± 60	960–560	Blind 33	Charcoal flecks	Unclear (soil core)	–16.1	Benedict 1996:Table 4
Flattop Mountain	Beta-79745	240 ± 60	465 . . .	Blind 51	Charred needles	Unclear (soil core)	–15.2	Benedict 1996:Table 4
Flattop Mountain	Beta-79749	220 ± 60	445 . . .	Blind 87	Charcoal flecks	Unclear (soil core)	–25.7	Benedict 1996:Table 4
Devil's Thumb Pass	Beta-111215	4100 ± 50	4825–4440	Blind 19	Charcoal flecks	Unclear (soil core)	–25.6	Benedict 2000:Table 2.2
Devil's Thumb Pass	Beta-108954	880 ± 60	915–690	Blind 8	Bulk charcoal	Unclear (soil core)	–23.8	Benedict 2000:Table 2.2

(Continued)

Table 1 (*Continued*)

Site	Lab no.	^{14}C age BP	cal BP (2σ)	Context	Material	Reliability	δ^{13}C	Reference
Devil's Thumb Pass	Beta-125430	730 ± 50	775–555	Blind 18	Charcoal flecks	Unclear (soil core)	–24.3	Benedict 2000:Table 2.2
Devil's Thumb Pass	Beta-125429	640 ± 50	845–485	Blind 1	Bulk charcoal	Unclear (soil core)	–25.9	Benedict 2000:Table 2.2
Bob Lake	Beta-96545	1650 ± 50	1695–1400	Blind 12	Bulk charcoal (*Picea*)	Unclear (soil core)	–23.4	Benedict and Cassells 2000:Table 1.1
Bob Lake	Beta-96543	1230 ± 50	1285–1005	Blind 9	Bulk charcoal	Unclear (soil core)	–24.7	Benedict and Cassells 2000:Table 1.1
Bob Lake	Beta-96544	1210 ± 50	1280–975	Blind 11	Bulk charcoal	Unclear (soil core)	–24.4	Benedict and Cassells 2000:Table 1.1
Bob Lake	Beta-96542	310 ± 70	510…	Blind 3	Charred needles (*Picea*)	Unclear (soil core)	–20.5	Benedict and Cassells 2000:Table 1.1
Bob Lake	Beta-101398	280 ± 60	495…	Blind 20	Bulk charcoal (*Picea*)	Unclear (soil core)	–26.0	Benedict and Cassells 2000:Table 1.1

11 charcoal dates from hunting blinds which were fully excavated and did not contain any thermal features (loose charcoal of unknown context), given that the excavations confirmed the absence of in situ burning in those specific blinds (Appendix 1). A total of 29 dates from general excavation areas were also removed (Appendix 2), including campsite locales from three sites (Trail Ridge, Devil's Thumb Valley, and Hungry Whistler), due to lacking horizontal or stratigraphic association with hunting features. At the Devil's Thumb Valley site (5GA3440), Benedict (2000:62–63) specifically described complications with the dates from the Area A campsite locality that are especially pertinent to their removal from this study:

> Most charred material was from tree trunks and branches, but some was from roots that had smoldered belowground. Some was slaggy and vesicular, indicating quenching by water while sap was still stewing from the wood. Twenty-one radiocarbon dates, all attributable to wildfire, were obtained from Area A. The dates range from 9570 +/- 80 BP (Beta-122996) to 2880 +/- 60 BP (Beta-98414).

Many sites with driveline features show evidence for a variety of other non-hunting activities, including toolmaking and repair (e.g., Whittenburg 2017), plant processing (Cassells 1995; LaBelle and Pelton 2013), ceremonial fasting (Benedict 1987; Brunswig 2005), and residential behavior (Benedict 1978; Benedict 2000). These activities demonstrate the multi-faceted nature of alpine occupations, but ^{14}C dates from these activities are not necessarily relevant for the chronology of driveline hunting. Benedict (2005a:429) mentioned one additional charcoal date (Beta-44747) from a hunting blind but the report does not include an associated site or feature, so I omitted it from analysis (Appendix 1). For dates on bone collagen, I rejected samples from site surfaces (n=5), given that natural death events can occur on sites without human predation (Appendix 3). Freeze-thaw cycles in the alpine may significantly alter bone surfaces when left exposed (Bertran et al. 2015), which limits the reliability of surface-collected bones for dating anthropogenic deposits.

Problematic charcoal dates with large errors can be informative for Bayesian modeling (see Hamilton and Krus 2018), but the dates should at least be accurate estimations of cultural events. In this study I eliminated charcoal dates with standard uncertainties greater than 100 years with missing information about sample selection and processing (Appendix 4). In the alpine, three-digit uncertainties for charcoal dates may be the result of mixed wood pieces with various degrees of inbuilt age (combinations of short-lived elements, old wood, and forest-fire debris), or perhaps very small sample quantities used in gas-proportional or liquid scintillation techniques prior to AMS ^{14}C dating (Spriggs 1989; Graf 2009; Gragson and Thompson 2022). Several of the ^{14}C dates were published in analyses of legacy collections which occurred decades after initial field collection, storage, and processing (e.g., LaBelle and Pelton 2013; Whittenburg 2017), which prohibited analysis of potential contaminants. The most reliable set of ^{14}C dates includes a total of 40 dates from 11 sites after chronometric hygiene (Table 1), or roughly 45 percent of the composite set of dates.

Lichenometric Dates

Lichenometry is not a well-known method in archaeology, but it is frequently used by geologists to date the redeposition of rock substrata resulting from glacial processes (Bickerton and Matthews 1993; Roberts et al. 2010; Wiles et al. 2010), earthquakes (Emerman 2017), rockslides (Winchester and Chaujar 2002), flood discharges (Foulds and Macklin 2016), and other natural events. Benedict (1985, 1996, 2009) pioneered the use of the size-frequency

Figure 3 Yellow *Rhizocarpon* sp. thallus photographed by J. Benedict at Ouzel Lake in Rocky Mountain National Park, Colorado. (Please see online version for color figures.)

method of lichenometry to date cultural stone features in the Front Range. Globally, there is abundant research on lichenometric dating with *Rhizocarpon* sp. and several key studies review the historical development and implementation of these numeric dating methods (Innes 1983; Loso and Doak 2006; Jomelli et al. 2007; Benedict 2009; Armstrong 2016), as well as criticisms leveled against specific types of lichenometric dating such as the maximum diameter technique (Jomelli et al. 2007; Osborn et al. 2015; Rosenwinkel et al. 2015).

Yellow members of *Rhizocarpon* sp. are crustose lichens that represent a symbiotic relationship between fungal mats and patches of algae (Figure 3). They quickly colonize exposed rock surfaces and make thalli with distinguishable edges. Individual thalli may grow for thousands of years at a near-linear rate if left undisturbed, making *Rhizocarpon* sp. a reliable lichen for numeric dating. The predictability of their growth depends largely on local climate variables (Loso and Doak 2006; Benedict 2009; Armstrong 2016), including effective moisture, snow cover, temperature, altitude, slope and aspect, sunlight, and air pollution as documented in recent studies (Armstrong 2016). When rocks are overturned because of natural or anthropogenic disturbances, existing colonies of yellow *Rhizocarpons* die off and their thalli spall from rocks within a period of about 10 years (Benedict 2009:151). Thalli may survive disturbance events if rocks are not completely overturned, and this prohibits the use of the largest observed thallus on cultural features for reliable dating. The growth and colonization rate of new colonists is highly distinguishable from survivors, however. Comprehensive random sampling of thalli diameters shows a significant negative log-linear relationship in the size and frequency of new thalli which grew after disturbance events (Benedict 2009: Figure 14; Loso and Doak 2006: Figure 2; Roberts et al. 2010:Figure 6). In the Colorado Front Range, Pearson's correlation coefficient values typically average 0.99 for regression lines run through data points representing the size and frequency of new colonists (Benedict 2009). Survivor measurements, on the other hand, show a clear break from this negative log-linear relationship in thalli size and frequency; survivor diameters are too large and sample sizes are either too few or too abundant depending on the intensity of the rock disturbance event.

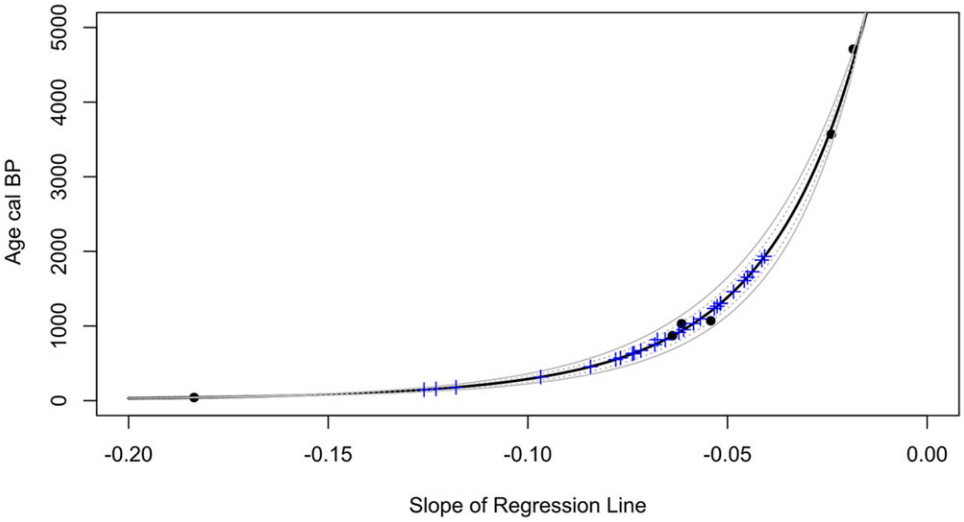

Figure 4 Revised age-growth calibration curve for *Rhizocarpon* sp. in the Colorado Front Range. Blue crosses indicate curve intercepts using the slope of regression lines for *Rhizocarpon* sp. thalli growing on driveline wall features. Black dots represent curve control points (rounded to the nearest 10 years), based on recalibration from Meyer (2021).

Numeric dating of lichen colonies requires a locally engineered age-growth calibration curve. Benedict (2009) constructed the Front Range growth curve for *Rhizocarpon* sp. by sampling large random sets of thalli diameters on disturbed rock substrata with associated ^{14}C dates. The curve uses control points built from regression line slope values fit to post-disturbance colonist diameter measurements at each substratum, followed by associated radiometric or historically known ages for the disturbance events (Benedict 1985). Several researchers have used the calibration curve to produce age estimates for driveline features by measuring thalli that grow on stone walls and predicting numeric ages based on intercepts with the curve (Benedict 1985, 1996, 2000; Hutchinson 1990; Cassells 1995; Benedict and Cassells 2000; Benedict 2009; LaBelle and Pelton 2013; Meyer 2021). A revised version of the curve gives standard uncertainties for lichenometric dates in cal BP (Meyer 2021:Supplemental Materials 1), based on recalibration of ^{14}C dates for each control point in the curve using IntCal20 (Reimer et al. 2020).

I present revised lichenometric dates for 29 features from nine alpine driveline sites (Figure 4, Table 2). The dates include both 1σ (68.3%) and 2σ (95.4%) credible ranges as well as median dates. The precision of the revised dates ranges widely, with 1σ uncertainty ranges spanning anywhere from 30 to 330 years and taking slightly asymmetrical probability distribution shapes. Wide probability ranges result from the shape of the curve and the coarse level of precision for conventional ^{14}C dates used for the curve control points. I apply chronometric hygiene to the set of lichenometric dates by excluding dates that are potentially inaccurate. Benedict (2009: Figure 17) simulated the effect of low sample sizes on lichenometric dating accuracy by comparing the maximum discrepancy in predicted ages for contemporaneous walls at Arapaho Pass, suggesting that age estimates stabilize after about 1000 measurements. The reliable set of lichenometric dates includes 22 dates from seven alpine sites after removing walls

Table 2 Complete list of size-frequency lichenometric dates from alpine driveline sites in Colorado, based on recalibration with the revised age-growth curve for *Rhizocarpon* sp in the Colorado Front Range (Meyer 2021).

Site	Wall	Thalli (n)	Regression line slope	cal BP (1σ)	cal BP (2σ)	Median	Reliability	Reference
Flattop Mountain	Wall D	1000	–0.0676	862–667	947–603	766	Good-sufficient sample	Benedict 1996:Figure 55
Sawtooth	Wall 1	1000	–0.0438	1884–1566	2019–1454	1727	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 2	700	–0.0407	2095–1767	2234–1650	1933	None-low sample size	Cassells 1995:133–135
Sawtooth	Wall 3	1000	–0.0526	1400–1126	1520–1032	1265	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 3A	600	–0.0414	2045–1719	2184–1603	1884	None-low sample size	Cassells 1995:133–135
Sawtooth	Wall 3B	800	–0.0517	1443–1164	1564–1068	1306	None-low sample size	Cassells 1995:133–135
Sawtooth	Wall 4	1000	–0.0568	1219–968	1329–883	1096	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 5	1000	–0.0585	1154–911	1259–830	1034	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 6	1000	–0.0533	1368–1098	1486–1005	1235	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 8	1000	–0.0682	846–654	930–591	751	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 10	1000	–0.0485	1606–1310	1734–1207	1461	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 10B	1000	–0.0458	1759–1451	1892–1343	1608	Good-sufficient sample	Cassells 1995:133–135
Sawtooth	Wall 10C	1000	–0.0533	1368–1098	1486–1005	1235	Good-sufficient sample	Cassells 1995:133–135
Murray	Wall 1	2000	–0.6380	960–740	1070–680	870	Good-sufficient sample	Benedict 1975a:168–169
Arapaho Pass	Wall D	600	–0.0610	1060–840	1064–835	951	None-low sample size	Benedict 1985:95–104
Arapaho Pass	Blind 1	400	–0.0622	1020–800	1023–801	914	None-low sample size	Benedict 1985:95–104
Arapaho Pass	Wall I	1500	–0.0734	719–551	792–497	636	Good-sufficient sample	Benedict 1985:95–104
Arapaho Pass	Wall E	1000	–0.0738	710–544	782–491	628	Good-sufficient sample	Benedict 1985:95–104
Arapaho Pass	Wall G	1500	–0.0768	648–495	714–446	572	Good-sufficient sample	Benedict 1985:95–104
Arapaho Pass	Wall H	1000	–0.0780	624–476	689–429	551	Good-sufficient sample	Benedict 1985:95–104
Devil's Thumb Pass	Wall 1	1010	–0.7170	758–582	834–526	672	Good-sufficient sample	Benedict 2000:31

Table 2 (*Continued*)

Site	Wall	Thalli (n)	Regression line slope	cal BP (1σ)	cal BP (2σ)	Median	Reliability	Reference
Bob Lake	Wall B	626	–0.0450	1808–1496	1942–1386	1654	None-low sample size	Benedict and Cassells 2000: Figure 1.13
Olson	Wall 1	1000	–0.0518	1438–1159	1559–1064	1301	Good-sufficient sample	Benedict 2009:Figure 13; LaBelle and Pelton 2013:55–56
Olson	Wall 2	1000	–0.0656	918–713	1008–646	817	Good-sufficient sample	Benedict 2009:Figure 13; LaBelle and Pelton 2013:55–56
High Grade	Wall A	1000	–0.1260	163–128	176–118	146	Good-sufficient sample	Meyer 2021:Figure 7
High Grade	Wall B	1000	–0.1180	201–156	218–143	179	Good-sufficient sample	Meyer 2021:Figure 7
High Grade	Wall C	1000	–0.1230	177–138	191–127	157	Good-sufficient sample	Meyer 2021:Figure 7
High Grade	Wall D	1050	–0.0843	517–392	570–353	455	Good-sufficient sample	Meyer 2021:Figure 7
Water Dog Divide	Wall 1	617	–0.0968	359–272	395–246	316	None-low sample size	Benedict 2009:Figure 14; Hutchinson 1990:67–69

and blinds with low sample sizes of *Rhizocarpon* sp. I supply individual date estimates and curve parameters using *R* code language in Supplementary Material 1.

Bayesian Modeling

Bayesian chronological modeling can improve our understanding of statistical uncertainty in calibrated date estimates (Buck et al. 1996; Bayliss 2009; Bronk Ramsey 2009a). This is especially important for the study of alpine drivelines, where the reliable set of ^{14}C dates and lichenometric dates is small and the precision of dates is generally poor. Visual interpretation of dates or "eyeballing" is unlikely to provide a clear understanding of the spread of dated events or underlying patterns of site use over time (Hamilton and Krus 2018). Bayesian modeling improves interpretations of dated event uncertainties by accounting for departures in the ^{14}C calibration curve with the use of prior information from archaeological context (Bronk Ramsey 2009a).

I calibrated and modeled all dates using Oxcal v.4.4 (Bronk Ramsey 2009a). The essential structure of Model A consists of a bounded **Phase** for the game drive tradition with nested overlapping subphases that correspond to individual sites. I applied a simple uniform **Boundary** to the beginning and end of the phase to characterize the probability distributions for unsampled events at the onset and conclusion of driveline hunting in the region. In this case, the uniform prior assumes that dated events from all game drive sites are a random selection of a uniformly distributed process which characterizes the overall chronology. This choice of boundary does not favor long or short phase lengths, nor does it impose significant bias on the presumed shape of the modeled probabilities; the uniform boundary is a "weakly" informative prior and is appropriate due to the poor understanding of processes influencing game drive construction, use, and reuse over time (Bayliss 2015; Taylor et al. 2017). I did not use additional boundaries on site subphases to avoid over-engineering the marginal posterior distributions of dated events. This was a practical choice given that some sites in the sample contain only one or very few reliable dates, which limits the effectiveness of site-by-site comparisons. There is no information to suggest site-specific factors in the overall temporality of the game drive tradition, but this could be explored with additional modeling studies.

Lichenometric dates were modeled alongside ^{14}C dates (**R_Dates**) in site subphases using the **C_Date** command, based on the median of predicted ages and 1σ uncertainties. Two error terms were included with the lichenometric dates to account for the slightly asymmetrical shape of each probability distribution (e.g., C_Date("Olson_Wall1", calBP(1301), +142, –137)). I implemented a *terminus ante quem* (TAQ) constraint on the game drive phase using the **Before** command. The TAQ date of CE 1880 represents the forced removal of the White River Ute (Yamparika and Parianuche) and Tabeguache Ute from Colorado immediately following the Meeker Massacre (AD September–October 1979). Ethnohistoric accounts suggest Yamparika Ute hunting parties occupied areas in the Front Range up until AD 1875 (Brunswig 2020:145; Simmons 2000), but events following the Meeker Massacre would have restricted access to game drives in the region.

I included additional parameters in the Bayesian model to query the modeled chronology. The **Interval** command was used to construct a probability distribution for the duration of the game drive phase. This command modeled the spread of dated events and undated events between the phase boundaries, which provided an indication for the total extent of time that game drive sites were used in the region. I then implemented the **KDE_Plot** function using the default settings in OxCal to illustrate the underlying density of the marginal posteriors of events within the game drive phase. This method is a combination of a frequentist and Bayesian approach to summing modeled events, whereby Kernel Density Estimation (KDE) averages the Bayesian likelihoods and priors generated from the Markov chain Monte Carlo (MCMC) ensembles (Bronk Ramsey 2017). KDE smoothing of event densities within the Bayesian model helped to reduce artificial noise resulting from calibration effects, sample sizes, and the spread of posterior uncertainties.

I constructed a supplementary Bayesian model (Model B) which augments the primary model structure and includes additional information about dated samples, making it the preferred model for archaeological interpretation (Figure 5). The fundamental difference between Model B and Model A is that I did not apply ^{14}C dates collected from soil core samples, which removed a significant number of dates from the analysis. Some of these soil core dates could represent in situ anthropogenic burning events, but there is no independent test available to prove or disprove this possibility. Model B applies a very strict interpretation of archaeological context, one which does not allow for guesswork about the origin of charcoal in hunting blinds when there is no additional information to evaluate each sample. The model only considers dates collected from clearly identifiable thermal features in hunting blinds and the sample of lichenometric dates.

In Model B I combined several outlier models (Bronk Ramsey 2009b; Dee and Bronk Ramsey 2014), including an “old wood” model for dated samples with inbuilt age issues (bulk charcoal, other large wood fragments, or unknown samples) and a general outlier model for other dates (lichenometric, bone collagen, charred twigs and needles). A series of simulations were then used to examine the sensitivity of the Model B output (Griffiths 2014; Holland-Lulewicz and Ritchison 2021). I tested for model reproducibility by randomly sampling a range (population mean (μ) ± 1σ) within the marginal posteriors of dated events from Model B. This simulation method determines if the number and precision of dates distributed throughout the modeled phase is sufficient to produce a consistent model output when calendar dates and ranges are varied (Meadows et al. 2020:1275). The **R_Simulate** and **C_Simulate** commands were used to generate random ^{14}C dates and lichenometric dates in place of expected calendar dates in each site subphase. These simulated dates were then included in a uniform phase model using the same priors and constraints as Model B.

I applied additional simulations to the existing set of dates from Model B (with flagged outliers manually removed) to reveal the effect of increasing sample sizes of high-precision ^{14}C dates. This method examines how robust the model output is to the addition of new high-quality dates, and in effect, reveals the minimum number of new dates needed to increase precision for estimates of the start and end boundaries for the game drive phase (Holland-Lulewicz and Ritchison 2021). For this test I generated random sample sets of simulated ^{14}C dates and constrained the date ranges for expected calendar dates based on the results of Model B. I provided a constant error of ± 20 years for each simulated ^{14}C date, assuming lab errors with high precision. Each iteration of the model was run 10 times with the same simulated dates and actual Model B dates, but new random sets of simulated dates were generated with sequential iterations of the model. Samples sizes increased by 10 for each model iteration. I accepted the results of the simulation tests when sequential iterations produced start and end boundaries that exhibited diminishing returns for improving precision (Holland-Lulewicz and Ritchison 2021:276–277). Model code and simulation code are provided in Supplementary Material 2.

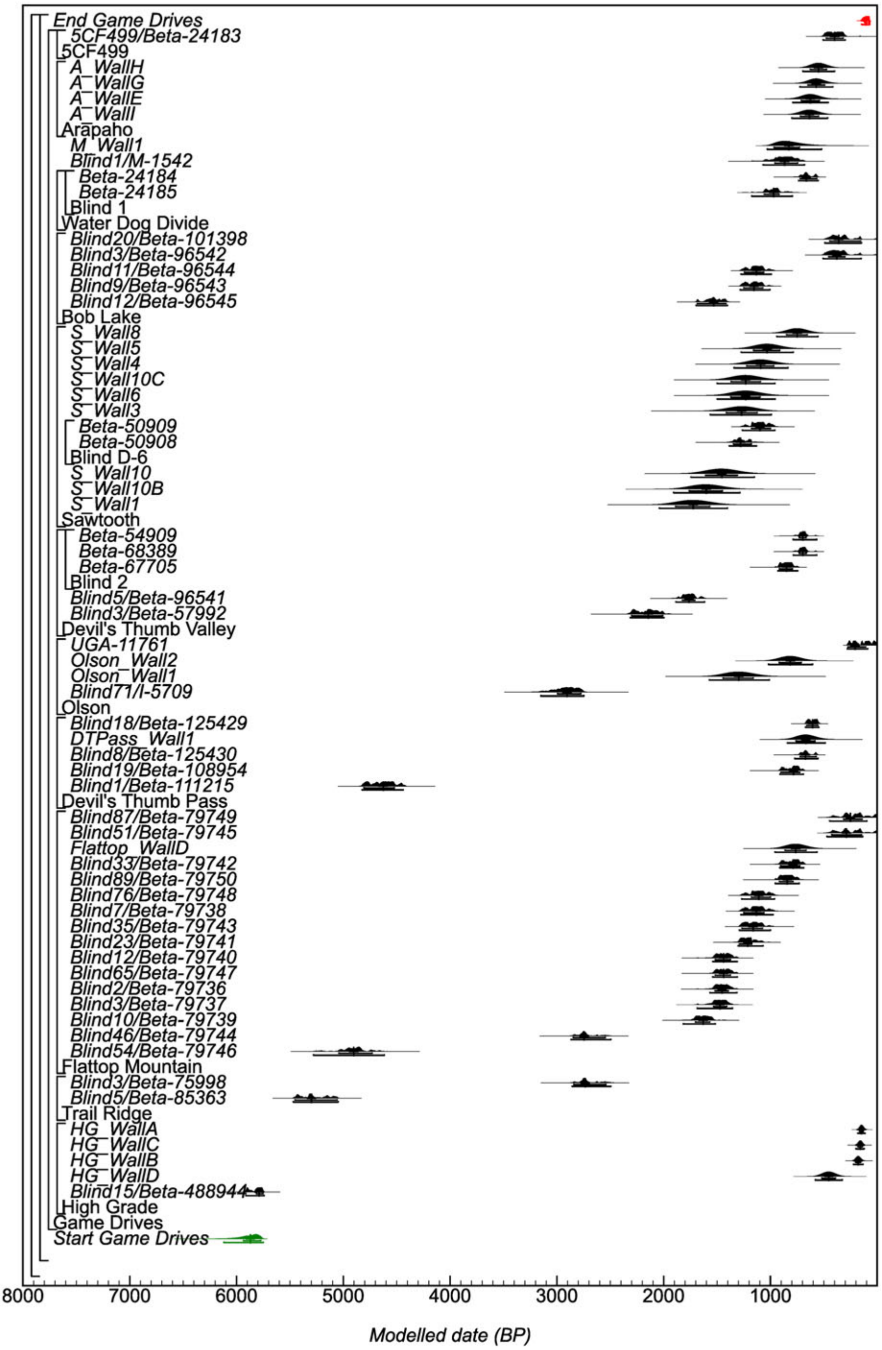

Figure 5 Model A Baysian structure, including modeled start (green) and end (red) boundaries for the game drive tradition phase.

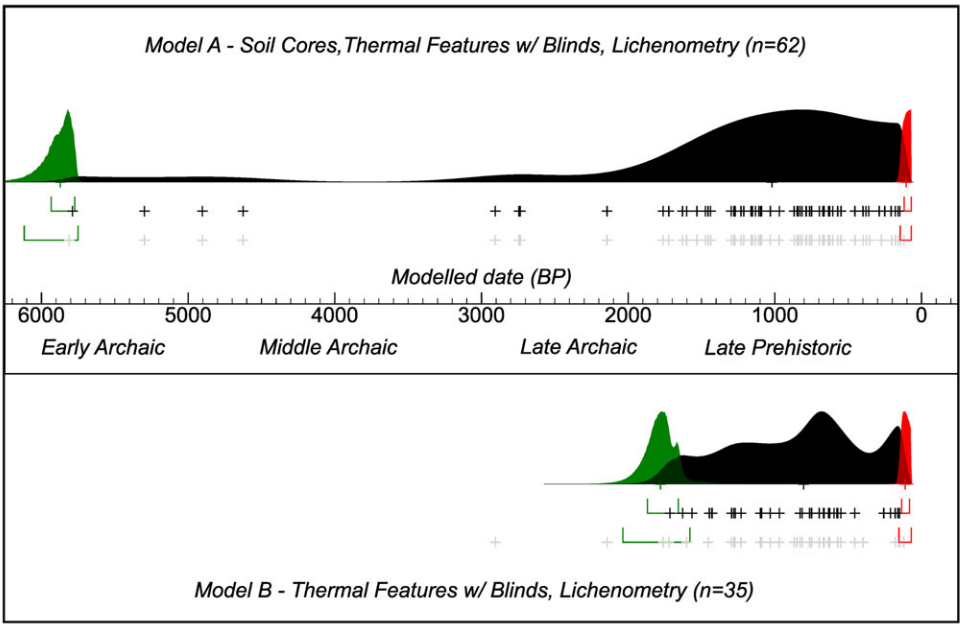

Figure 6 KDE plots of the uniform phase model (Model A) and Bayesian model with outlier analysis (Model B). Gray crosses represent calibrated median dates of unmodeled events, and black crosses show the medians of modeled posteriors. Bars underneath modeled distributions represent 68.3 (upper) and 95.4 (lower) credible ranges for the start boundary (green) and end boundary (red) for the game drive tradition phase.

RESULTS

Modeled dates and ranges are presented in italics and rounded to the nearest five years, including 68.3% and 95.4% credible ranges as well as median dates (see Supplementary Materials 3 and 4 for complete model results). Model A passed with good agreement (A_{model}=102.4, $A_{overall}$=101.4) and the results suggest that alpine hunting with drivelines spanned a period of *5620–6020 years*, beginning *6120–5750 cal BP* and ending *145-70 cal BP* (95.4% credible range). These ranges encompass the Early Archaic period (7500–5000 BP) and span through the Middle Archaic (5000–3000 BP), Late Archaic (3000–1800 BP), Late Prehistoric (1800–400 BP), as well as the Protohistoric (400–100 BP) (Gilmore 1999; Tate 1999). The KDE plot displays a highly non-random spread of events between the start and end boundaries, however. The distribution shows very low quantities of dates between 6000 and 2000 cal BP and then rises exponentially, suggesting the assumption of uniformity in modeled events is inaccurate (Figure 6). In practical terms, the results of Model A suggest that hunters may have used sites infrequently during an experimental period within the Early Archaic and again in the Middle Archaic. The latter end of the phase indicates abundant use of sites after 2000 years ago with the Archaic-Late Prehistoric transition.

The results of Model B reflect the high density of dated events after 2000 years ago by downweighing the effect of outliers and soil core samples which may not be cultural in origin. The “old wood” outlier model shifts the modeled posteriors of problematic charcoal dates (bulk samples from hearths) towards non-outlier date estimates with better precision (charred twigs, burned needles, and bone). The values of the outlier shift are randomly selected by an

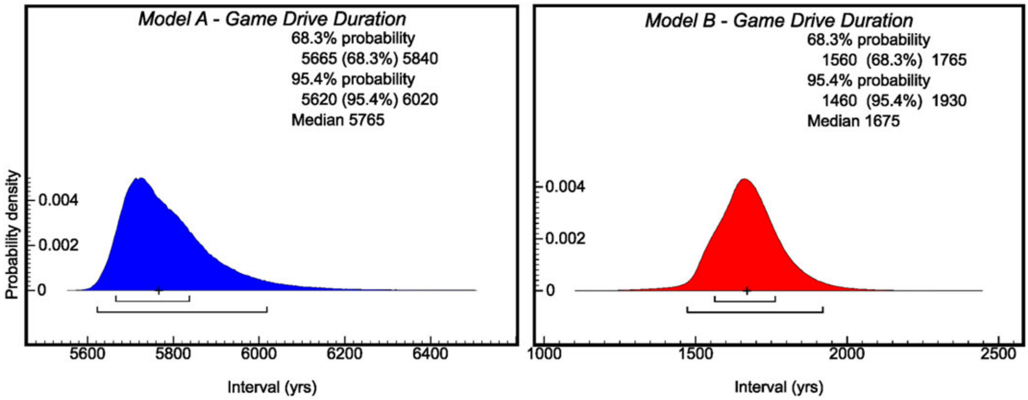

Figure 7 Modeled duration (interval) for the alpine game drive tradition in Colorado based on Model A and Model B results.

exponential distribution calculated during MCMC ensembles which consider all the dates in the model (Bronk Ramsey 2009b; Dee and Bronk Ramsey 2014). Model B results suggest that driveline hunting started *2040–1575 cal BP* and ended sometime between *155–65 cal BP* (95.4% credible range), with an interval period of *1460–1930 years* at the 2σ credible range (Figure 7). The ranges of these dates correspond to the end of the Late Archaic period and span several sequential periods in the Late Prehistoric era (Gilmore 1999; Tate 1999), including the Early Ceramic period (1800–800 BP) and Middle Ceramic (800–400 BP). The tradition ended during the Protohistoric period in northern Colorado (400–100 BP) when Euroamerican operations in the Colorado Front Range grew rapidly (Clark 1999). The output of the KDE plot shows an approximately uniform distribution, but there is a peak in the density of dated events between 700–650 BP which corresponds to the end of the Early Ceramic and the onset of the Middle Ceramic period (Figure 6).

Model Sensitivity

The initial set of simulations used random calendar dates and uncertainties in place of actual modeled events from Model B. Ten runs of the simulation revealed that the output of Model B is generally reproducible, but the low quantity and poor precision of dates towards the beginning of the phase causes greater variation in results than the end of the phase. Simulation runs favored solutions roughly one or two centuries younger than the Model B start boundary, with maximum estimates ranging *1950 cal BP* to *1730 cal BP* and minimum start dates between *1510 cal BP* and *1355 cal BP* (95.4% credible range). For the end boundary, simulation results consistently supported estimates from Model B. Repeated runs of the simulation produced a range of *195 cal BP* and *145 cal BP* for the maximum date of the ending boundary, and *70* to *65 cal BP* for the minimum end (95.4% credible range). These results reflect the relative quality of dates for the youngest modeled events in the sample, but also the TAQ constraint on the end of the phase which restricts excessive spread in modeled uncertainties.

Additional simulation tests revealed effects from increasing sample sizes of randomly generated high-precision ^{14}C dates. The results demonstrated that overall variance of Model B decreases with the addition of new ^{14}C dates while model precision simultaneously increases (Figure 8).

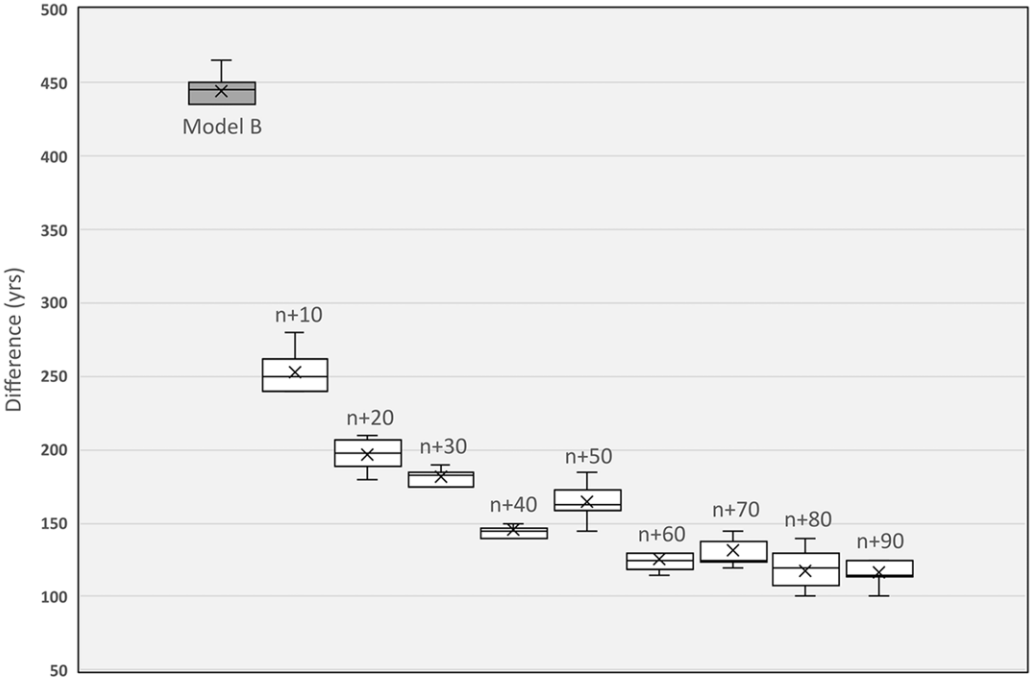

Figure 8 Variance of differences (yrs) between the maximum and minimum estimates (95.4% credible range) for the modeled start boundary of the game drive phase based on sequential simulation runs with increasing sample sizes of random ^{14}C dates. The quantity of randomized dates increased by 10 for each iteration, and the simulations were run 10 times.

Differences between the maximum and minimum date estimate for the Model B start boundary shortened by roughly two centuries with as few as 10 new ^{14}C dates, from *445 yrs* to *250 yrs* based on simulation averages (95.4% credible range). Precision of the start boundary steadily improved with sequential iterations but started to stabilize with simulations of 60 random ^{14}C dates. The most precise simulations produced differences of *100 yrs* for the maximum and minimum estimates of the start boundary, which occurred during simulations of 80 and 90 new ^{14}C dates. Precision and variance of the modeled end boundary went essentially unchanged over the course of simulation runs. The difference between the maximum and minimum dates improved by *25 yrs* with the addition of 70 new ^{14}C dates (*135–70 cal BP*), but simulations favored solutions of *155–70 cal BP* overall. These results further demonstrated that the younger end of the phase is well-sampled up to the TAQ constraint (AD 1880) on the ending boundary.

DISCUSSION

Model A displays a much broader temporal range for the duration of the game drive tradition phase than Model B (a difference of *4090 years* between the median interval estimates of the two models). This is primarily due to the inclusion of dates from soil cores in Model A, which are treated as evidence for in situ anthropogenic fires. Model A reaffirms a long-held belief that the onset of the game drive tradition developed prominently throughout the Early Archaic period with the Mount Albion complex (Benedict 1978), and this was a process that continued with increasing frequency into the Late Prehistoric and Protohistoric periods. Model B, on the other hand, applies a stricter approach to chronological hygiene which focuses only on ^{14}C samples from well-defined hearths inside hunting blinds and lichenometric dates on rock walls. Model B may be too strict, however, and the rejection of certain soil core dates from the chronology may falsely truncate the earlier age of the game drive tradition phase – especially dates representing the Early Archaic and Middle Archaic periods. Ultimately, the reader must choose which model best fits their own interpretation of the archaeological record given the immense variation in reliable sample types. I believe Model B is the most defensible result given its exclusive focus on cultural events.

Late Paleoindian-aged dates are notably absent from the modeled Bayesian chronologies in this paper, and it is worth exploring this issue with fine detail. Archaeologists have documented Late Paleoindian projectile points as surface finds from Flattop Mountain and Trail Ridge in Rocky Mountain National Park, including "Yuma", Eden, Allen, and Foothills-Mountain complex types (Benedict 1996; Brunswig 2005; LaBelle personal communication). However, the most tantalizing and simultaneously problematic evidence for Late Paleoindian use of game drives comes from the Devil's Thumb Valley site (Benedict 2000), which is the only game drive site that has produced Late Paleoindian-aged ^{14}C dates.

The Devil's Thumb Valley driveline consists of several short walls, cairn lines, and blinds that hunter-gatherers used to capture animals between a narrow bedrock trough as they travelled between a high mountain pass and a well-watered valley floor in the Indian Peaks Wilderness. The site connects with another ^{14}C dated driveline, 5BL103, located beneath Devil's Thumb Pass. Benedict (2000) collected a Foothills-Mountain projectile point fragment from the surface of the site in the tailings of a gopher hole near Blind 3, found at the terminal end of Drive Line C on the valley floor near spruce-fir krummholz and several wetland deposits. Benedict excavated the hunting blind and produced a ^{14}C date of 2155 ± BP from a charcoal stain in the center of the feature, representing a Late Archaic-aged date. He continued his search for Paleoindian materials within several block excavations at Area A and Area B, which represented surface lithic scatters near the Foothills-Mountain point fragment. Benedict produced two ^{14}C dates from a single hearth feature in Area B, dated 2250 ± 70 BP and 2160 ± 60 BP, again representing a Late Archaic age. I previously described the 21 non-cultural dates from Area A, which ranged from approximately 9000 to 3000 BP, and Benedict (2000:69) determined "At least six, and probably seven, wildfires affected this small tract of forest-tundra ecotone during the Holocene" based on his analysis of the clustering of the ^{14}C dates.

When Benedict's attempts to excavate and absolutely date the Late Paleoindian component at Devil's Thumb Valley failed, he turned his attention to alternative dating methods. He applied a granodiorite weathering technique to the driveline walls which accounts for the "…grain by grain disintegration that causes an initially smooth rock to become rough to the touch." (Benedict 2000:80). He proposed that the weathering profile of rock walls changed significantly after wall construction events, and that disturbances over time would be visible based on differential weathering between rock surfaces in the walls and the background slope of natural granite. It is unclear exactly how Benedict determined the degree of rock surface weathering quantitatively, other than noting a general appearance of the stones, and he did not provide usable data to reproduce his estimates that the Drive Line C wall dated between 12,000 and 10,000 years ago. He ultimately conceded that the granodiorite rate curve "…itself is preliminary, with too few control points to provide accurate dates in this early time range. Thus, construction during the Early Archaic Period cannot be completely excluded." (Benedict 2000:81–82). Given the totality of the information at hand, it remains unclear whether the driveline is Late Paleoindian-aged. There is very little data in support of a testable hypothesis concerning the earliest use of the site, but Benedict's attempts at dating did confirm a Late Archaic presence that is supported by ^{14}C dates in hunting blinds as well as diagnostic projectile points found in several other lithic scatters closely adjacent to the blinds and walls (Benedict 2000:Figure 2.14, Figure 2.19).

The Devil's Thumb Valley driveline is one of several quintessential sites showing the complexity of palimpsest deposits in the alpine tundra. Archaeologists must decide whether to link artifacts from different ages found on site surfaces to driveline features located nearby, or attempt dating of features directly via selective sampling. Ultimately, such practices in combination with one another may not yield perfectly digestible or expected results. Taphonomic bias is not a fully sufficient explanation for the lack of Late Paleoindian ^{14}C ages in secure context at drivelines, however. The set of dates from Devil's Thumb Valley proves that there is at least some degree of preservation of Late Paleoindian-aged materials near hunting features, suggesting that natural landscape changes over time did not completely erase organic materials from the early Holocene. Researchers have dated Late Paleoindian occupations elsewhere in the Southern Rocky Mountains at the subalpine/alpine ecotone (Pitblado 2000; Benedict 2005b; Brunswig and Doerner 2021), which demonstrate the importance of high-altitude landscapes for peoples living 10 ka-7500 BP. I do not question the technological capabilities of Late Paleoindian groups; sites of this age throughout the Rocky Mountain region show a diverse range of subsistence strategies involving communal hunting and intercept tactics (Morris 1990; Pitblado 1999; Kornfeld and Larson 2008; Lee and Puseman 2017). I do question whether there is sufficient evidence to support a hypothesis of Late Paleoindian-aged construction of drivelines in the Southern Rocky Mountains, given the results of chronological hygiene and Bayesian modeling. The modeled chronology presented in this paper is conservative and does not consider the age and affiliation of more than 60 other hunting sites with dry-laid features in the region, which *could be* much older, but these sites lack formal chronological research.

It is more difficult to rebuke the potential relationship between hunter-gatherers of the Early Archaic Mount Albion complex and stone drivelines in the Southern Rocky Mountains. In the Bayesian analysis of Model A, this time frame corresponds with the earliest portion of the game drive tradition phase which is supported by low quantities of ^{14}C dates collected by soil cores in blinds from several sites in the sample. Mount Albion projectile points have been found across the surface of numerous game drives in the Southern Rockies (LaBelle and Pelton 2013), including the recently published High Grade site (Meyer 2019, 2021). It is remarkable, however, that Mount Albion points have not been reported in direct association with driveline intercept areas for sites with demonstrated survey coverage (e.g., Meyer 2019). Seven of the game drive sites in the sample have produced time-diagnostic artifacts within hunting blinds (Table 3), amounting to 55 projectile points and one glass trade bead. Whittenburg (2017:45, 48–49) reported a tentative Mount Albion point from Blind 573 at the 5GA35 site, but a ^{14}C date of 3090 ± 250 BP from the feature is roughly 2000 years later than the accepted range for the Mount Albion complex. Other early projectile point styles from blinds include possible Duncan-Hanna types based on fragments found in Blind D-6 at the Sawtooth Game Drive (5BL55), which date regionally to the latter end of the Middle Archaic (Cassells 1995). The overwhelming majority of projectile points from hunting blinds date to the Early Ceramic period, represented by at least 37 Hogback phase corner-notched arrows. At the Murray site, Benedict (1975a) excavated 15 Hogback corner-notched points along with a thermal feature

Table 3 Time-diagnostic projectile points and unspecified point types collected during excavation of hunting blinds pits at alpine drivelines in Colorado.

Site	Blind	Late Paleoindian	Early Archaic	Middle/Late Archaic	Early Ceramic	Middle Ceramic	Protohistoric/ Early Historic	Not Specified	Reference
Sawtooth	Blind B-2				1[3]				Cassells 1995:219
Sawtooth	Blind D-6			2[1]	6[3]	4[4]			Cassells 1995:219
Murray	Blind 1				15[3]				Benedict 1975a:167
Murray	Blind 4				6[3]	2[4]			Benedict 1975a:167
Murray	Blind 5				2[3]	0			Benedict 1975a:167
Olson	Blind 42			1[2]	5[3]	1[5]			LaBelle and Pelton 2013:56
Olson	Blind 61				1[3]	0	1[6]		LaBelle and Pelton 2013:56
Olson	Blind 71				1[3]	1[5]			LaBelle and Pelton 2013:56
High Grade	Blind 280						1[7]		Meyer 2021:98
Water Dog Divide	Blind 1						1[8]		Hutchinson 1990: Fig.14f
5BL68	Blind 2					1[4]			Benedict 1975b:Fig.8
5GA35	Blind 541							1	Whittenburg 2017:45
5GA35	Blind 573		1?					2	Whittenburg 2017:45, 48–49

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[1] McKean or Duncan-Hanna dart (5350–2950 BP): (Metcalf 1973; Morris et al. 1985).

[2] Pelican Lake dart (3200–1720 BP): (Todd et al. 2001; LaBelle and Pelton 2013).

[3] Hogback corner-notched arrow (1350–950 BP): (Nelson 1971; Benedict 1975b, 1975a).

[4] Unspecified side-notched arrow.

[5] Plains side-notched arrow (850–150 BP): (Kornfeld et al. 2016).

[6] Plains tri-notched arrow (350–150 BP): (Reher and Frison 1980; Kornfeld et al. 2016).

[7] Small white glass seed bead (115–100 BP): (Von Wedell 2011; Newton 2016).

[8] Unspecified tri-notched arrow.

Figure 9 Early Ceramic period Hogback corner-notched projectile points from Blind 1 at the Murray site.

and other tools in Blind 1 (Figure 9), suggesting gear caching behavior, a discarded toolkit, a votive offering, or frequent site revisits during the Early Ceramic period.

Hungry Whistler (5BL67) is both the type site for the Mount Albion tradition and the best possible case demonstrating the connection between Early Archaic hunter-gatherers and driveline sites in the region (Benedict 1978). The site is situated between three other driveline complexes, including the Murray site (5BL65) and 5BL68 which date to the Early Ceramic and Middle Ceramic periods, or roughly 3000 years later than Hungry Whistler. It is a unique site given that it is made up primarily of very low-lying and dispersed cairns as opposed to aggregated walls and hunting blinds like other formal driveline complexes. There is a v-shaped arrangement to the features like most drivelines, with a principal cairn wall that leads to a concentration of several tree islands at timberline. Only two hunting blinds were noted at the site, downslope of the primary concentration of features. Benedict (1978) did not directly date any of the hunting features, hence the exclusion of the dates from this analysis, but they did excavate two open lithic campsites in close vicinity to the game drive on flat benches at the western and eastern flanks of the drive system. In addition to Mount Albion complex materials, the team observed projectile points from later occupations including untyped stemmed, shouldered, and small lanceolate varieties comparable to McKean and Duncan-Hanna types (Benedict 1978:72).

Benedict produced five ^{14}C dates from hearths and stains at the closest campsite to the principal cairn line at Hungry Whistler (roughly 30 m away) which spanned 5800–4010 BP (Benedict 1978:26), a roughly 2000-year period. Four of these dates have standard uncertainties greater than 100 years, which also excluded them from the Bayesian analysis in this paper. The team observed three cairns in the excavation area which were embedded near the contact between stratigraphic units containing the hearths (about 15 cm beneath the modern surface), suggesting a potential relationship between the driveline features, hearths, and artifacts. However, the excavation team also documented intense vertical mixing of deposits because of the Triple Lakes Stade Neoglaciation as well as late Neoglacial frost disturbance, visible through the reactivation of sorted nets and dilation cracks onsite (Benedict 1978:40). The extreme periglacial environment at Hungry Whistler allows for some speculation about spatial relationships between cultural materials, and it is worth introducing Benedict's own interpretations to avoid biasing the reader. Regarding neoglacial frost disturbance (frost-heaving), Benedict (1978:73) stated:

> Because of vertical mixing and the probability that each of several prehistoric groups visited the terrace made use of most of its limited level surface area, it is impossible to relate generalized butchering with grinding tools to specific projectile point styles or radiocarbon ages.

The team did demonstrate that cairns within the excavation area closely coincided with hearth features, but they also revealed that "with a single exception, hearths at the site were modified so strongly by early Neoglacial frost disturbance that their original characteristics could not be determined." (Benedict 1978:45). Only the youngest basin hearth, dated to 4010 ± 90 BP (after Mount Albion), escaped significant modification by periglacial processes and this feature is in the same stratigraphic unit as the other dated hearths. I think it is reasonable to assume, based on the information presented, that the driveline features could post-date the Mount Albion component and perhaps relate to later components present on the site. Earlier in the report, Benedict (1978:10) also conceded that it is "... uncertain whether the wall and multiple cairn lines are part of a single drive unit, or whether different systems of different ages are superimposed."

CONCLUSION

The Bayesian analysis, including Model A and Model B, overwhelmingly supports construction and use of stone drivelines beginning at the end of the Late Archaic period and continuing to the mid-to-late 1800s AD. This portion of the modeled chronology spans several regional technological traditions that are distinguishable based on changes in projectile point designs (Nelson 1971; Metcalf 1973; Morris et al. 1985; Gilmore 1999; Todd et al. 2001; Kornfeld et al. 2016), but also the emergence and proliferation of ceramic styles (Butler 1988; Owenby et al. 2021), rock oven technologies (Troyer 2014; Hedlund 2019), residential architecture (Cassells and Farrington 1986; Perlmutter 2015; Brunswig 2016), and mortuary practices (Gilmore 2008). Importantly, researchers have linked rapid changes in material culture to population expansion in northern Colorado at the end of the Archaic era (e.g., Gilmore 2008), and consequently, adjustments to landscape use stemming from population pressure between hunter-gatherer bands living in the Southern Rocky Mountains. The results of this study strongly suggest that the alpine game driving phenomenon is an additional development within a larger suite of socio-technological answers to demographic changes in the region. The game drive tradition most likely ended when the United States government began to enact legislations that forced Native Americans from their traditional hunting grounds at high altitudes (Simmons 2000; Brunswig 2020). More precise modeling of regional technological transitions and correlations with the game drive tradition will require chronological hygiene of the regional ^{14}C dataset, implementing improved methods for summing ^{14}C dates, and potentially revising chronologies by using Bayesian estimation as a statistically valid framework. Similar revisions of the regional climate record and its effect on high-altitude occupations may prove useful for interpreting the ebb and flow of alpine driveline construction and use over the last 2000 years (Benedict 1999).

New dating efforts at these sites must prioritize modern methods for ^{14}C sample selection and processing as well as independent validation of lichenometric dating techniques. The results of the sensitivity analyses revealed that model precision can be markedly improved with the addition of as few as 10 new ^{14}C dates from good context. Researchers should focus on measuring new random sample sets of *Rhizocarpon* sp. on walls with existing lichenometric dates to determine if dates are reproducible within an acceptable margin of statistical error. Researchers can revise the calibrated error of lichenometric dates with the addition of new control points in the age-growth calibration curve, and by redating existing control points. Archaeologists should also consider constructing independent calibration curves in other mountain ranges to better understand local climate effects on *Rhizocarpon* sp. growth over time, as well as the spatial range limits of accurate date predictions with calibration curves.

Additional prior information is needed to improve Bayesian modeling of alpine driveline sites. Specifically, archaeologists must prioritize establishing occupation sequences within individual sites which may be used as informative prior information to constrain date uncertainties and thus improve model precision. This will be a difficult task given that vertical separation of materials in alpine sites is often weak, mixed, or totally absent. The Devil's Thumb Valley and Hungry Whistler sites are perfect examples of this persistent issue. Spatial statistical modeling and clustering algorithms may prove useful for grouping together sets of dated features based on functional relationships (i.e., clusters of hunting blinds and walls within sites). Such methods should be applied to surface distributions of artifacts, which may provide evidence to link projectile points to driveline intercept areas. Additionally, archaeologists should pursue new simulation studies involving comparisons with other technological traditions that span the Bayesian chronology presented here. Archaeologists may wish to explore new Bayesian models testing whether these weapon technologies overlapped in time at alpine driveline sites, or if intervals of site abandonment occurred between the development of new weapon technologies.

ACKNOWLEDGMENTS

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SUPPLEMENTARY MATERIAL

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COMPETING INTERESTS STATEMENT

The author does not identify any competing interests in the publication of this article.

REFERENCES

Armstrong RA. 2016. Lichenometric dating (lichenometry) and the biology of the lichen genus rhizocarpon: challenges and future directions. Geografiska Annaler: Series A, Physical Geography 98(3):183–206.

Barge O, Albukaai D, Boelke M, Guadagnini K, Régagnon E, Crassard R. 2022. New Arabian desert kites and potential proto-kites extend the global distribution of hunting mega-traps. Journal of Archaeological Science: Reports 42:103403.

Barge O, Brochier JE, Deorn J-M, Sala R, Karakhanyan A, Avagyan A, Plakhov K. 2016. The "desert kites" of the Ustyurt plateau. Quarternary International 395:113–132.

Bayliss A. 2009. Rolling out revolution: using radiocarbon dating in archaeology. Radiocarbon 51:123–147.

Bayliss A. 2015. Quality in Bayesian chronological models in archaeology. World Archaeology 47(4):677–700.

Benedict JB. 1975a. The Murray Site: a Late Prehistoric game drive system in the Colorado Rocky Mountains. Plains Anthropologist 20(69):161–174.

Benedict JB. 1975b. Scratching deer: a Late Prehistoric campsite in the Green Lakes Valley, Colorado. Plains Anthropologist 20(70):267–278.

Benedict JB. 1978. Excavations at the Hungry Whistler Site. In: Benedict JB, Olson BL, editors. The Mount Albion Complex: a study of prehistoric man and the altithermal. Ward (CO): Center for Mountain Archaeology. Research report. p. 1–70.

Benedict JB. 1979. Excavations at the Blue Lake Valley site, Front Range, Colorado. Southwestern Lore 45(4):7–17.

Benedict JB. 1985. Arapaho Pass: glacial geology and archaeology at the crest of the Colorado Front Range. Ward (CO): Center for Mountain Archaeology Research. Research report No.: 3.

Benedict JB. 1987. A fasting bed and game drive site on the Continental Divide in the Colorado Front Range. Southwestern Lore 53(3):1–27.

Benedict JB. 1992. Footprints in the snow: high-altitude cultural ecology of the Colorado Front Range, USA. Arctic and Alpine Research 24(1):1–16.

Benedict JB. 1996. The game drives of Rocky Mountain National Park. Ward (CO): Center for Mountain Archaeology Research. Report report No.:7.

Benedict JB. 1999. Effects of changing climate on game-animal and human use of the Colorado High Country (USA) since 1000 BC. Arctic, Antarctic, and Alpine Research 31(1):1–15.

Benedict JB. 2000. Game drives of the Devil's Thumb Pass area. In: Cassells ES, editor. This land of shining mountains: archaeological studies in Colorado's Indian Peaks Wilderness Area. Ward (CO): Center for Mountain Archaeology. Research report. p. 18–94.

Benedict JB. 2002. Eolian deposition of forest-fire charcoal above tree limit, Colorado Front Range, USA: potential contamination of AMS radiocarbon samples. Arctic, Antarctic, and Alpine Research 34(1):33–37.

Benedict JB. 2005a. Tundra game drives: an Arctic-Alpine comparison. Arctic, Antarctic, and Alpine Research 37(4):425–434.

Benedict JB. 2005b. Rethinking the Fourth of July Valley site: a study in glacial and periglacial geoarchaeology. Geoarchaeology 20(8): 797–836.

Benedict JB. 2009. A review of lichenometric dating and its applications to archaeology. American Antiquity 74(1):143–172.

Benedict JB, Cassells ES. 2000. The Bob Lake Game Drive. In: Cassells ES, editor. This land of shining mountains: archaeological studies in Colorado's Indian Peaks Wilderness Area. Ward (CO): Center for Mountain Archaeology. Research report. p. 1–19.

Bertran P, Beauval C, Boulogne S, Brenet M, Costamagno S, Feuillet T, Laroulandie V, Lenoble A, Malaurent P, Mallye J-B. 2015. Experimental archaeology in a mid-latitude periglacial context: insight into site formation and taphonomic processes. Journal of Archaeological Science 57:283–301.

Bickerton RW, Matthews JA. 1993. "Little ice age" variations of outlet glaciers from the jostedalsbreen ice-cap, southern Norway: a regional lichenometric-dating study of ice-marginal moraine sequences and their climatic significance. Journal of Quarternary Science 8(1):45–66.

Black KD. 1991. Archaic continuity in the Colorado Rockies: the mountain tradition. Plains Anthropologist 36(133):1–29.

Brink JW. 2005. Inukshuk: Caribou drive lanes on southern Victoria Island, Nunavut, Canada. Arctic Anthropology 42(1):1–28.

Bronk Ramsey C. 2009a. Bayesian analysis of radiocarbon dates. Radiocarbon 51(1):337–360.

Bronk Ramsey C. 2009b. Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51(3):1023–1045.

Bronk Ramsey C. 2017. Methods for summarizing radiocarbon datasets. Radiocarbon 59(6): 1809–1833.

Brunswig RH. 2005. Prehistoric, protohistoric, and early historic Native American archeology of Rocky Mountain National Park: final report of system-wide archeological inventory program investigations by the University of Northern Colorado (1998–2002). Estes Park, Colorado: Rocky Mountain National Park, National Park Service.

Brunswig RH. 2016. Valley View (5LR1085): a shallow pithouse site in Colorado's Northern Front Range Foothills. Southwestern Lore 82(2):1–34.

Brunswig RH. 2020. Mountain Ute and the earliest Numic colonization of the Southern Rocky Mountains: A New Perspective from the Sue Site (5JA421), North Park, Colorado. In: Brunswig RH, editor. Spirit Lands of the Eagle and Bear: Numic archaeology and ethnohistory in the Rocky Mountains and Borderlands. Louisville: University Press of Colorado. p. 118–150.

Brunswig RH, Doerner J, Diggs D. 2014. Eleven millennia of human adaptation in Colorado's High Country: modeling cultural and climatic change in the Southern Rocky Mountains. In: Lacey S, Tremain C, Sawyer, Madelaine, editors. Climates of change: the shifting environments of archaeology. Calgary, Canada: Chacmool Archaeological Association, University of Calgary. p. 273–286.

Brunswig RH, Doerner JP. 2021. Lawn Lake, a high montane hunting camp in the Colorado (USA) rocky mountains: Insights into early Holocene Late Paleoindian hunter-gatherer adaptations and paleo-landscapes. North American Archaeologist 42(1):5–44.

Buck CE, Cavanagh WG, Litton CD. 1996. Bayesian approach to interpreting archaeological data. West Sussex, United Kingdom: Wiley.

Butler WB. 1988. The Woodland Period in northeastern Colorado. Plains Anthropologist 33(122):449–465.

Carcaillet C. 2001. Are Holocene wood-charcoal fragments stratified in alpine and subalpine soils? Evidence from the Alps based on AMS ^{14}C dates. The Holocene 11(2):231–242.

Cassells ES. 1995. Hunting the Open High Country: prehistoric game driving in the Colorado Alpine Tundra [dissertation]. Madison (WI): University of Wisconsin.

Cassells ES. 2012. Lichenometry applications on archaeological sites in the Colorado High Country. In: LaBelle JM, Cassells ES, editors. Footprints in the snow: papers in honor of James B. Benedict. Vol. 78. Southwestern Lore. p. 35–40.

Cassells ES, Farrington RN. 1986. Excavations at the Indian Mountain Site, 5BL876: a multi-component stone circle site in Colorado's Northeastern Foothills. Plains Anthropologist 31(112):129–139.

Clark B. 1999. Protohistoric stage. In: Colorado prehistory: a context for the Platte River Basin. Denver: Colorado Council of Professional Archaeologists. p. 309–336.

Crassard R, Barge O, Bichot C-E, Brochier JE, Chahoud J, Chambrade M-L, Chataigner C, Madi K, Régagnon E, Seba H, et al. 2015. Addressing the Desert Kites Phenomenon and its global range through a multi-proxy approach. Journal of Archaeological Method and Theory 22(4):1093–1121.

Dee MW, Bronk Ramsey C. 2014. High-precision Bayesian modeling of samples susceptible to inbuilt age. Radiocarbon 56(1):83–94.

Douglass K, Hixon S, Wright HT, Godfrey LR, Crowley BE, Manjakahery B, Rasolondrainy T, Crossland Z, Radimilahy C. 2019. A critical review of radiocarbon dates clarifies the human settlement of Madagascar. Quarternary Science Reviews 221:105878.

Emerman SH. 2017. The use of lichenometry for assessment of the destruction and reconstruction of Buddhist sacred walls in Langtang Valley, Nepal Himalaya, following the 2015 Gorkha earthquake. Arctic, Antarctic, and Alpine Research 49(1):61–79.

Foulds SA, Macklin MG. 2016. A hydrogeomorphic assessment of twenty-first century floods in the UK. Earth Surface Processes and Landforms 41(2):256–270.

Gilmore KP. 1999. Late Prehistoric Stage. In: Gilmore KP, Tate MJ, Chenault ML, Clark B, McBride T, Wood M, editors. Colorado Prehistory: a context for the Platte River Basin. Denver: Colorado Council of Professional Archaeologists. p. 175–307.

Gilmore KP. 2008. Ritual landscapes, population, and changing sense of place during the Late Prehistoric transition in Eastern Colorado. In: Scheiber LL, Clark BJ, editors. Archaeological landscapes on the High Plains. Boulder (CO): University Press of Colorado. p. 71–114.

Graf KE. 2009. '"The Good, the Bad, and the Ugly"': evaluating the radiocarbon chronology of the middle and late Upper Paleolithic in the Enisei River valley, south-central Siberia. Journal of Archaeological Science 36(3): 694–707.

Gragson TL, Thompson VD. 2022. Legacy radiocarbon dates and the archaeological chronology of the Western Pyrenees. Journal of Archaeological Science: Reports 43:103483.

Griffiths S. 2014. Simulations and outputs. Radiocarbon. 56(2):871–876.

Hamilton WD, Krus AM. 2018. The myths and realities of Bayesian chronological modeling revealed. American Antiquity 83(2):187–203.

Hedlund JR. 2019. Thermal feature morphology change and implications for prehistoric subsistence and settlement on the northern escarpment of the Palmer Divide, Colorado [master's thesis]. Boulder (CO): University of Colorado.

Holland-Lulewicz J, Ritchison BT. 2021. How many dates do I need?: Using simulations to determine robust age estimations of archaeological contexts. Advances in Archaeological Practice 9(4):272–287.

Hutchinson LA. 1990. Archaeological Investigations of High Altitude Sites Near Monarch Pass, Colorado [master's thesis]. Fort Collins (CO): Colorado State University.

Innes JL. 1983. Size frequency distributions as a lichenometric technique: an assessment. Arctic and Alpine Research 15(3):285–294.

Jomelli V, Grancher D, Naveau P, Cooley D, Brunstein D. 2007. Assessment study of lichenometric methods for dating surfaces. Geomorphology 86(1–2):131–143.

Kornfeld M, Frison GC, Larson ML. 2016. Prehistoric hunter-gatherers of the High Plains and Rockies. 3rd ed. New York: Routledge.

Kornfeld M, Larson ML. 2008. Bonebeds and other myths: Paleoindian to Archaic transition on north American great plains and rocky mountains. Quarternary International 191(1):18–33.

LaBelle JM, Pelton SR. 2013. Communal hunting along the Continental Divide of Northern Colorado: results from the Olson game drive (5BL147), USA. Quarternary International. 297:45–63.

Lee CM, Puseman K. 2017. Ice patch hunting in the greater Yellowstone area, rocky mountains, USA: wood shafts, chipped stone projectile points, and bighorn sheep (*Ovis canadensis*). American Antiquity 82(2):223–243.

Lemke A. 2021. Literal niche construction: Built environments of hunter-gatherers and hunting architecture. Journal of Anthropological Archaeology 62:101276.

Lemke A. 2022. The architecture of hunting: the built environment of hunter-gatherers and its impact on mobility, property, leadership, and labor. College Station (TX): Texas A&M University Press.

Loso MG, Doak DF. 2006. The biology behind lichenometric dating curves. Oecologia 147(2):223–229.

Meadows J, Rinne C, Immel A, Fuchs K, Krause-Kyora B, Drummer C. 2020. High-precision Bayesian chronological modeling on a calibration plateau: the Niedertiefenbach gallery grave. Radiocarbon 62(5):1261–1284.

Metcalf MD. 1973. Archaeology at Dipper Gap: an archaic campsite, Logan County, CO [master's thesis]. Fort Collins (CO): Colorado State University.

Meyer, KA. 2019. Absolute and Relative Chronology of a Complex Alpine Game Drive Site (5BL148), Rollins Pass, Colorado [master's thesis]. Fort Collins (CO): Colorado State University.

Meyer KA. 2021. A multi-method approach to dating: persistent occupation of the alpine Tundra at Rollins Pass, Colorado. Journal of Field Archaeology 46(2):93–107.

Morris EA. 1990. Prehistoric game drives in the Rocky Mountains and High Plains areas of Colorado. In: Davis LB, Reeves BOK, editors. Hunters of the recent past. London: Unwin-Hymin. p. 195–207.

Morris EA, Blakeslee RC, Thompson K. 1985. Preliminary description of McKean sites in northeastern Colorado. In: Kornfeld M, Todd LC, editors. McKean/Middle Plains Archaic: Current Research. Laramie. (Occasional Papers on Wyoming Archaeology). p. 11–20.

Napolitano MF, DiNapoli RJ, Stone JH, Levin MJ, Jew NP, Lane BG, O'Connor JT, Fitzpatrick SM. 2019. Reevaluating human colonization of the Caribbean using chronometric hygiene and Bayesian modeling. Science Advances 5(12): eaar7806.

Nelson CE. 1971. The George W. Lindsay Ranch site, 5JF11. Southwestern Lore. 37(1):1–14.

Newton CC. 2016. The Lykins Valley Site (5LR263): an early nineteenth century Indigenous occupation at the western edge of the Central Plains. Plains Anthropologist 61(237):50–75.

Novák J, Petr L, Treml V. 2010. Late-Holocene human-induced changes to the extent of alpine areas in the East Sudetes, Central Europe. The Holocene 20(6):895–905.

Osborn G, McCarthy D, LaBrie A, Burke R. 2015. Lichenometric dating: science or pseudo-science? Quaternary Research 83(1):1–12.

Owenby MF, LaBelle JM, Pelton H. 2021. Mobility and ceramic paste choice: petrographic analysis of prehistoric pottery from northeastern Colorado. Plains Anthropologist 66(260):277–312.

Payette S, Gagnon R. 1985. Late Holocene deforestation and tree regeneration in the forest–tundra of Québec. Nature 313(6003):570–572.

Perlmutter B. 2015. Bringing it all back home: Early Ceramic period residential occupation at the Kinney Spring site (5LR144c), Larimer County, Colorado [master's thesis]. Fort Collins (CO): Colorado State University.

Pettitt PB, Davies W, Gamble CS, Richards MB. 2003. Palaeolithic radiocarbon chronology: quantifying our confidence beyond two half-lives. Journal of Archaeological Science. 30(12):1685–1693.

Pitblado BL. 1999. Late Paleoindian occupation of the Southern Rocky Mountains: Projectile points and land use in the high country [PhD dissertation]. Tucson (AZ): University of Arizona.

Pitblado BL. 2000. Living the High Life in Colorado: Late Paleoindian occupation of the Caribou Lake site. In: Cassells ES, editor. This land of shining mountains: archaeological studies in Colorado's Indian Peaks wilderness area. Ward (CO): Center for Mountain Archaeology. Research report. p. 124–158.

Reher CA, Frison GC. 1980. The Vore site, 48CK302: A Stratified Buffalo Jump in the Wyoming Black Hills. Plains Anthropologist Memoir 16, Lincoln.

Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG, Bronk Ramsey C, Butzin M, et al. 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radiocarbon 62:725–757.

Roberts SJ, Hodgson DA, Shelley S, Royles J, Griffiths HJ, Deen TJ, Thorne MAS. 2010. Establishing lichenometric ages for nineteenth- and twentieth-century glacier fluctuations on South Georgia (South Atlantic). Geografiska Annaler: Series A, Physical Geography 92(1):125–139.

Rosenwinkel S, Korup O, Landgraf A, Dzhumabaeva A. 2015. Limits to lichenometry. Quarternary Science Reviews 129:229–238.

Simmons VM. 2000. The Ute Indians of Utah, Colorado, and New Mexico. Boulder (CO): University Press of Colorado.

Spriggs M. 1989. The dating of the Island Southeast Asian Neolithic: an attempt at chronometric hygiene and linguistic correlation. Antiquity 63(240):587–613.

Tate MJ. 1999. Archaic Stage. In: Gilmore KP, Tate MJ, Chenault ML, Clark B, McBride T, Wood M, editors. Colorado Prehistory: a context for the Platte River Basin. Denver: Colorado Council of Professional Archaeologists. p. 91–174.

Taylor WTT, Jargalan B, Lowry KB, Clark J, Tuvshinjargal T, Bayarsaikhan J. 2017. A Bayesian chronology for early domestic horse use in the Eastern Steppe. Journal of Archaeological Science 81:49–58.

Tinner W, Hofstetter S, Zeugin F, Conedera M, Wholgemuth T, Zimmerman L, Zweifel R. 2006. Long-distance transport of macroscopic charcoal by an intensive crown fire in the Swiss Alps/ implications for fire history reconstruction. The Holocene 16(2):287–292.

Todd LC, Jones DC, Walker RS, Burnette PC, Eighmy J. 2001. Late Archaic bison hunters in Northern Colorado: 1997–1999 excavations at the Kaplan-Hoover bison bonebed (5LR3953). Plains Anthropologist 46(176):125–147.

Troyer MD. 2014. Cooking with rock: an investigation of prehistoric hearth morphology in northern Colorado [master's thesis]. Fort Collins (CO): Colorado State University.

Von Wedell CR. 2011. Methods of dating glass beads from protohistoric sites in the South Platte River Basin, Colorado [master's thesis]. Fort Collins (CO): Colorado State University.

Whittenburg AM. 2017. Communal hunting in the Colorado High Country: archaeological investigations of three game drive sites near Rollins Pass, Grand County, Colorado [master's thesis]. Fort Collins (CO): Colorado State University.

Wiles GC, Barclay DJ, Young NE. 2010. A review of lichenometric dating of glacial moraines in Alaska. Geografiska Annaler: Series A, Physical Geography 92(1):101–109.

Winchester V, Chaujar RK. 2002. Lichenometric dating of slope movements, Nant Ffrancon, North Wales. Geomorphology 47(1):61–74.

Appendix 1 ^{14}C dates from excavated hunting blinds containing loose charcoal and no thermal features (n=11) – removed from analysis

Site	Lab no.	^{14}C age BP	Error	Material	Sample collection	Context	$\delta^{13}C$	$\delta^{15}N$	C: N	Primary reference
Trail Ridge (5LR15)	Beta-161359	1340	40	Organic sediment (unknown)	Excavation	Blind 5 (matrix)				Brunswig 2005:860–663
Flattop Mountain (5LR6)	Beta-161358	1740	50	Organic sediment (unknown)	Excavation	Blind 56? (matrix)				Brunswig 2005:860–663
Sawtooth (5GA55)	Beta-39156	1325	60	Charred twig (unknown)	Excavation	Blind B-2 (beneath rock slab, not in matrix)				Cassells 1995: Appendix 3
Sawtooth (5GA55)	Beta-39155	1265	60	Charred needles (Picea)	Excavation	Blind B-2 (beneath rock slab, not in matrix)				Cassells 1995: Appendix 3
Sawtooth (5GA55)	Beta-39154	915	50	Charred twig (unknown)	Excavation	Blind A-1 (matrix)				Cassells 1995: Appendix 3
Sawtooth (5GA55)	Beta-39158	430	60	Charred twig (unknown)	Excavation	Blind B-4 (matrix)				Cassells 1995: Appendix 3
Sawtooth (5GA55)	Beta-39157	255	60	Charred twig (unknown)	Excavation	Blind B-4 (matrix)				Cassells 1995: Appendix 3
Blue Lake Valley (5BL141)	I-8281	3215	90	Charcoal (bulk - unknown)	Excavation	Blind 1 (matrix)				Benedict 1979:12
5BL68	I-2423	1360	180	Charcoal (bulk - unknown)	Unknown	Blind 1 (matrix)				Benedict 1975b:276
5BL68	SI-302	1230	360	Charcoal (bulk - unknown)	Unknown	Blind 2 (matrix)				Benedict 1975b:276
Unknown	Beta-44747	6175	65	Charcoal (unknown)	Unknown	unknown				Benedict 2005:429

Appendix 2 ^{14}C dates from campsite hearths or wildfire deposits as defined by the original investigators (n=29) – removed from analysis

Site	Lab no.	^{14}C age BP	Error	Material	Sample collection	Context	δ^{13}C	δ^{15}N	C: N	Primary reference
Trail Ridge (5LR15)	Beta-133230	260	40	Charcoal (unknown)	Excavation	Campsite test unit (hearth)				Brunswig 2005:860–663
Hungry Whistler (5BL67)	I-3267	5800	125	Charcoal (bulk - unknown)	Excavation	Unit 8SW/8E (charred layer)				Benedict 1978:26
Hungry Whistler (5BL67)	I-3817	5730	130	Charcoal (bulk - unknown)	Excavation	Unit 8SW/87E (charred layer)				Benedict 1978:26
Hungry Whistler (5BL67)	I-9434	5520	190	Charcoal (bulk - unknown)	Excavation	Unit 7NE/4SE (charred layer)				Benedict 1978:26
Hungry Whistler (5BL67)	I-4418	5300	130	Charcoal (bulk - unknown)	Excavation	Unit 6SW/2SE (charred layer)				Benedict 1978:26
Hungry Whistler (5BL67)	I-9777	4010	90	Charcoal (bulk - unknown)	Excavation	Unit 3SW/1SE (hearth)				Benedict 1978:26
Devil's Thumb Valley (5GA3440)	Beta-122996	9570	80	Charcoal (unknown)	Excavation	Area A Unit 2S/3W (charred layer)	–24.2			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-122997	9550	80	Charcoal (unknown)	Excavation	Area A Unit 3S/4W (matrix)	–22.7			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-126919	9410	90	Charcoal (unknown)	Excavation	Area A Debitage Column 4 (matrix)	–22.5			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-85362	9390	70	Charcoal (bulk - unknown)	Excavation	Area A Unit 3N/2W (charred stain)	–20.9			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-109991	9340	50	Charred needles (Picea)	Excavation	Area A Unit 4N/2W (charred stain)	–24			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-123606	9310	60	Charcoal (unknown)	Excavation	Area A Debitage Column 4 (matrix)	–23.8			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-129167	9270	40	Charcoal (unknown)	Excavation	Area A Debitage Column 4 (matrix)	–22.6			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-109992	8620	50	Charcoal (unknown)	Excavation	Area A Unit 2N/3W (matrix)	–22.8			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-109990	5710	40	Charcoal (unknown)	Excavation	Area A Unit 3N/3W (charred layer)	–26.7			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-102253	5680	50	Charcoal (unknown)	Excavation	Area A Unit 3N/2W (charred stain)	–23.2			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-109993	5550	50	Charcoal (unknown)	Excavation	Area A Unit 2S/4W (matrix)	–22.6			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-74908	4960	70	Charcoal (unknown)	Excavation	Area A Unit 1N/2W (matrix)	–27.1			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-126918	4900	60	Charcoal (unknown)	Excavation	Area A Debitage Column 4 (matrix)	–24.5			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-102255	4390	50	Charcoal (unknown)	Excavation	Area A Unit 3N/3W (charred stain)	–25.6			Benedict 2000: Table 2.6

(Continued)

Appendix 2 (*Continued*)

Site	Lab no.	^{14}C age BP	Error	Material	Sample collection	Context	δ^{13}C	δ^{15}N	C: N	Primary reference
Devil's Thumb Valley (5GA3440)	Beta-109989	4270	50	Charred needles (Picea)	Excavation	Area A Unit 3N/3W (charred layer)	–25.5			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-122995	4250	50	Charcoal (unknown)	Excavation	Area A Unit 2S/3W (matrix)	–22.2			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-111214	3370	60	Charcoal (unknown)	Excavation	Area A Unit 2S/4W (matrix)	–24.7			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-60763	3305	55	Charcoal (unknown)	Excavation	Area A Unit 3N/5W (surface)	–23.8			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-102254	3220	70	Charcoal (unknown)	Excavation	Area A Unit 3N/3W (charred layer)	–32.7			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-98419	3200	50	Charred twig (unknown)	Excavation	Area A Unit 4N/2W (charred layer)	–24.3			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-79098	2250	70	Charcoal (bulk - unknown)	Excavation	Area B Unit B-6 (hearth)	–24.4			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-96540	2220	40	Charcoal (unknown)	Excavation	Area B Unit B-2 (matrix)	–22.8			Benedict 2000: Table 2.6
Devil's Thumb Valley (5GA3440)	Beta-74907	2160	60	Charred twig (Abies)	Excavation	Area B Unit B-6 (hearth)	–26.3			Benedict 2000: Table 2.6

Appendix 3 ^{14}C dates from surface collected animal bone (n=5) – removed from analysis

Site	Lab no.	^{14}C age BP	Error	Material	Sample collection	Context	δ^{13}C	δ^{15}N	C: N	Primary reference
Olson (5BL147)	UGA-11760	80	25	Collagen (Ovis canadensis)	Surface	Blind 2 (surface)				LaBelle and Pelton 2013:Table 4
High Grade (5BL148)	Beta-504029	1360	30	Collagen (Odocoileus sp.)	Surface	Wall C (surface)	–18.8	4.6	3.1	Meyer 2021:Table 2
High Grade (5BL148)	Beta-504030	200	30	Collagen (Ovis canadensis)	Surface	None (surface)	–19.8	5.4	3.2	Meyer 2021:Table 2
High Grade (5BL148)	Beta-488945	180	30	Collagen (unknown)	Surface	Wall A (surface)	–20.1	5.4	3.3	Meyer 2021:Table 2
High Grade (5BL148)	Beta-504031	170	30	Collagen (Ovis canadensis)	Surface	Wall C (surface)	–20.9	5.5	3.2	Meyer 2021:Table 2

Appendix 4 ^{14}C dates with standard uncertainties exceeding the minimum threshold of 100 years (n=10) – removed from analysis

Site	Lab no.	^{14}C age BP	Error	Material	Sample collection	Context	δ^{13}C	δ^{15}N	C: N	Primary reference
Murray (5BL65)	SI-301	670	150	Charcoal (bulk - Picea/Abies)	Excavation	Blind 4 (hearth)				Benedict 1975a:167–169
Hungry Whistler (5BL67)*	I-3267	5800	125	Charcoal (bulk - unknown)	Excavation	Unit 8SW/8E (charred layer)				Benedict 1978:26
Hungry Whistler (5BL67)*	I-3817	5730	130	Charcoal (bulk - unknown)	Excavation	Unit 8SW/87E (charred layer)				Benedict 1978:26
Hungry Whistler (5BL67)*	I-9434	5520	190	Charcoal (bulk - unknown)	Excavation	Unit 7NE/4SE (charred layer)				Benedict 1978:26
Hungry Whistler (5BL67)*	I-4418	5300	130	Charcoal (bulk - unknown)	Excavation	Unit 6SW/2SE (charred layer)				Benedict 1978:26
5BL68	I-2423	1360	180	Charcoal (bulk - unknown)	Unknown	Blind 1 (matrix)				Benedict 1975b:276
5BL68	SI-302	1230	360	Charcoal (bulk - unknown)	Unknown	Blind 2 (matrix)				Benedict 1975b:276
5GA35	I-11132	3090	250	Charcoal (bulk - unknown)	Excavation	Blind 573 (matrix)				Whittenburg 2017:13
Olson (5BL147)	I-3856	3275	120	Charcoal (bulk - unknown)	Excavation	Blind 42 (hearth?)				LaBelle and Pelton 2013:Table 4
Olson (5BL147)	I-11133	360	170	Charcoal (bulk - unknown)	Excavation	Blind 93 (matrix)				LaBelle and Pelton 2013:Table 4

*Dates from Hungry Whistler also removed due to relationship with campsite hearths.