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A Precise Chronology of Middle to Late Holocene Bison Exploitation in the Far Southern Great Plains

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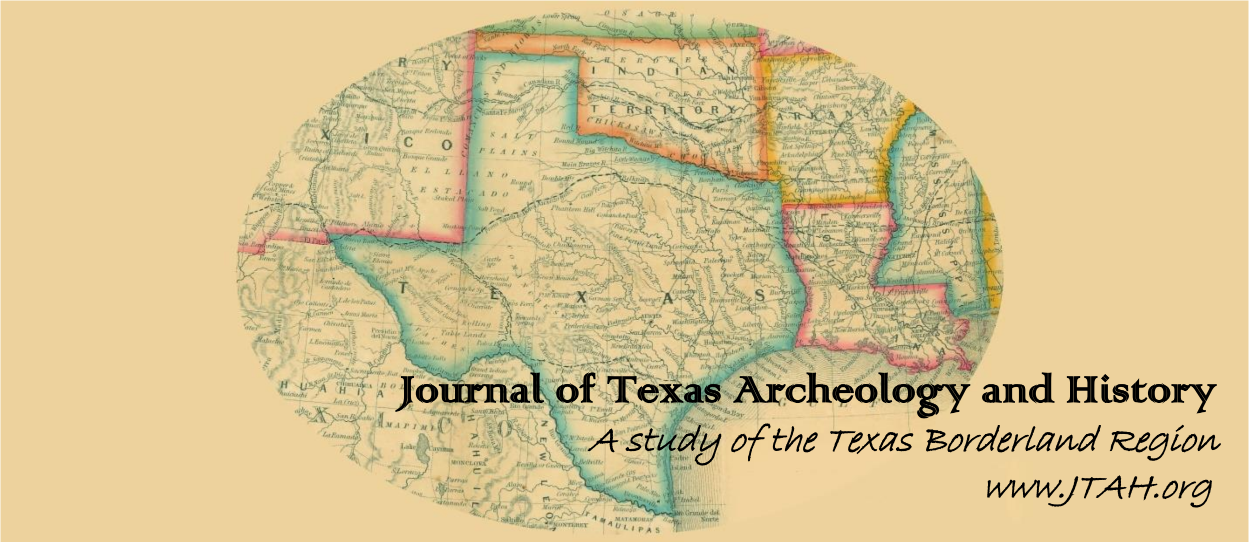

Article Title: A PRECISE CHRONOLOGY of MIDDLE to LATE HOLOCENE BISON EXPLOITATION in the FAR SOUTHERN GREAT PLAINS

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A PRECISE CHRONOLOGY OF MIDDLE TO LATE HOLOCENE BISON EXPLOITATION IN THE FAR SOUTHERN GREAT PLAINS

Jon C. Lohse, Brendan J. Culleton, Stephen L. Black, and Douglas J. Kennett

ABSTRACT

In regions on the margins of the Great Plains grasslands, documenting the intermittent history of bison exploitation has presented challenges to archeologists. Chronologies based on archeological associations have long been useful in regional research, but can be imprecise and of inadequate resolution for constructing precise sequences of prehistoric events. Here, we present a record of directly dated bison from archeological contexts spanning the last 6000 years on the very southern extent of the Great Plains. This study includes 61 specimens from archeological contexts that were dated by XAD purified AMS radiocarbon, with reported errors of only 15-20 14C years for most dates. The resulting record of bison exploitation for this area defines four main periods (Calf Creek, Late Archaic 1 and 2, and early Toyah) during which bison were exploited. Several dates also indicate an early historic presence of bison; this period may represent a late facet of the Toyah horizon. This study adds significant chronological resolution to the regional record of bison in parts of Texas and begins to help correlate cultural chronologies with important climatic data. It also points to the research value of obtaining additional directly dated bison samples from temporally and geographically diverse archeological contexts in our study area and beyond.

INTRODUCTION

The North American genus *Bison* was among the very top-ranked resources available to hunter-gatherers up to and even following the arrival of European explorers. Millennia of bison hunting on the Plains are documented from Early Paleoindian times onward (Bamforth 1988, 2011; Bement and Buehler 1994; Bozell et al. 2011; Carlson and Bement 2013; Cooper 2008; Frison 1991, 1998, 2004; Guthrie 1980). In Late Prehistoric times, agriculturalists in the American Southwest and Mississippi River drainages to the east often hunted bison or traded for their products, bringing them into frequent contact with Plains tribes (Creel 1991; Spielmann 1991; Speth 2004; Speth and Newlander 2012; Vehik 1990, 2002). Bison exploitation, for meat and other uses, has played a significant role in shaping prehistoric and early historic economies across the Plains. As a top-ranked food resource, the

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presence of bison would have had tremendously important implications for prehistoric subsistence practices, mobility, the organization of labor, and other social characteristics.

While bison were present almost continuously in the cool, predominantly C_3 grasslands of the Northern Plains, only occasionally in the Middle to Late Holocene periods did they extend into other environments characterized by mixed grasslands or other habitats. These areas include parts of the Great Basin (Grayson 2006), northern Mexico (List et al. 2007), and the southern limits of the Plains that include Central and coastal Texas (Baugh 1986; Dillehay 1974; Huebner 1991; Lynott 1979; Mauldin et al. 2012; Ricklis 1992). Understanding precisely when bison were present in regions located around the periphery of the Plains is important not only for our general knowledge regarding bison ecology, climate, and environmental change in North America, but also for providing insights into human responses during these periods.

In this study, we present and evaluate AMS radiocarbon data for 61 XAD purified samples of bison bone recovered from archeological contexts at seven sites located in Central and South Texas. The culture history of these areas shares much with Plains traditions to the north during some time intervals, while maintaining their own distinct patterns during others (Collins 1995, 2004; Hester 2004; Lohse et al. 2014a). Precisely defining periods when bison were present in these areas has been a challenge, largely as a result of the traditional reliance on dating bison by association with other archeological remains. Our approach involves directly dating bison from archeological contexts as a way to avoid the imprecision that can result from dating by association. The resulting chronology defines four primary periods of prehistoric bison exploitation beginning around 6000 cal B.P. and also indicates an early Historic use by North American Indians. Earlier periods of bison presence remain to be worked out for these areas, ideally using a similar methodology to the one we discuss herein. This precise chronology not only clarifies regional prehistoric subsistence and related technological practices, but can also help researchers correlate cultural developments with environmental or paleoclimatic data that may be associated with periods of rapid cultural change.

DATING BISON IN THE STUDY AREA AND THE PRESENT SAMPLE

Beginning with Dillehay (1974), many investigators have examined the issue of bison presence in the region (Baugh 1986; Collins 1995; Huebner 1991; Lynott 1979; Mauldin et al. 2012; Quigg 1997; Ricklis 1992). These studies commonly evaluate the presence of bison at a regional scale based on archeological components that are themselves dated by radiocarbon or by cross-dating using associated time-marker artifacts (Table 1). Typically, bison presence is modeled as a series of long periods of presence or absence, the beginnings and endings of which are imprecisely dated.

In contrast to regional models, single-site records (such as the one at Wilson-Leonard, 41WM235 [Collins 1998]), where bison were not present for certain intervals when they appear elsewhere, exemplify the limitations of site-specific studies. A given site's stratigraphy may be compressed or mixed, affecting an analysts' ability to precisely reconstruct periods of bison exploitation. This condition most directly and adversely affects bison chronologies that rely on archeological association. In other cases, a single site's occupation history may not include periods during which bison were present nearby. For example, Bonfire Rockshelter (41VV218) offers a fascinating record of bison hunting during certain periods in the Lower Pecos of southwest Texas, including Late Archaic, Folsom, and perhaps Clovis times (Bement 1986; Dibble and Lorrain 1968). However, this record does not include bison remains from the Calf Creek horizon, material traces of which are reported in nearby Eagle Cave (41VV167, Ross 1965) as well as from Jeff Davis and Brewster counties some 150 km to the west (Gray 2013; Walter 2013), indicating that the record at Bonfire Rockshelter does not completely reflect the character of regional bison histories.

Table 1. Some models of bison presence and visibility in the study region.

Southern Plains (Dillehay 1974)	Central Texas (Mauldin et al. 2012)		Wilson-Leonard (Sichler et al. 2011, from data by Baker 1998)	
Presence Period 3 800 B.P.	473.8 avg. NISP/component	700-400 B.P.	18 NISP/component	1700-4200 B.P.
Absence Period 2 1500-800 B.P.	2.9 avg. NISP/component	1250-700 B.P.	1 NISP/component	4200-5200 B.P.
Presence Period 2 4500-1500 B.P.	7.3 avg. NISP/component	1600-1250 B.P.	59 NISP/component	>11,000-9000 B.P.
Absence Period 1 ca. 7000 B.P.-4500 B.P.	316.9 avg. NISP/component	2500-1600 B.P.		
Presence Period 1 >11,000-7000 B.P.	6.0 avg. NISP/component	4450-2500 B.P.		

Our study draws from several sites geographically dispersed across a wide area. We do not imply that our study area corresponds with any particular archeological region(s). Indeed, the size of what might be called a "bison catchment" that is represented by this study is not precisely known. However, previous research indicates the potential size of prehistoric bison ranges. Carlson and Bement (2013) estimate mobility ranges from ca. 100 km (Clovis times) to up to ca. 600 km (late Folsom times) in diameter in an area centered on Oklahoma that includes southern Kansas, the Texas Panhandle, and eastern New Mexico. Widga et al. (2010) reconstruct inter-annual movements of ≤500 km over a period of about 4-5 years for Early/Middle Holocene (ca. 7-8.5 ka) bison in the eastern Great Plains of eastern Nebraska, South Dakota, western Iowa, and southwest Wisconsin. An area of ca. 600 km in diameter easily encompasses all of the sites from which samples in this study were taken (Figure 1).

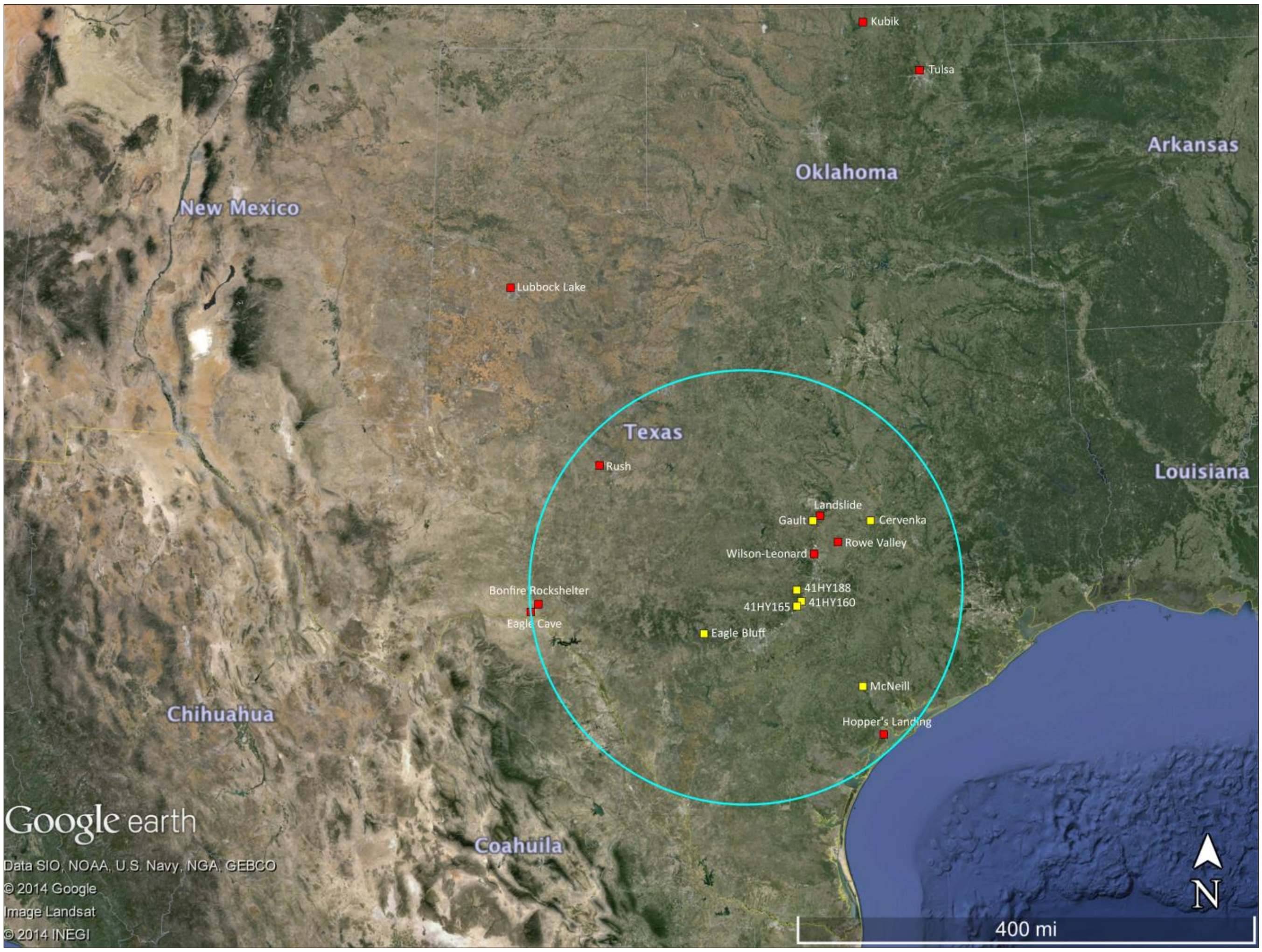

Figure 1. 600 km diameter study area illustrating the distance prehistoric herds may have travelled if they maintained mobility patterns comparable to those reconstructed elsewhere in North America. Sites dated in this study are shown in yellow; other sites discussed in the text are shown in red.

The presence of bison in the archeological record is, first, the result of environmental process and, second, a reflection of hunter-gatherer behavior. The key to building reliable bison chronologies, therefore, involves the number of temporal components that are sampled (i.e., selected for direct dating) within a given bison range. We propose that bison histories can be accurately reconstructed using sites with intermittent occupation records, so long as each period of bison presence in the total study area is well represented in at least one site's deposits. Alternatively, large portions of a bison chronology can also be compiled from a small number of sites, assuming that each period during which bison were present on the landscape is represented in site components and has been sampled. In this approach, compiling a large number of assays (i.e., high sample density) helps to ensure that all or most intervals of bison presence within the region are included. A weakness of this approach is that the geographic limits of bison territorial ranges will likely remain poorly known until sampling densities clearly define the geographic limits for each temporal period of bison presence.

Minimally, the patterns presented below are valid for the sites and time periods included in our study. Although we consider it likely that these patterns reflect larger-scale trends across a much broader area, only future sampling following the methods we employ here can precisely identify the extent of territorial ranges that are associated with the temporal periods in our chronology. For example, reports of bison presence throughout the Holocene at Lubbock Lake (41LU1) (Johnson 1987; Johnson and Holiday 1987) seem to suggest that the chronology presented here does not extend to the Texas Panhandle (see Figure 1).

Our sample draws heavily from 41HY160 and HY165, sites that are associated with Spring Lake, formed by impounded freshwater springs at the headwaters of the San Marcos River in Hays County, Texas. Based on temporally diagnostic artifacts and radiocarbon data (Figure 2), the Spring Lake sites exhibit a nearly continuous record of occupation from Clovis to historical periods (Lohse 2013). These sites are important to this study because their essentially continuous sequence means that remains of bison, as a top-ranked food resource, should be expected to occur whenever bison were present on the surrounding landscape. The occupation record of these sites distinguishes them from others, like Bonfire, with intermittent histories of site use. Controlled excavations at Spring Lake have generally not extended below the Early Archaic archeological deposits and intensive archeological sampling has only been conducted to ca. 6000 cal B.P. depths (Lohse et al. 2013), which represents the temporal limit of our study. Another site (41HY188) is less than 5 km from Spring Lake and evidences Late Prehistoric and Late Archaic occupation associated with bison (Bettis 1996). Two other specimens come from Eagle Bluff (41ME147) in Medina County (Hester 2010, 2011), one from Gault (41BL323) in Bell County, two from McNeill (41VT141) in Victoria County, and one from Cervenka (41WM267) in Williamson County (Peter et al. 1982). Each site contains deep, multi-component deposits in stratified alluvial settings, and is interpreted as a long-term encampment, making it unlikely that bison were killed at any of these locations. Rather, butchered remains were likely transported from kill sites back to these occupation areas for additional processing.

Assemblages from 41HY160, 41HY165, and 41HY188 were examined for bison remains suitable for dating. Virtually all specimens identified as bison were fragmented to the point that age and sex could not be consistently estimated. Therefore, no age and sex data are presented for the bison from any of our study sites. All cataloged contexts were evaluated, and specimens were selected from as many different proveniences by depth and site area as possible. Through this approach, every time period characterized by bison presence (and sampled by controlled excavation) had an equal chance of being identified. As noted, high sampling density was a priority in order to better model periods of bison presence. Samples were included from the other sites based on accessibility, preservation, and the limits of available funding.

Selected specimens were pre-treated for collagen extraction and purification using a XAD process modified from earlier work by Stafford that isolates individual amino acid chains (Stafford et al. 1988, 1991). Two modern approaches to removing exogenous carbon from bone collagen samples have been developed and refined over the last two decades: modified Longin (1971) extraction with *ultrafiltration* (Brown et al. 1988) and *XAD-purification* (Stafford et al. 1988, 1991). Ultrafiltration works

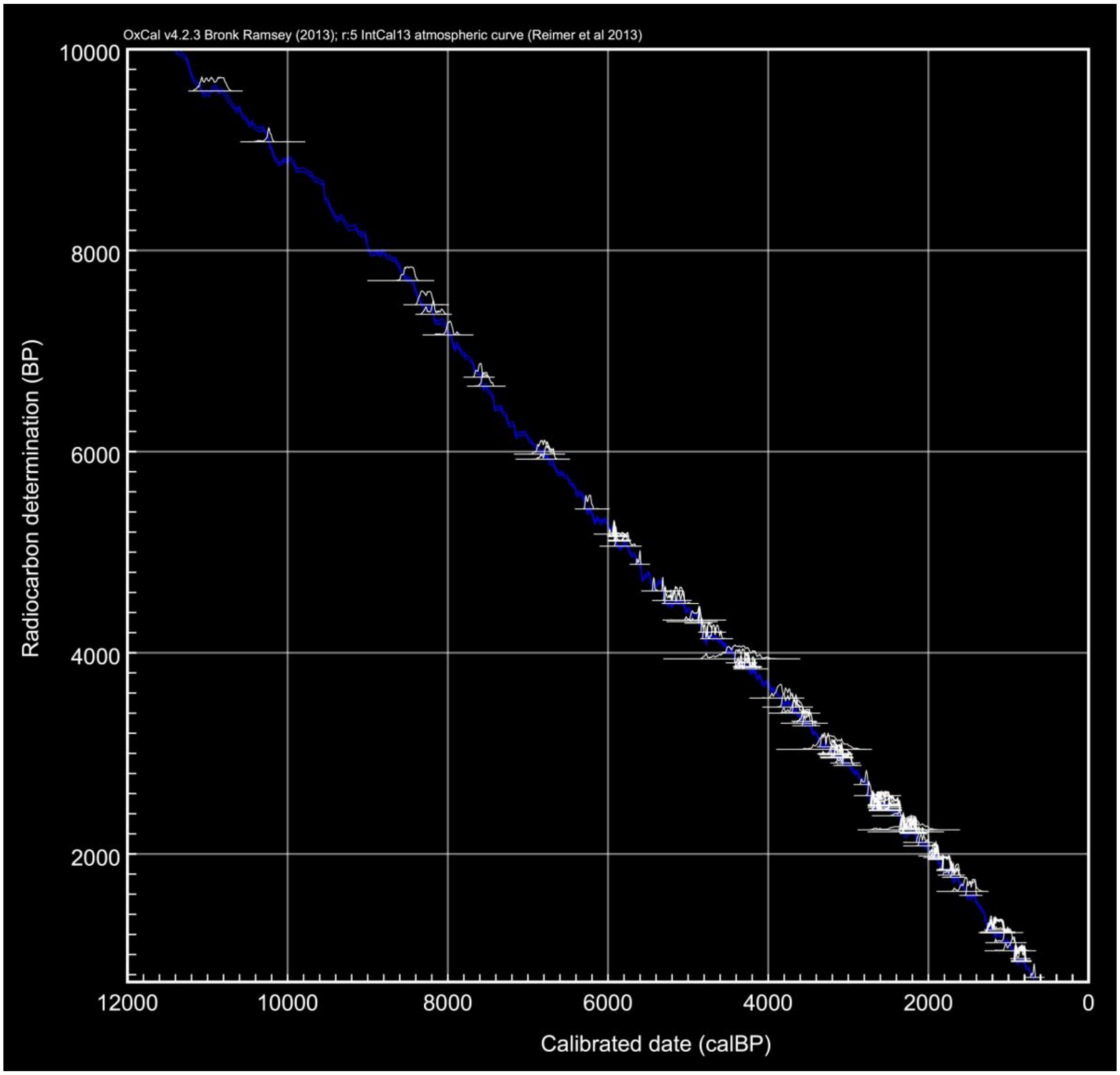

Figure 2. Calibrated results of 94 radiocarbon dates from Spring Lake, showing the nearly continuous occupation record extending to just after 6000 cal B.P. and the subsequent decline of dates that reflects the limits of controlled excavations. Two older dates not from archeological contexts are excluded (redrawn from Lohse 2013:Figure 4-1).

by retaining long-chain gelatin molecules (typically larger than 30kDa) and filtering out smaller, potentially degraded gelatin molecules and contaminating humates smaller than 30kDa. The lower yield of datable gelatin that results from ultrafiltration can limit its use on very poorly preserved bone (e.g., in cases where little or no long-chain protein survives), but smaller chains may be recoverable. One advantage of the modified XAD method is that all of the crude gelatin extracted from the bone can be processed for stable isotope measurement and AMS ^{14}C dating. Another advantage is that exogenous carbons that can remain following ultrafiltration treatments are removed, ensuring greater accuracy of measured ages.

Stafford et al. (1988, 1991) argued that gelatinization as described by Longin (1971) is not adequate to disassociate all humic and fulvic acids bound to collagen and that contaminants may cross-bind with smaller degraded collagen chains to create longer chains that would be retained in the filter. Our approach to eliminating these contaminants is to break the collagen down to individual amino acids by hydrolysis in concentrated (6N) HCl, thereby releasing humic and fulvic acids into solution. Polar contaminants are then removed from the solution by chromatography using a column filled with XAD resin. The method used in this study is adapted from that of Stafford et al. (1988, 1991). Similar methods of XAD amino acid dating has been used to reliably reevaluate pre-Clovis, Clovis, and other Early Paleoindian chronologies in North America (Waters and Stafford 2007, 2014; Waters et al. 2011) by dating osseous remains and artifacts clearly associated with Terminal Pleistocene cultural deposits.

At the Human Paleoecology and Isotope Geochemistry Lab at Pennsylvania State University, each sample was cleaned and sectioned with disposable Dremel cut-off wheels and then demineralized in 0.5 N HCl for two to three days at 5°C. The demineralized collagen pseudomorph was then gelatinized at 60°C in 4-5 mL 0.01N HCl for eight to 10 hours. Sample gelatin was pipetted into a pre-cleaned 10ml disposable syringe with an attached 0.45 µm Millex Durapore PVDF filter (precleaned with methanol and Nanopure H_2O) and driven into a thick-walled culture tube. The filtered solution was then lyophilized and percent gelatinization and yield determined by weight. The sample gelatin was then hydrolyzed in 2mL 6N HCl for 22 hours at 110°C. Supelco ENVI-Chrom® SPE (Solid Phase Extraction; Sigma-Aldrich) columns were prepped with two washes of methanol (2mL) and rinsed with 10ml DI H_2O. With a 0.45 µm Millex Durapore filter attached, the SPE Column was equilibrated with 50mL 6N HCl and the washings discarded. 2 mL collagen hydrolyzate as HCl was pipetted onto the SPE column and driven with an additional 10ml 6N HCl dropwise with the syringe into a 20 mm culture tube. The hydrolyzate was finally dried into a viscous syrup by passing UHP N_2 gas over the sample heated at 50°C for ca. 12 hr.

Stable carbon and nitrogen isotope measurements, %C and %N, were determined on amino acid hydrolyzate samples (~0.7 mg) at the University of California, Irvine Keck Carbon Cycle Accelerator Mass Spectrometer facility, on a Fisons NA1500NC elemental analyzer/Finnigan Delta Plus isotope ratio mass spectrometer with a precision of <0.1‰ for $\delta^{13}C$ and $\delta^{15}N$. Only samples with atomic C:N ratios between 3.0-3.4, indicative of good collagen preservation (Ambrose and Norr 1992; DeNiro 1985; van Klinken 1999), were submitted for AMS ^{14}C dating and are included in this study. AMS samples (~4.0 mg) were combusted for three hours at 900° C in vacuum-sealed quartz tubes with CuO wire and Ag wire to produce sample CO_2. Sample CO_2 was reduced to graphite at 550°C using H_2 and a Fe catalyst, with reaction water drawn off with C-9 Mg $(ClO_4)_2$ (Santos et al. 2004). Graphite samples were pressed into targets in Al boats and loaded on a target wheel with OX-1 (oxalic acid) standards, known age bone secondaries, and a ^{14}C-free Pleistocene whale blank. The ^{14}C measurements were made on a modified National Electronics Corporation compact spectrometer with a 0.5MV accelerator (NEC 1.5SDH-1). Analytical error in the 2-3‰ range was achieved, which for the current study translates to standard deviations in the range of ± 15-20 ^{14}C years. Radiocarbon ages were $\delta^{13}C$-corrected for mass dependent fractionation with $\delta^{13}C$ values measured on the AMS (Stuiver and Polach 1977), and compared with samples of Pleistocene whale bone (background, >48k ^{14}C B.P.), a ca. 12400 ^{14}C B.P. horse bone, ca. 1840 ^{14}C B.P. bison bone, late A.D. 1800s cow bone, and OX-1 oxalic acid standards for calibration. All dates are calibrated with the IntCal13 curve (Reimer et al. 2013) using OxCal 4.2 (Bronk Ramsey 2010) and are presented in calibrated years before present (cal B.P.). In order not to imply undue precision, all results are rounded to the nearest five-year interval (Table 2).

Regarding data presented in Table 2, a small number (n=4) of statistical outliers are present in our sample. Statistical outliers in each temporal period that contain five or more specimens are those samples with δ^{13}C values more than 1.5 times the interquartile range below the first quartile or higher than the third quartile (Fenner 2007). These specimens are identified in Table 2 as having very low (negative) δ^{13}C values. No statistical outliers were identified based on δ^{15}N. Outliers such as these are often reported from archeological bison herds such as at Folsom (Meltzer 2006:Table 6.19) and Jones-Miller (Tieszen et al. 1997), and elsewhere we have speculated that these may represent sexually mature bulls that had migrated into the study area from elsewhere (Lohse et al. 2014b). We are not aware of any research to date that has focused specifically on explaining or interpreting these outliers, but they are not uncommon in archeological studies of prehistoric bison isotopes.

We define periods of bison presence (also called temporal groups) based on the clustering of calibrated ^{14}C dates. In addition to standard calibration we calculate the duration of each period as the *Difference* of the earliest and latest samples in each group using OxCal, and summarize the range with means of those dates. Because we are unlikely to have directly dated the earliest or latest bison for any of our temporal groups, future dating is likely to affect the span of one or more groups. OxCal's *Sum* command is used to visually summarize the distributions within each group of dates, but this is merely a heuristic rather than an analytical tool. Because of the high density of samples taken from 41HY160, 41HY165, and 41HY188, it is possible that the same animals from these sites may have been dated more than once. If such cases exist, however, they do not adversely affect our chronology, since assays are only used to indicate when bison were hunted, and are not used to reconstruct herd population dynamics. Evaluating the individual carbon and nitrogen isotope measurements for each sample (shown in Table 2) shows that no two samples returned the same radiocarbon and isotope values. This suggests that any duplicate measurement of the same animal is minimal.

As noted, one result of our analytical approach is that the resulting chronology has greater precision than temporal models based on traditional (i.e., non-pretreated) bone dating and/or those relying on archeological association. While such methods have long provided useful information about the general timing of events, they are not well suited for addressing the precise timing of prehistoric events or when researchers are interested in documenting periods of rapid or punctuated cultural adaptations. Precise chronologies, sometimes also called "short chronologies" (e.g., Denham et al. 2012; Kennett et al. 2011, 2014; Tzedakis 2003; Wilmshurst et al. 2011) because they cover shorter spans of time than "long chronologies" of the same phenomena, are based on careful selection and AMS ^{14}C measurement of short-lived, pretreated species that minimizes the difference between the dated and target events. This approach can be differentiated from simple "dating," which might include no particular strategy to help ensure greater chronometric precision, and "high precision" dating, which we see as efforts that begin with the kind of sample selection and treatment we use but that also employ appropriate statistical manipulation, such as Bayesian statistics, of constrained data

Table 2. XAD-purified bison dates by lab number and provenience and stable isotope measurements discussed in this study. All dates are calibrated using IntCal13 (Reimer et al. 2013) (from Lohse et al. 2014b:Table 2).

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15}N	delta^{13}C	2σ calibrated range (cal BP)
29246	41VT141, Area B, N376, E826, level 10	3.26	190 ± 20	5.5	-7.8	290-265 (19.6%), 215-145 (52.9%)
81005	41HY165, Unit 2, level 7	3.16	215 ± 15	8.6	-11.1	300-275 (34.5%), 175-150 (50.2%)
81002	41HY165, Unit 2, level 2	3.14	250 ± 15	8.9	-9.4	310-285 (86.7%), 165-155 (8.7%)
87921	41HY160, Unit 4, level 3	3.16	275 ± 15	6.9	-14.3	425-395 (27.6%), 320-290 (67.8%)
106463	41HY160, Unit 3, level 5	3.03	515 ± 15	6.72	-11.51	545-515
129247	41VT141, Area 5(B), N376, E826, Feature 2, level 10	3.26	515 ± 15	5.5	-7.8	545-515
81003	41HY165, Unit 2, level 3	3.14	520 ± 15	5.3	-9.0	545-515
80131	41HY165, Unit 7, level 2	3.16	535 ± 20	6.2	-9.8	625-605 (11.8%), 555-515 (83.6%)
87940	41HY188, Unit 35 SE, level 5	3.16	535 ± 15	5.9	-8.7	620-610 (4.6%), 555-520 (90.8%)
87929	41HY188, Unit 4, level 5	3.21	540 ± 15	5.7	-9.4	620-610 (10.0%), 555-520 (85.4%)
87926	41HY188, Unit 1 NE, level 4	3.21	545 ± 15	6.4	-10.8	625-605 (17.5%), 560-525 (77.9%)
87932	41HY188, Unit 11 NE, level 4	3.17	545 ± 15	6.1	-9.6	625-605 (17.5%), 560-525 (77.9%)
87928	41HY188, Unit 4 NW, level 3	3.19	545 ± 15	7.9	-10.2	625-605 (17.5%), 560-525 (77.9%)
87937	41HY188, Unit 22 SW, level 11	3.19	545 ± 15	6.2	-9.3	625-605 (17.5%), 560-525 (77.9%)
81007	41HY165, Unit 11, level 3	3.15	555 ± 15	6.7	-8.9	630-600 (34.7%), 560-530 (60.7%)

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15}N	delta^{13}C	2σ calibrated range (cal BP)
87930	41HY188, Unit 6 NE, level 8	3.15	555 ± 15	8.4	-10.5	630-600 (34.7%), 560-530 (60.7%)
111183	41ME147, N807 E629, level 3	3.07	560 ± 15	5.5	-8.6	630-600 (42.7%), 560-530 (52.7%)
80133	41HY165, Unit 7, level 4	3.11	565 ± 20	4.6	-7.3	635-595 (51.8%), 560-530 (43.6%)
87927	41HY188, Unit 2 SW, level 3	3.19	570 ± 15	5.9	-10.2	635-595 (56.1%), 560-535 (39.3%)
80132	41HY165, Unit 2, level 4	3.12	575 ± 20	5.1	-9.6	640-590 (61.2%), 565-535 (34.2%)
87935	41HY188, Unit 22 SE, level 5	3.21	580 ± 15	6.1	-10.9	635-590 (65.4%), 565-540 (30.0%)
87931	41HY188, Unit 7 NW/NE, level 3	3.19	580 ± 15	6.7	-10.2	635-590 (65.4%), 565-540 (30.0%)
87936	41HY188, Unit 22 NE, level 10	3.23	585 ± 15	6.1	-9.7	640-590 (68.5%), 565-540 (26.9%)
87933	41HY188, Unit 11 NE, level 5	3.21	595 ± 15	5.9	-10.2	645-585 (73.6%), 565-545 (21.8%)
80134	41HY165, Unit 11, level 7	3.12	2205 ± 20	6.6	-8.5	2310-2150
80137	41HY160, Unit 10, level 7	3.13	2210 ± 20	5.7	-7.6	2310-2155
80135	41HY160, Unit 13, level 5	3.12	2255 ± 20	5.5	-8.4	2345-2305 (41.3%), 2245-2180 (51.4%), 2170-2160 (2.7%)
87925	41HY160, Unit 23 SE, level 10	3.19	2270 ± 15	5.2	-8.6	2345-2305 (73.1%), 2235-2185 (22.3%)
87922	41HY160, Unit 4, level 8	3.26	2275 ± 15	5.0	-9.3	2350-2305 (82.4%), 2230-2205 (12.3%), 2195-2190 (0.7%)
106470	41HY160, Unit 3, level 14	3.04	2415 ± 20	7.4	-14.5	2680-2665 (2.1%), 2655-2645 (2.5%), 2490-2355 (90.8%)
87920	41HY160, Unit 1, level 2	3.21	2460 ± 15	6.0	-8.2	2705-2630 (41.5%), 2620-2560 (20.3%), 2545-2430 (32.8%), 2390-2385 (0.8%)
81004	41HY165, Unit 3, level 8	3.29	2460 ± 25	5.1	-9.0	2705-2630 (31.8%), 2620-2380 (63.6%)

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15} N	delta^{13}C	2σ calibrated range (cal BP)
87938	41HY188, Unit 23 SE, level 8	3.22	2470 ± 15	6.3	-8.6	2705-2630 (37.9%), 2620-2465 (57.5%)
87923	41HY160, Unit 6, level 10	3.20	2470 ± 15	5.6	-8.9	2705-2630 (37.9%), 2620-2465 (57.5%)
81006	41HY165, Unit 3, level 6	3.18	2475 ± 15	5.9	-8.1	2710-2485
106465	41HY160, Unit 3, level 6	3.05	2475 ± 20	5.3	-8.05	2715-2465
87924	41HY160, Unit 6, level 11	3.18	2480 ± 15	5.1	-8.4	2710-2490
87934	41HY188, Unit 20, level 12	3.21	2480 ± 15	5.6	-8.4	2710-2490
106464	41HY160, Unit 3, Level 6	3.08	2480 ± 15	5.41	-9.19	2710-2490
106471	41HY160, Unit 4, level 7	3.07	2490 ± 20	6.57	-9.25	2720-2650 (21.8%), 2645-2490 (73.6%)
80138	41HY160, Unit 13, level 13	3.11	2955 ± 20	5.5	-7.8	3210-3200 (1.1%), 3180-3060 (93.0%), 3050-3040 (1.2%)
80130	41HY165, Unit 8, level 11	3.15	2965 ± 20	5.1	-8.4	3210-3190 (4.4%), 3185-3065 (91.0%)
80140	41HY160, Unit 13, level 13	3.12	2985 ± 20	5.4	-9.5	3225-3075
87939	41HY188, Unit 25, level 14	3.24	2995 ± 15	5.2	9.3	3230-3140 (88.2%), 3130-3115 (2.8%), 3095-3080 (4.3%)
80129	41HY165, Unit 3, level 7	3.12	3000 ± 20	5.6	-7.8	3320-3310 (1.7%), 3240-3140 (85.4%), 3130-3110 (3.8%), 3095-3080 (4.4%)
106472	41HY160, Unit 4, level 7	3.11	3000 ± 20	7.18	-8.77	3320-3310 (1.7%), 3240-3140 (85.4%), 3130-3110 (3.8%), 3095-3080 (4.4%)
129245	41BL323, N1161, E1081, 94.4-94.37 elevation	3.32	3000 ± 15	5.6	-8.3	3235-3140 (91.6%), 3125-3115 (1.3%), 3095-3080 (2.5%)
95718	41HY165, Unit 11, level 10	3.24	3065 ± 15	4.9	-20.0	3350-3225

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15} N	delta^{13}C	2σ calibrated range (cal BP)
80999	41HY160, Unit 9, level 14	Too small	5060 ± 40	-	-	5910-5715
95717	41HY160, Unit 14, level 13	3.21	5110 ± 15	8.1	-10.7	5915-5885 (47.2%), 5820-5760 (48.2%)
80139	41HY160, Unit 7, level 14	3.14	5115 ± 20	6.8	-9.8	5920-5880 (48.4%), 5825-5755 (47.0%)
80136	41HY160, Unit 7, level 15	3.15	5120 ± 20	9.3	-9.6	5925-5885 (56.4%), 5820-5760 (39.0%)
80998	41HY160, Unit 7, level 14	3.13	5120 ± 20	8.5	-10.5	5925-3935 (56.4%), 5820-5760 (39.0%)
129248	41WM267, Area D, E-6, level 120-121, 93.3-93.2 elevation	3.28	5135 ± 20	5.7	-8.6	5935-5890 (81.4%), 5810-5765 (14.0%)
106473	41HY160, Unit 13, level 13	3.14	5140 ± 20	9.38	-11.9	5935-5890 (87.3%), 5805-5770 (8.1%)
106468	41HY160, Unit 3, level 14	3.11	5140 ± 20	7.43	-19.0	5935-5890 (87.3%), 5805-5770 (8.1%)
106469	41HY160, Unit 3, level 14	3.17	5145 ± 20	9.59	-11.9	5940-5890 (91.3%), 5805-5795 (1.8%), 5785-5770 (2.3%)
81000	41HY160, Unit 16, level 13	3.25	5155 ± 15	8.7	-11.1	5935-5900
81001	41HY160, Unit 16, level 13	3.19	5165 ± 15	8.3	-11.5	5980-5980 (1.8%), 5940-5905 (93.6%)
80997	41HY160, Unit 7, level 9	3.12	5180 ± 15	8.5	-9.4	5990-5970 (16.4%), 5945-5910 (79.0%)
111182	41ME147, N802 E631, level 4	3.46	5205 ± 20	3.6	-16.7	5990-5920

to construct or build chronological models characterized by greatly reduced age range probabilities. While this study focuses on precisely dating bison, we include an example of high-precision chronology, below, based on our work with the Calf Creek archeological component at Spring Lake.

RADIOCARBON RESULTS

Prehistoric bison exploitation is dated to four main periods in our study area, the first lasting from ca. 5955-5815 cal B.P.; the second and third involving two pulses between 3295-3130 cal B.P. and

2700-2150 cal B.P. separated by a 400+ year hiatus from ca. 3130 to 2700 cal B.P.; and the fourth consisting of a short Late Prehistoric interval from 650 to 530 cal B.P (Figure 3). Four historic period dates range from approximately 400-150 cal B.P. This last interval is hard to date precisely because of variations in atmospheric radiocarbon concentration during this period. However, historic documents record widespread bison hunting across Texas and nearby regions (e.g., Speth 2004; Wade 2003), and this period is critical for understanding regional culture historical events for the preceding three or four centuries. The prehistoric periods include the widespread Calf Creek horizon, found across the Southern Plains (Thurmond and Wyckoff 1999); two different periods in the regional Late Archaic (termed Late Archaic Bison 1 and Late Archaic Bison 2, LA_B1 and LA_B2, to distinguish these bison periods from subdivisions in the regional chronology); and what appears to be an early facet of the Toyah phase or horizon (Kenmotsu and Boyd 2012).

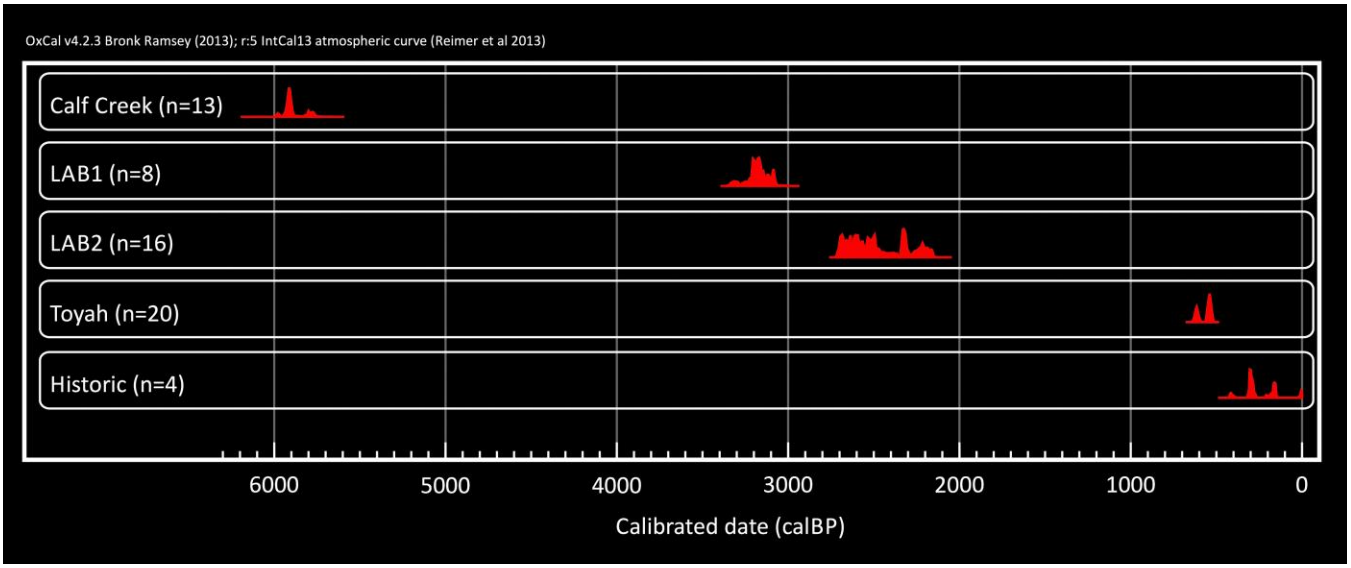

Figure 3. Summed probabilities for 61 XAD-purified AMS dates on bison bone from archeological contexts in Central and South Texas.

Calf Creek: ca. 5955-5815 cal B.P.

The earliest period of bison presence in our study is associated with the Calf Creek horizon. This period, which marks the end of the Early Archaic in Central Texas (Lohse et al. 2014a), is defined by the widespread occurrence of distinctive basally notched Bell and Andice points (Figure 4) often found in direct association with bison. Calf Creek materials are reported across Oklahoma (Bement et al. 2005; Duncan 1996; Neal 1999; Neal and Duncan 1998; Thurmond and Wyckoff 1999; Wyckoff 1994, 1995; Wyckoff et al. 2009); Central and South Texas, the Trans Pecos, and northern Tamaulipas (Calame et al. 2002; Collins 1994; Gray 2013; McReynolds 2002; Prewitt 1983; Ricklis 1988; Ross 1965; Sorrow et al. 1967; Walter 2013); western Arkansas (Dickson 1970); and into eastern New Mexico (Carmichael 1986). They are also present but less well documented in eastern Colorado, Missouri (O'Brien and Wood 1998), and Kansas (Stites 2006). Two Calf Creek points have recently been reported as far north as southern Utah (Wyckoff and Richens 2010). The brevity of this period has made it difficult to date these deposits with any precision. For example, this horizon is not represented in Dillehay's (1974) model for the Southern Plains (see Table 1), and is only poorly resolved at many sites (e.g., Wilson-Leonard). Stable carbon and nitrogen isotope data from samples in this study indicate that Calf Creek climates were among the coldest and perhaps driest experienced in the entire Holocene (Lohse et al. 2014b).

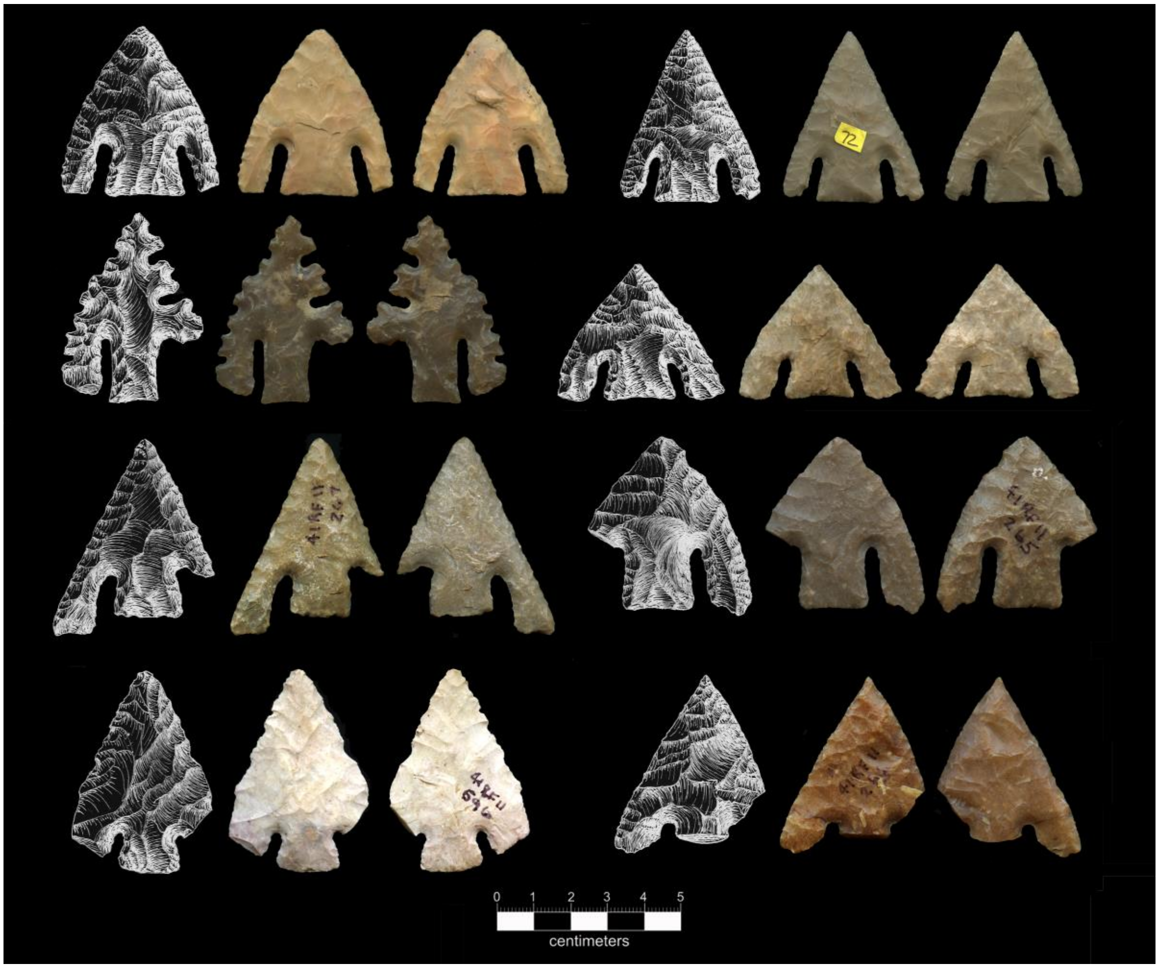

Figure 4. Examples of basally notched Calf Creek horizon points (Bell type). Top two rows are from Zapata County in South Texas (courtesy of Richard McReynolds). Bottom two rows are from the Hopper's Landing site (41RF11) (courtesy of the Museum of the Coastal Bend). All line drawings by Richard McReynolds.

Our Calf Creek bison data derive from three sites: Spring Lake (41HY160), Eagle Bluff, and Cervenka; the latter two have only a single date each. A bison bone sample associated with a Bell point from Feature 2 at the Landslide site (41BL85; Sorrow et al. 1967) was curated at the Texas Archeological Research Laboratory and was submitted for dating as part of this study, but did not yield enough collagen to be reliably measured. Two separate contexts at Spring Lake, over 40 m apart, have yielded Calf Creek remains including 11 AMS dates on bison (Lohse et al. 2013). Conservatively, the 13 dates together span the interval from 5990-5715 cal B.P., taking the extreme 2 sigma ranges for the earliest and latest dates. However, most dates fall onto an ideal part of the calibration curve, centering around 5900 cal B.P., between a modest reversal at about 5960 cal B.P. and a minor plateau spanning from approximately 5850-5770 cal B.P. (Figure 5). The effect of these two parts of the curve is to draw out or extend the calibrated probabilities of the earliest and last dates.

However, the difference of the earliest and latest dates allows us to estimate the duration of the Calf Creek components to be between 25 and 260 calibrated years (mean=140 cal years).

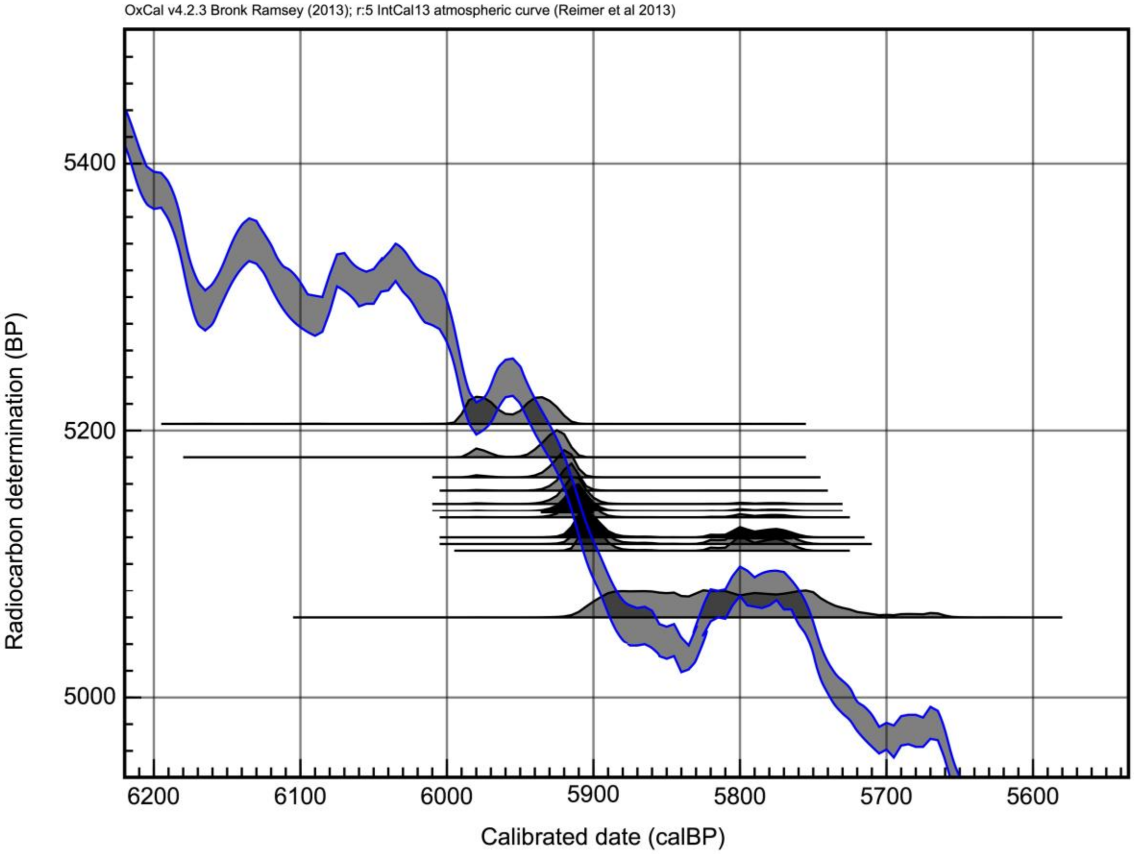

Figure 5. Calibrated probabilities for 13 Calf Creek dates superimposed on IntCal13 calibration curve.

Radiocarbon dates reported in association with Calf Creek materials commonly span over seven hundred years (see Wyckoff et al. 2009), and some "long" chronologies ascribe as much as a thousand years to this period (e.g., Collins 2004). Based on our results, however, we argue that this horizon may have been considerably shorter in duration. A moderately conservative treatment of these dates suggests a period of about 140 years. However, Bayesian modeling of the calibrated dates from Spring Lake suggests the presence of bison during a very short interval of no more than about 40 years (Figure 6), from 5937-5897 cal B.P. (A_{model}=122.3). This model indicates the short duration that can be identified with calibrated radiocarbon dates under ideal circumstances and with high-density sampling. The single date from Eagle Bluff is slightly earlier than this range, indicating regional variation in terms of timing and age of different site components. This model substantially narrows the overall age span for Calf Creek, and creates an opportunity to develop and test hypotheses relating to the overall chronology of bison movements and cultural responses during this period.

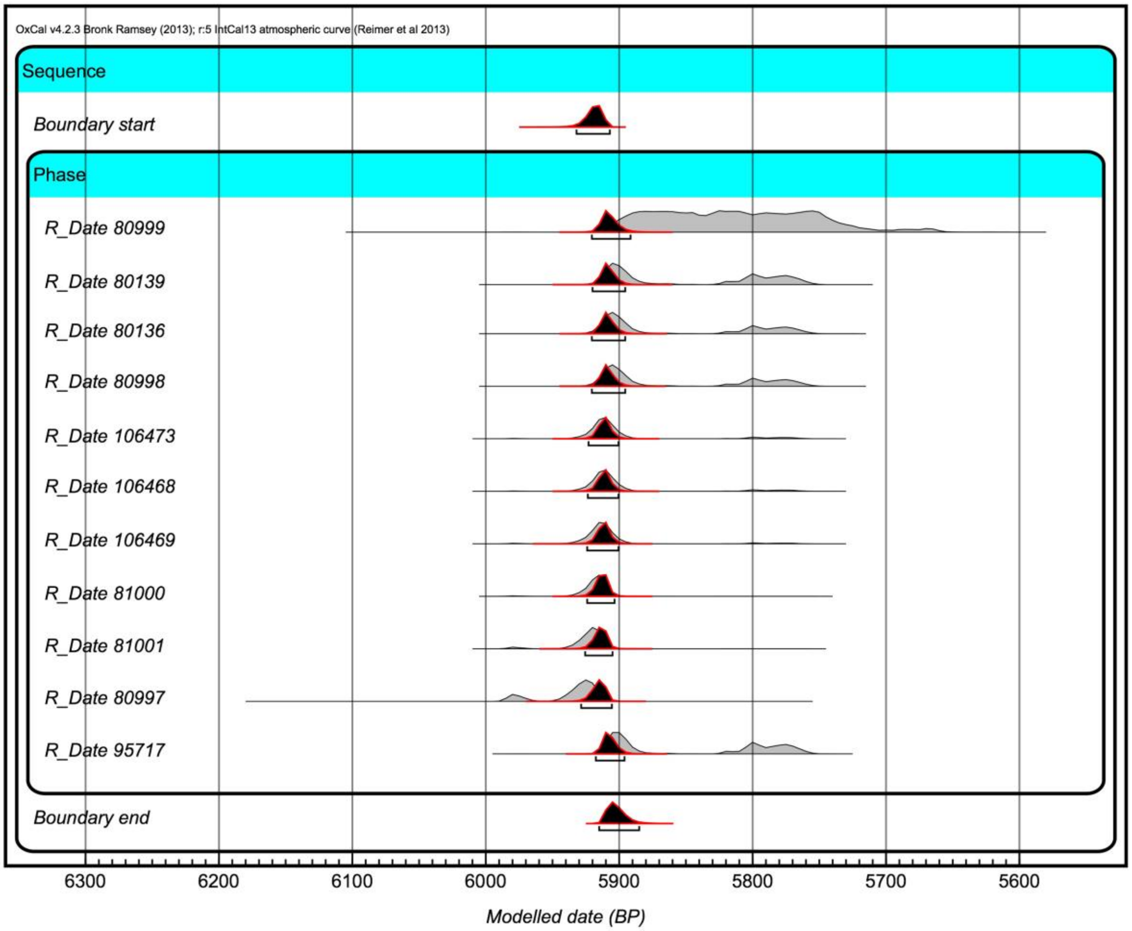

Figure 6. Simple Bayesian phase model of AMS ^{14}C from Calf Creek deposits at Spring Lake. These data suggest that the occupation during this horizon may have been limited to only a single event or a few rapid visitations.

Other than our data, very few precise assays are available for this time period. A Calf Creek point embedded in a juvenile bison (*B. occidentalis*) skull found in river gravels near Tulsa, Oklahoma (Bement et al. 2005) and dated at 5120 ± 20 ^{14}C years B.P. (approximately 5925-5760 cal B.P.) falls squarely within the range of dates we report. The Calf Creek component at the Kubik site, also in Oklahoma, has produced three dates: 4990 ± 100 (NZA6601) (5950-5465 cal B.P.), 5020 ± 120 (NZA6602), and 5050 ± 60 (Beta 98146) radiocarbon years B.P. (Neal 1999). The latter two dates, from a split nut hull, average to about 5895-5735 cal B.P. All three partially overlap with but are generally younger than our bison dates by a couple of centuries. The large 2 sigma probabilities of the Kubik dates relate to their large standard deviations compared with samples in our study, and also partly to a reversal in the calibration curve that occurs at ca. 5800 cal B.P. (see Figure 5). However, the nutshell dates are considered highly reliable, and the Kubik data suggest that the Calf Creek horizon extended later in Oklahoma than in our study area. Additional sampling using precision dating protocols will be necessary to define the temporal extent of the Calf Creek horizon as it occurred elsewhere on the Southern Plains.

Late Archaic: ca. 3295-3130 and 2700-2150 cal B.P.

Following Calf Creek, bison appear to have been absent from the landscape for more than two thousand years, from ca. 5750-3300 cal B.P. Regional models (see Table 1) show bison throughout the Late Archaic, but are vague about when they appear and tend to treat the Late Archaic as a single undifferentiated period. Single component sites with bison dating to this time are uncommon. Most sites, like Wilson-Leonard, have mixed or compressed Late Archaic components. Our Late Archaic bison dates come from four sites: two Spring Lake sites (41HY160 and 41HY165), 41HY188, and Gault.

Our data suggest that Late Archaic bison exploitation took place over two distinct intervals. The first period (LA_B1) began by 3295 cal B.P. (mean of 3355-3220 cal B.P., UCIAMS-95718) and continued until approximately 3130 cal B.P. (mean of 3215-3005 cal B.P., UCIAMS-80138). The duration of the period is estimated at between 55 and 270 cal years, with a mean of 165 cal years. This bison pulse is followed by a hiatus of at least 400 years (the 2 sigma difference is 380-700 cal years) after which a subsequent pulse, LA_B2, lasts from about 2700-2150 cal B.P. The more than 400 year hiatus after 3130 cal B.P. is previously unreported, likely as a result of the reliance on archeological associations for reconstructing cultural patterns (Figure 7). Stable carbon and nitrogen isotope data indicate that Late Archaic climates were relatively stable for the entire LA_B1 and LA_B2 periods, and that both periods were somewhat warmer and had more effective moisture than the earlier Calf Creek or later Toyah periods (Lohse et al. 2014b). However, both also correspond with a period of globally cool climates (Wanner et al. 2011). Importantly, Viau et al. (2006) identify the period around 3000 B.P., approximately the middle of our postulated hiatus, as among the warmest of the entire North American Holocene and van Geel et al. (1996) identify a cool, moist period in Europe and North America starting by around 2650 cal B.P. If verified, these temperature changes could help explain or contextualize bison movements into and out of the study area at different times during the Late Archaic period.

Although there appears to be a gap in bison exploitation in LA_B2 between ca. 2275 and 2415 ^{14}C B.P. (see Table 2), this gap is likely an artifact of the calibration curve. A plateau in the curve occurs during LA_B2, followed by a steep decline and then another mild reversal. These statistical plateaus affect the interpretation of radiocarbon data most obviously by creating very broad calibrated distributions for the dates in these groups. Indeed, the estimated length of LA_B2 (200-550 cal years) is the longest in our study, and it is possible that the duration of this period is overestimated because of fluctuations in the calibration curve during this interval.

A less obvious effect of the plateaus and associated steep segments of the curve is that even with precise measurements and very dense sampling, conventional ages corresponding to plateaus will be overrepresented, and those during steep sections may tend to be underrepresented (Calf Creek is an

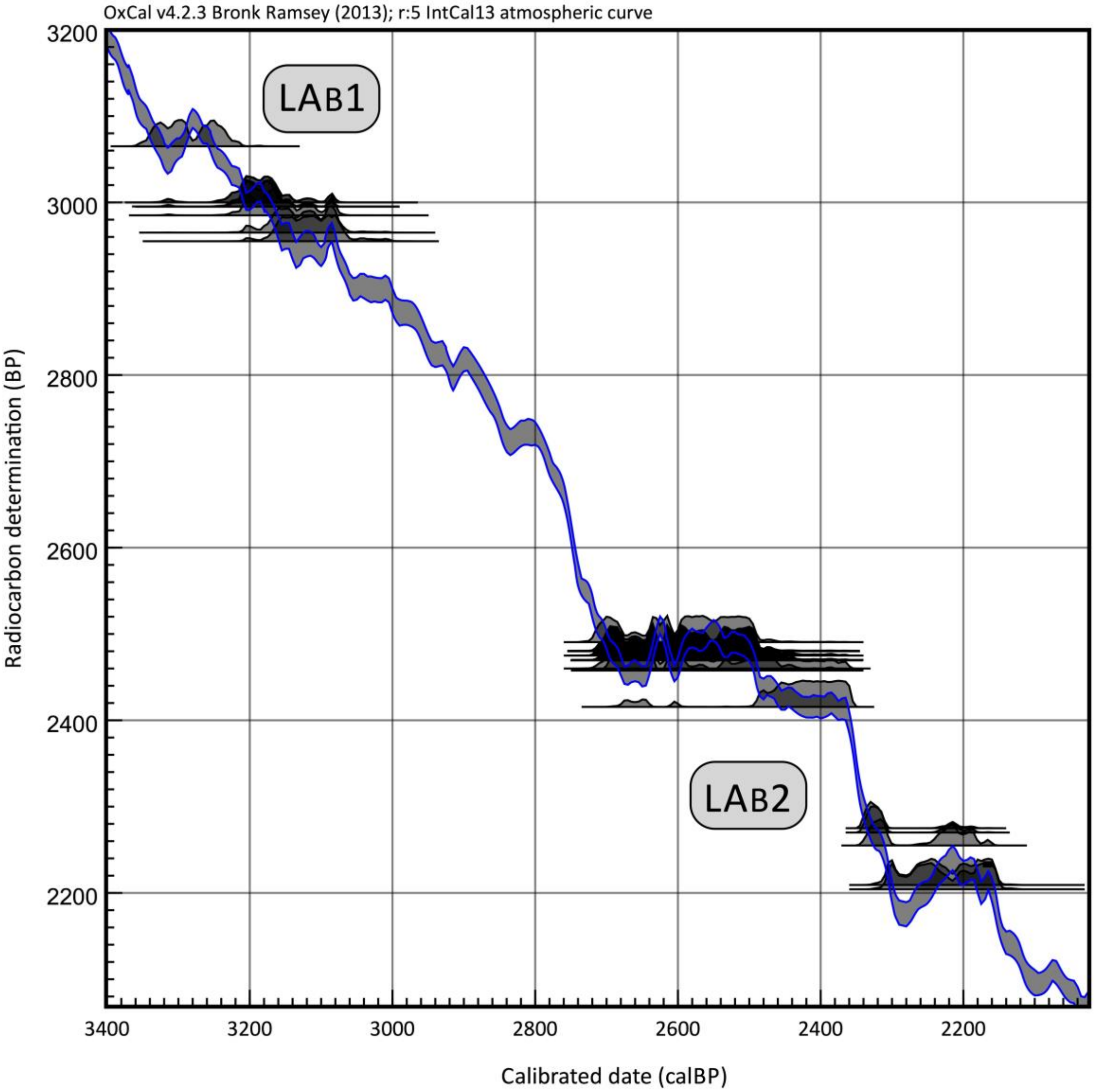

Figure 7. Calibrated probability distributions for 24 Late Archaic AMS ^{14}C bison dates. The LAB2 occupies a relatively flat part of the curve from about 2700-2360 cal B.P., which contributes to temporal imprecision during this interval. The steep decline following this plateau creates the appearance that a brief hiatus separates this period from a third Late Archaic period of bison exploitation.

exception; see Figure 5). This phenomenon can be modeled with OxCal using the *R_Simulate* command, which produces a conventional age from a calendar age with a given measurement error, and then calibrates it. To better understand the effect of the curve on our calibrated sample, we simulated a group of 170 dates (10 dates every 25 years) from 2500 to 2100 cal B.P. assuming a measurement precision of ± 20 ^{14}C years to mirror the precision of our study. This very dense dataset is analogous to recovering and dating 40 bison per century from the archeological record, or roughly 10 times what we have sampled for the period. Plotting the frequency of conventional ages demonstrates that even at this density, conventional ages from ca. 2380 to 2260 cal B.P. are relatively unlikely (roughly 10-20 percent as likely) to be sampled compared with ages on the plateaus before and after that time (Figure 8). The congruence between the distributions of simulated and observed conventional ages through this period suggests that the apparent gap is an artifact of the calibration curve, and that further sampling is unlikely to produce many more conventional ages between 2415 and 2275 ca. B.P.

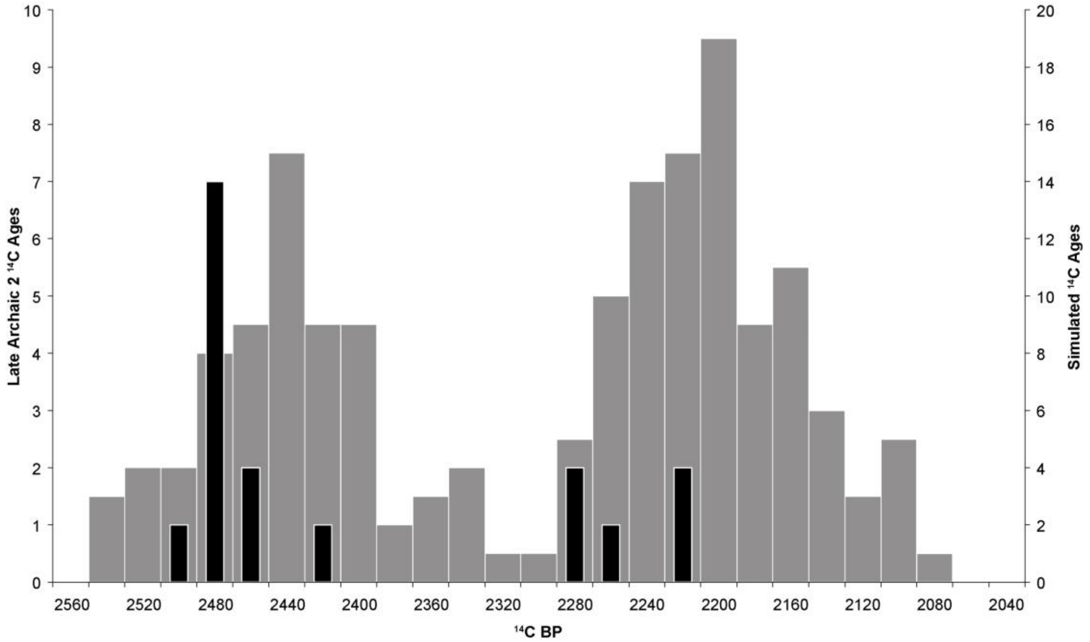

Figure 8. Frequency of simulated ^{14}C ages (gray columns) versus measured ^{14}C ages (black columns) on bison across two plateaus in the Late Archaic from 2500-2100 cal B.P. (2560-2040 14C yr B.P.) and the apparent gap in ^{14}C ages that is an artifact of the calibration curve. Simulated ages were generated in OxCal 4.17 (Bronk Ramsey 2010) using R_Simulate, assuming 10 dates every 25 cal years and a precision of ± 20 ^{14}C yr, comparable to the precision of the dates in this study. The "gap" in LAB$_2$ ^{14}C ages is likely not a true hiatus in bison exploitation.

Toyah: 650-530 cal B.P.

Following the Late Archaic, bison again appear to have been absent from the study area for approximately 1500 years, until ca. 650 cal B.P. They reappeared suddenly and may have been present for less than 120 cal years before once again disappearing. This Toyah bison interval is the shortest in our study. Climatically, our early Toyah bison period occurred immediately after the onset of the Little Ice Age (LIA), a prolonged cool and dry period, the beginning of which corresponds with one of the largest volcanic events of the entire Holocene as well as severely reduced solar activity (Mayewski et al. 2004; Wanner et al. 2011). Stable carbon and nitrogen isotope data (Lohse et al. 2014b) indicate that temperatures during this brief interval were not as cool as the Calf Creek period, and that effective moisture was slightly greater than in the Calf Creek period. However, the period was still cooler and drier than either LA$_B$1 or LA$_B$2. The LIA was complex climatologically, and significant variation has been documented within it. Based on over a thousand tree-ring, ice core, coral, sediment, and other proxy records, Mann et al. (2009) reconstruct a brief cold period in the northern hemisphere centering around A.D. 1340 (ca. 610 cal B.P.) that precedes a short warm interval before temperatures decline once again just prior to ca. A.D. 1500 (ca. 450 cal B.P.). The reconstructed cool periods correspond with the Wolf and Spöer grand solar minima, respectively

(Bard et al., 2000; Steinhilber and Beer 2011), brief intervals of reduced solar activity (e.g., sun spots, solar flares, etc.) that are associated with global cooling.

The bimodal calibrated distributions of our 20 dates from this period (Figure 9) partially reflect the shape of the calibration curve during this interval, which exhibits a sharp reversal resulting in paired intercepts for each assay. Taking the difference of the oldest and youngest dates in our Toyah bison period, the period lasted between 10 and 120 cal years, with a mean of 70 cal years. Toyah dates come from five sites: two Spring Lake sites (41HY160 and 41HY165), 41HY188, Eagle Bluff, and McNeill.

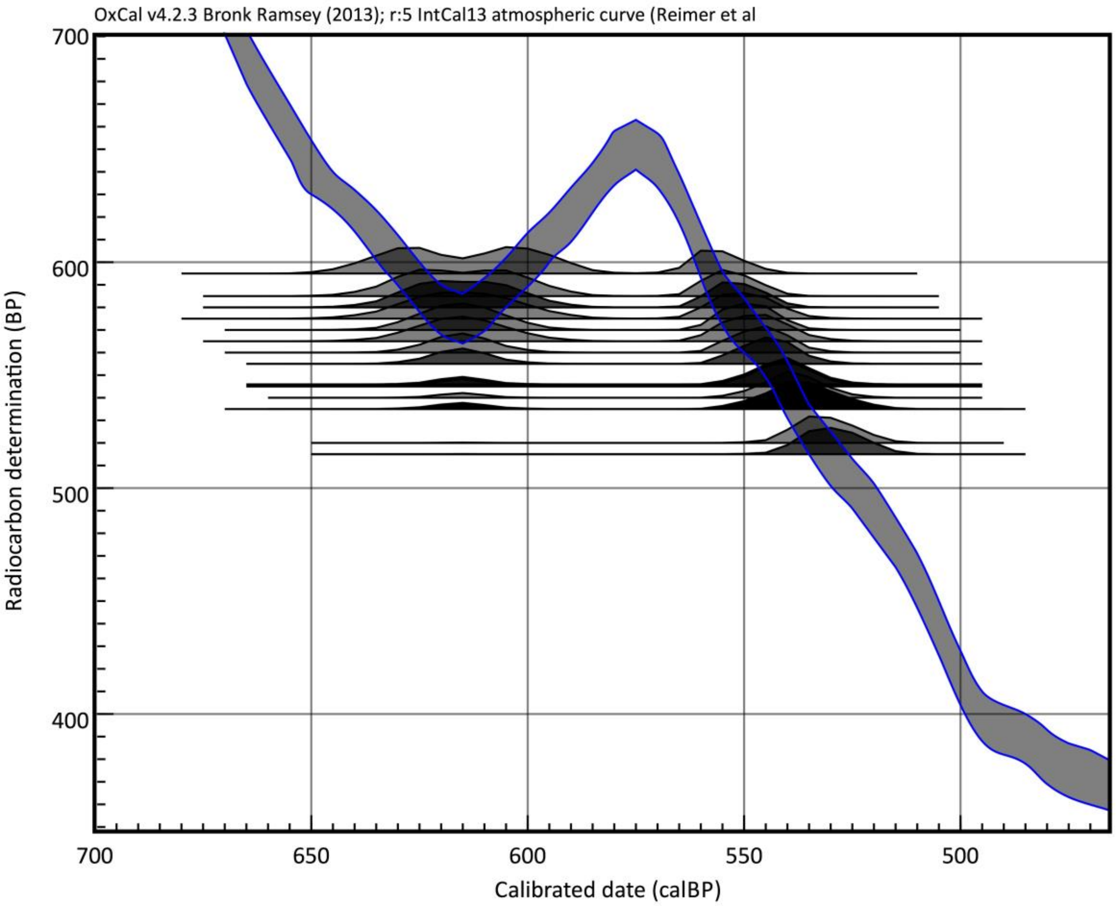

Figure 9. Calibrated probability distributions for 20 early Toyah AMS 14C bison dates. The reversal at ca. 575 cal B.P., resulting in bimodal distributions, causes the calibrated span of time to cover a longer period than is likely. Nonetheless, this is the shortest period of bison exploitation documented in our study.

The brevity of this period of bison exploitation is significant in the culture history of North America. In the regional sequence, the Toyah horizon begins by approximately 650 cal B.P. or A.D. 1300, and lasts as late as A.D. 1700. Native American cultural practices extending to the end of this sequence are difficult to link with earlier prehistoric antecedents because of the influences of Spanish *entradas and* colonization, not to mention population declines and social disruptions due to European diseases and group displacement practices that started in the early 1500s (Arnn 2012; Kenmotsu and

Hester 2001). Nonetheless, Toyah culture has typically been defined as exhibiting a technological focus on the exploitation of bison (Johnson 1994; Kenmotsu and Boyd 2012; Prewitt 2012; Ricklis 1994) and artiodactyls generally (Black 1986). Some have noted variation in Toyah subsistence practices (e.g., Dering 2008; Mauldin et al. 2013), including what appears as a decreased emphasis in bison, but temporal controls frequently lack the precision needed to demonstrate whether this variation is temporal or geographic in nature.

Archeologists argue that Toyah is important for our broader anthropological understanding of hunter-gatherer cultural patterns just prior to ethnographically-documented foragers that occupied the region when the Spanish arrived (Collins 1995). Our data suggest that the Toyah horizon may have been characterized by more varied subsistence practices and associated social and technological adaptations than conventional views suggest. From the early A.D. 1500s through the late 1700s, historical groups were recorded pursuing bison across Texas (Arnn 2012; Speth 2004; Wade 2003), and it has been widely presumed that this pattern is an extension of practices that began as early as A.D. 1300 (ca. 650 cal. B.P.). Prior research on the southern Plains has documented widespread trade between Puebloan settlements to the west and Plains groups focusing on bison meat, hide, and other products (Boyd 1997; Creel 1991; Krieger 1946; Prewitt 1982; Speth and Newlander 2012; Spielmann 1991; Vehik 1990, 2002). Considering the sudden appearance of bison and their role in both subsistence and economic patterns, we suggest that early Toyah (ca. A.D. 1300-1420, or 650-530 cal B.P.) can be partly understood as a southern extension of this interregional system. Our findings suggest, however, that middle Toyah sites, those dating after around 530 cal B.P. (A.D. 1420), but pre-dating the reappearance of bison in the mid-1500s, may have maintained an altogether different orientation, with significantly less reliance on bison than previously thought. Although sites with late Toyah material such as the Rush site (41TG346, ca. A.D. 1575; Quigg 1997) or the upper Toyah component at Rowe Valley (41WM437; Prewitt 2012) contain bison and appear to support this three-part model of Toyah chronology, dating resolution is so far lacking to demonstrate the postulated middle Toyah facet. However, the four historic dates in our sample provide partial support for this model. More dates are needed from this late period before this model can be further developed.

DISCUSSIONS AND CONCLUSIONS

Our record of 61 AMS dates on bison bone recovered from archeological contexts from the southeastern periphery of the Great Plains adds to what is known about the exploitation of a top-ranked resource starting approximately 6000 years ago. We show that bison were present only occasionally since the Early-Middle Holocene. While our study is generally consistent with previous regional models, it adds important precision to the overall understanding of these periods. It is well known that bison were present in the region prior to 6000 cal B.P., but this part of the record has not been directly dated using the XAD-based protocols we report here. Because the early sequence for bison exploitation is dated primarily by archeological association, in our view it remains imprecise.

In spite of its limitations in terms of geographic and temporal coverage, our record of XAD-purified AMS ^{14}C dates on bison offers one of the most precise models for the presence and prehistoric exploitation of this key resource anywhere in North America. In addition to refining local and regional chronologies, our findings also contribute to hypotheses about fluctuations in "Plains-like" cultural patterns that depended, in part, on environmental and climatic change and the subsequent exploitation of bison for subsistence and economic purposes. For example, what appears as the sudden onset of bison-related cultural patterns, especially Calf Creek and Toyah, may have been associated with rapid climate change (Mayewski et al. 2004). This important possibility, which deserves further attention, would have significant implications for how archeologists understand the nature and timing of prehistoric culture change. Additionally, the rapid appearance of widespread horizons associated with the Calf Creek and early Toyah periods is ostensibly linked to the sharing of weapons- and processing-related technologies involved with logistically organized bison hunting at these times. Projectile point styles associated with these intervals are among the most widespread post-Paleoindian styles in Texas (cf. Prewitt 1995), and may reflect the distances traveled by bison hunters and the kinds of social encounters that occurred as part of these forays.

More than only subsistence practices are implicated as well. Trade patterns beginning by A.D. 1250 (ca. 700 cal B.P.) in the Southern Plains and focused on bison are also well known (e.g., Creel 1991; Speth 2004). Toyah sites commonly show a sharp increase in exotic materials compared with earlier periods (Kibler 2012), suggesting that exchange networks also extended south into Central and southern Texas. Like connections with climate change, this proposition also requires much additional research before these economic processes are fully understood. Future AMS radiocarbon dating work on Toyah sites should be mindful of our evidence suggesting a three-part bison chronology. Sample selection should avoid large carbonized wood fragments susceptible to the old wood effect and focus instead on annuals or perennials. Radiocarbon results should be matched against zooarcheological assemblages indicating the presence or absence of bison.

Our study highlights the research value of adding to the record of XAD-purified AMS dates of bison remains. Adding samples with greater time depth and from additional sites will help improve the bison record and increase its usefulness as a means for understanding larger cultural and environmental processes at the southern extent of the far Southern Plains.

ACKNOWLEDGEMENTS

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A PRECISE CHRONOLOGY OF MIDDLE TO LATE HOLOCENE BISON EXPLOITATION IN THE FAR SOUTHERN GREAT PLAINS

Jon C. Lohse, Brendan J. Culleton, Stephen L. Black, and Douglas J. Kennett

ABSTRACT

In regions on the margins of the Great Plains grasslands, documenting the intermittent history of bison exploitation has presented challenges to archeologists. Chronologies based on archeological associations have long been useful in regional research, but can be imprecise and of inadequate resolution for constructing precise sequences of prehistoric events. Here, we present a record of directly dated bison from archeological contexts spanning the last 6000 years on the very southern extent of the Great Plains. This study includes 61 specimens from archeological contexts that were dated by XAD purified AMS radiocarbon, with reported errors of only 15-20 14C years for most dates. The resulting record of bison exploitation for this area defines four main periods (Calf Creek, Late Archaic 1 and 2, and early Toyah) during which bison were exploited. Several dates also indicate an early historic presence of bison; this period may represent a late facet of the Toyah horizon. This study adds significant chronological resolution to the regional record of bison in parts of Texas and begins to help correlate cultural chronologies with important climatic data. It also points to the research value of obtaining additional directly dated bison samples from temporally and geographically diverse archeological contexts in our study area and beyond.

INTRODUCTION

The North American genus *Bison* was among the very top-ranked resources available to hunter-gatherers up to and even following the arrival of European explorers. Millennia of bison hunting on the Plains are documented from Early Paleoindian times onward (Bamforth 1988, 2011; Bement and Buehler 1994; Bozell et al. 2011; Carlson and Bement 2013; Cooper 2008; Frison 1991, 1998, 2004; Guthrie 1980). In Late Prehistoric times, agriculturalists in the American Southwest and Mississippi River drainages to the east often hunted bison or traded for their products, bringing them into frequent contact with Plains tribes (Creel 1991; Spielmann 1991; Speth 2004; Speth and Newlander 2012; Vehik 1990, 2002). Bison exploitation, for meat and other uses, has played a significant role in shaping prehistoric and early historic economies across the Plains. As a top-ranked food resource, the

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presence of bison would have had tremendously important implications for prehistoric subsistence practices, mobility, the organization of labor, and other social characteristics.

While bison were present almost continuously in the cool, predominantly C_3 grasslands of the Northern Plains, only occasionally in the Middle to Late Holocene periods did they extend into other environments characterized by mixed grasslands or other habitats. These areas include parts of the Great Basin (Grayson 2006), northern Mexico (List et al. 2007), and the southern limits of the Plains that include Central and coastal Texas (Baugh 1986; Dillehay 1974; Huebner 1991; Lynott 1979; Mauldin et al. 2012; Ricklis 1992). Understanding precisely when bison were present in regions located around the periphery of the Plains is important not only for our general knowledge regarding bison ecology, climate, and environmental change in North America, but also for providing insights into human responses during these periods.

In this study, we present and evaluate AMS radiocarbon data for 61 XAD purified samples of bison bone recovered from archeological contexts at seven sites located in Central and South Texas. The culture history of these areas shares much with Plains traditions to the north during some time intervals, while maintaining their own distinct patterns during others (Collins 1995, 2004; Hester 2004; Lohse et al. 2014a). Precisely defining periods when bison were present in these areas has been a challenge, largely as a result of the traditional reliance on dating bison by association with other archeological remains. Our approach involves directly dating bison from archeological contexts as a way to avoid the imprecision that can result from dating by association. The resulting chronology defines four primary periods of prehistoric bison exploitation beginning around 6000 cal B.P. and also indicates an early Historic use by North American Indians. Earlier periods of bison presence remain to be worked out for these areas, ideally using a similar methodology to the one we discuss herein. This precise chronology not only clarifies regional prehistoric subsistence and related technological practices, but can also help researchers correlate cultural developments with environmental or paleoclimatic data that may be associated with periods of rapid cultural change.

DATING BISON IN THE STUDY AREA AND THE PRESENT SAMPLE

Beginning with Dillehay (1974), many investigators have examined the issue of bison presence in the region (Baugh 1986; Collins 1995; Huebner 1991; Lynott 1979; Mauldin et al. 2012; Quigg 1997; Ricklis 1992). These studies commonly evaluate the presence of bison at a regional scale based on archeological components that are themselves dated by radiocarbon or by cross-dating using associated time-marker artifacts (Table 1). Typically, bison presence is modeled as a series of long periods of presence or absence, the beginnings and endings of which are imprecisely dated.

In contrast to regional models, single-site records (such as the one at Wilson-Leonard, 41WM235 [Collins 1998]), where bison were not present for certain intervals when they appear elsewhere, exemplify the limitations of site-specific studies. A given site's stratigraphy may be compressed or mixed, affecting an analysts' ability to precisely reconstruct periods of bison exploitation. This condition most directly and adversely affects bison chronologies that rely on archeological association. In other cases, a single site's occupation history may not include periods during which bison were present nearby. For example, Bonfire Rockshelter (41VV218) offers a fascinating record of bison hunting during certain periods in the Lower Pecos of southwest Texas, including Late Archaic, Folsom, and perhaps Clovis times (Bement 1986; Dibble and Lorrain 1968). However, this record does not include bison remains from the Calf Creek horizon, material traces of which are reported in nearby Eagle Cave (41VV167, Ross 1965) as well as from Jeff Davis and Brewster counties some 150 km to the west (Gray 2013; Walter 2013), indicating that the record at Bonfire Rockshelter does not completely reflect the character of regional bison histories.

Table 1. Some models of bison presence and visibility in the study region.

Southern Plains (Dillehay 1974)	Central Texas (Mauldin et al. 2012)		Wilson-Leonard (Sichler et al. 2011, from data by Baker 1998)	
Presence Period 3 800 B.P.	473.8 avg. NISP/ component	700-400 B.P.	18 NISP/ component	1700-4200 B.P.
Absence Period 2 1500-800 B.P.	2.9 avg. NISP/ component	1250-700 B.P.	1 NISP/ component	4200-5200 B.P.
Presence Period 2 4500-1500 B.P.	7.3 avg. NISP/ component	1600-1250 B.P.	59 NISP/ component	>11,000-9000 B.P.
Absence Period 1 ca. 7000 B.P.-4500 B.P.	316.9 avg. NISP/ component	2500-1600 B.P.		
Presence Period 1 >11,000-7000 B.P.	6.0 avg. NISP/ component	4450-2500 B.P.		

Our study draws from several sites geographically dispersed across a wide area. We do not imply that our study area corresponds with any particular archeological region(s). Indeed, the size of what might be called a "bison catchment" that is represented by this study is not precisely known. However, previous research indicates the potential size of prehistoric bison ranges. Carlson and Bement (2013) estimate mobility ranges from ca. 100 km (Clovis times) to up to ca. 600 km (late Folsom times) in diameter in an area centered on Oklahoma that includes southern Kansas, the Texas Panhandle, and eastern New Mexico. Widga et al. (2010) reconstruct inter-annual movements of ≤500 km over a period of about 4-5 years for Early/Middle Holocene (ca. 7-8.5 ka) bison in the eastern Great Plains of eastern Nebraska, South Dakota, western Iowa, and southwest Wisconsin. An area of ca. 600 km in diameter easily encompasses all of the sites from which samples in this study were taken (Figure 1).

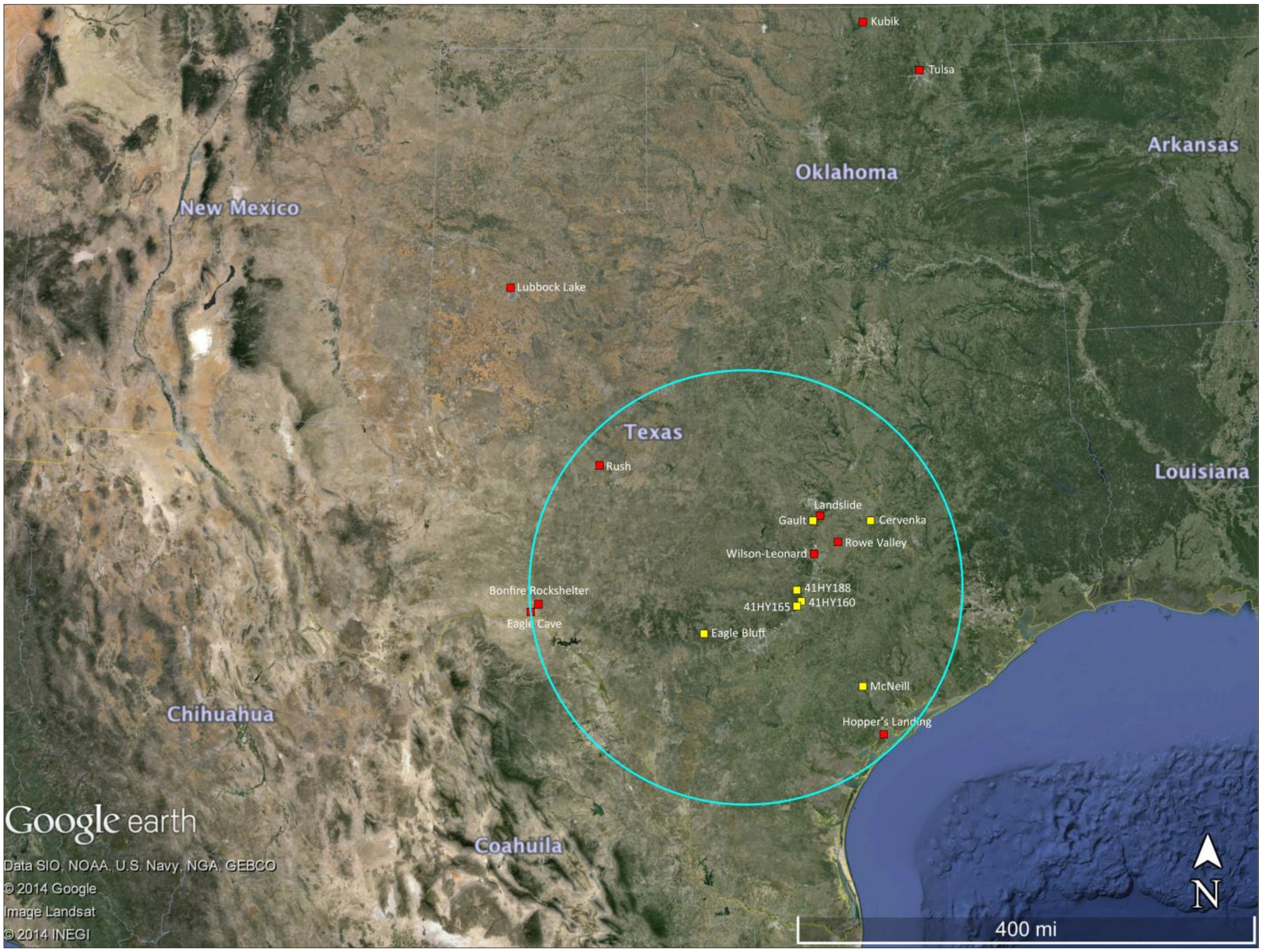

Figure 1. 600 km diameter study area illustrating the distance prehistoric herds may have travelled if they maintained mobility patterns comparable to those reconstructed elsewhere in North America. Sites dated in this study are shown in yellow; other sites discussed in the text are shown in red.

The presence of bison in the archeological record is, first, the result of environmental process and, second, a reflection of hunter-gatherer behavior. The key to building reliable bison chronologies, therefore, involves the number of temporal components that are sampled (i.e., selected for direct dating) within a given bison range. We propose that bison histories can be accurately reconstructed using sites with intermittent occupation records, so long as each period of bison presence in the total study area is well represented in at least one site's deposits. Alternatively, large portions of a bison chronology can also be compiled from a small number of sites, assuming that each period during which bison were present on the landscape is represented in site components and has been sampled. In this approach, compiling a large number of assays (i.e., high sample density) helps to ensure that all or most intervals of bison presence within the region are included. A weakness of this approach is that the geographic limits of bison territorial ranges will likely remain poorly known until sampling densities clearly define the geographic limits for each temporal period of bison presence.

Minimally, the patterns presented below are valid for the sites and time periods included in our study. Although we consider it likely that these patterns reflect larger-scale trends across a much broader area, only future sampling following the methods we employ here can precisely identify the extent of territorial ranges that are associated with the temporal periods in our chronology. For example, reports of bison presence throughout the Holocene at Lubbock Lake (41LU1) (Johnson 1987; Johnson and Holiday 1987) seem to suggest that the chronology presented here does not extend to the Texas Panhandle (see Figure 1).

Our sample draws heavily from 41HY160 and HY165, sites that are associated with Spring Lake, formed by impounded freshwater springs at the headwaters of the San Marcos River in Hays County, Texas. Based on temporally diagnostic artifacts and radiocarbon data (Figure 2), the Spring Lake sites exhibit a nearly continuous record of occupation from Clovis to historical periods (Lohse 2013). These sites are important to this study because their essentially continuous sequence means that remains of bison, as a top-ranked food resource, should be expected to occur whenever bison were present on the surrounding landscape. The occupation record of these sites distinguishes them from others, like Bonfire, with intermittent histories of site use. Controlled excavations at Spring Lake have generally not extended below the Early Archaic archeological deposits and intensive archeological sampling has only been conducted to ca. 6000 cal B.P. depths (Lohse et al. 2013), which represents the temporal limit of our study. Another site (41HY188) is less than 5 km from Spring Lake and evidences Late Prehistoric and Late Archaic occupation associated with bison (Bettis 1996). Two other specimens come from Eagle Bluff (41ME147) in Medina County (Hester 2010, 2011), one from Gault (41BL323) in Bell County, two from McNeill (41VT141) in Victoria County, and one from Cervenka (41WM267) in Williamson County (Peter et al. 1982). Each site contains deep, multi-component deposits in stratified alluvial settings, and is interpreted as a long-term encampment, making it unlikely that bison were killed at any of these locations. Rather, butchered remains were likely transported from kill sites back to these occupation areas for additional processing.

Assemblages from 41HY160, 41HY165, and 41HY188 were examined for bison remains suitable for dating. Virtually all specimens identified as bison were fragmented to the point that age and sex could not be consistently estimated. Therefore, no age and sex data are presented for the bison from any of our study sites. All cataloged contexts were evaluated, and specimens were selected from as many different proveniences by depth and site area as possible. Through this approach, every time period characterized by bison presence (and sampled by controlled excavation) had an equal chance of being identified. As noted, high sampling density was a priority in order to better model periods of bison presence. Samples were included from the other sites based on accessibility, preservation, and the limits of available funding.

Selected specimens were pre-treated for collagen extraction and purification using a XAD process modified from earlier work by Stafford that isolates individual amino acid chains (Stafford et al. 1988, 1991). Two modern approaches to removing exogenous carbon from bone collagen samples have been developed and refined over the last two decades: modified Longin (1971) extraction with *ultrafiltration* (Brown et al. 1988) and *XAD-purification* (Stafford et al. 1988, 1991). Ultrafiltration works

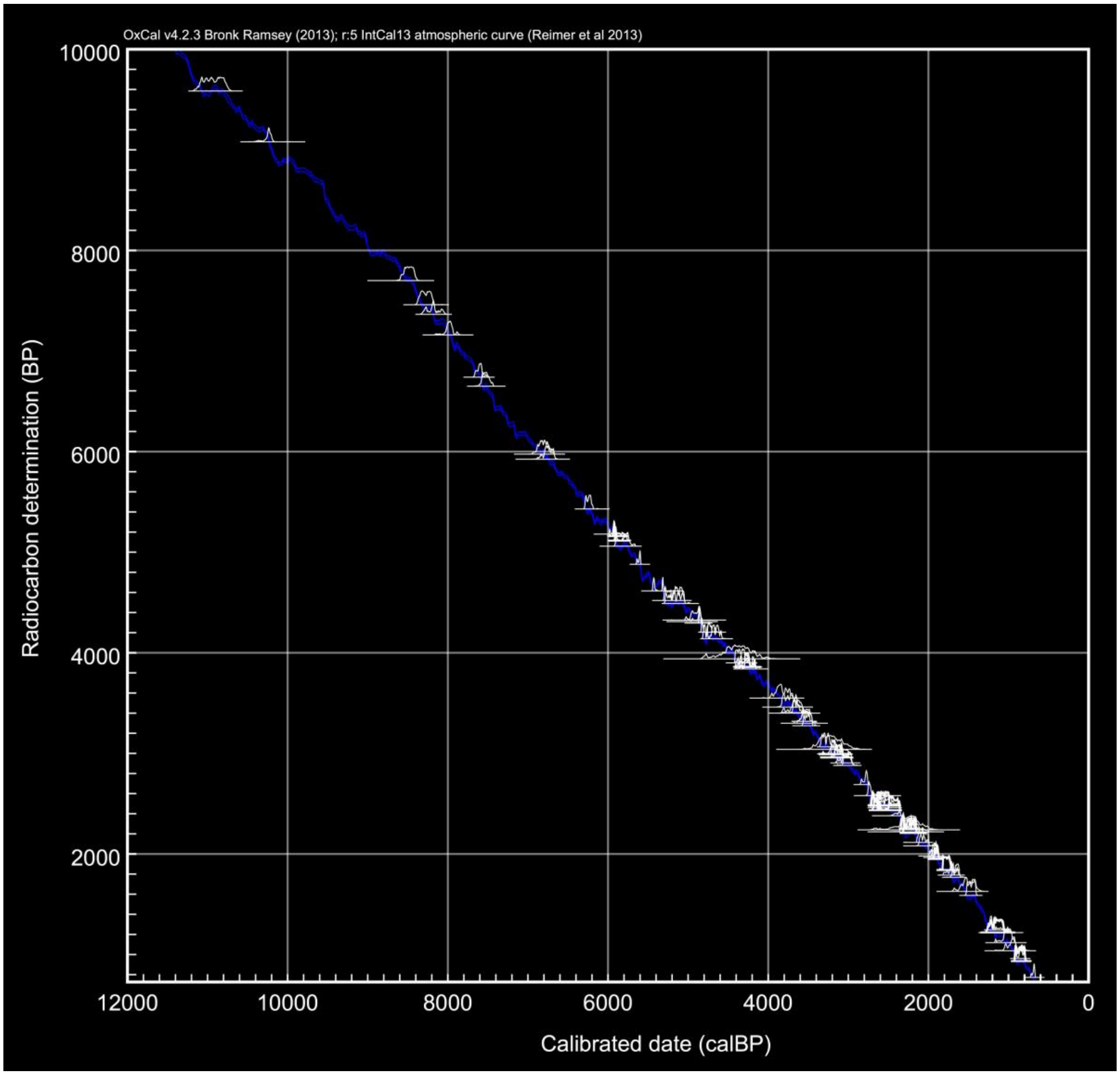

Figure 2. Calibrated results of 94 radiocarbon dates from Spring Lake, showing the nearly continuous occupation record extending to just after 6000 cal B.P. and the subsequent decline of dates that reflects the limits of controlled excavations. Two older dates not from archeological contexts are excluded (redrawn from Lohse 2013:Figure 4-1).

by retaining long-chain gelatin molecules (typically larger than 30kDa) and filtering out smaller, potentially degraded gelatin molecules and contaminating humates smaller than 30kDa. The lower yield of datable gelatin that results from ultrafiltration can limit its use on very poorly preserved bone (e.g., in cases where little or no long-chain protein survives), but smaller chains may be recoverable. One advantage of the modified XAD method is that all of the crude gelatin extracted from the bone can be processed for stable isotope measurement and AMS ^{14}C dating. Another advantage is that exogenous carbons that can remain following ultrafiltration treatments are removed, ensuring greater accuracy of measured ages.

Stafford et al. (1988, 1991) argued that gelatinization as described by Longin (1971) is not adequate to disassociate all humic and fulvic acids bound to collagen and that contaminants may cross-bind with smaller degraded collagen chains to create longer chains that would be retained in the filter. Our approach to eliminating these contaminants is to break the collagen down to individual amino acids by hydrolysis in concentrated (6N) HCl, thereby releasing humic and fulvic acids into solution. Polar contaminants are then removed from the solution by chromatography using a column filled with XAD resin. The method used in this study is adapted from that of Stafford et al. (1988, 1991). Similar methods of XAD amino acid dating has been used to reliably reevaluate pre-Clovis, Clovis, and other Early Paleoindian chronologies in North America (Waters and Stafford 2007, 2014; Waters et al. 2011) by dating osseous remains and artifacts clearly associated with Terminal Pleistocene cultural deposits.

At the Human Paleoecology and Isotope Geochemistry Lab at Pennsylvania State University, each sample was cleaned and sectioned with disposable Dremel cut-off wheels and then demineralized in 0.5 N HCl for two to three days at 5°C. The demineralized collagen pseudomorph was then gelatinized at 60°C in 4-5 mL 0.01N HCl for eight to 10 hours. Sample gelatin was pipetted into a pre-cleaned 10ml disposable syringe with an attached 0.45 μm Millex Durapore PVDF filter (precleaned with methanol and Nanopure H_2O) and driven into a thick-walled culture tube. The filtered solution was then lyophilized and percent gelatinization and yield determined by weight. The sample gelatin was then hydrolyzed in 2mL 6N HCl for 22 hours at 110°C. Supelco ENVI-Chrom® SPE (Solid Phase Extraction; Sigma-Aldrich) columns were prepped with two washes of methanol (2mL) and rinsed with 10ml DI H_2O. With a 0.45 μm Millex Durapore filter attached, the SPE Column was equilibrated with 50mL 6N HCl and the washings discarded. 2 mL collagen hydrolyzate as HCl was pipetted onto the SPE column and driven with an additional 10ml 6N HCl dropwise with the syringe into a 20 mm culture tube. The hydrolyzate was finally dried into a viscous syrup by passing UHP N_2 gas over the sample heated at 50°C for ca. 12 hr.

Stable carbon and nitrogen isotope measurements, %C and %N, were determined on amino acid hydrolyzate samples (~0.7 mg) at the University of California, Irvine Keck Carbon Cycle Accelerator Mass Spectrometer facility, on a Fisons NA1500NC elemental analyzer/Finnigan Delta Plus isotope ratio mass spectrometer with a precision of <0.1‰ for $\delta^{13}C$ and $\delta^{15}N$. Only samples with atomic C:N ratios between 3.0-3.4, indicative of good collagen preservation (Ambrose and Norr 1992; DeNiro 1985; van Klinken 1999), were submitted for AMS ^{14}C dating and are included in this study. AMS samples (~4.0 mg) were combusted for three hours at 900° C in vacuum-sealed quartz tubes with CuO wire and Ag wire to produce sample CO_2. Sample CO_2 was reduced to graphite at 550°C using H_2 and a Fe catalyst, with reaction water drawn off with C-9 Mg $(ClO_4)_2$ (Santos et al. 2004). Graphite samples were pressed into targets in Al boats and loaded on a target wheel with OX-1 (oxalic acid) standards, known age bone secondaries, and a ^{14}C-free Pleistocene whale blank. The ^{14}C measurements were made on a modified National Electronics Corporation compact spectrometer with a 0.5MV accelerator (NEC 1.5SDH-1). Analytical error in the 2-3‰ range was achieved, which for the current study translates to standard deviations in the range of ± 15-20 ^{14}C years. Radiocarbon ages were $\delta^{13}C$-corrected for mass dependent fractionation with $\delta^{13}C$ values measured on the AMS (Stuiver and Polach 1977), and compared with samples of Pleistocene whale bone (background, >48k ^{14}C B.P.), a ca. 12400 ^{14}C B.P. horse bone, ca. 1840 ^{14}C B.P. bison bone, late A.D. 1800s cow bone, and OX-1 oxalic acid standards for calibration. All dates are calibrated with the IntCal13 curve (Reimer et al. 2013) using OxCal 4.2 (Bronk Ramsey 2010) and are presented in calibrated years before present (cal B.P.). In order not to imply undue precision, all results are rounded to the nearest five-year interval (Table 2).

Regarding data presented in Table 2, a small number (n=4) of statistical outliers are present in our sample. Statistical outliers in each temporal period that contain five or more specimens are those samples with δ^{13}C values more than 1.5 times the interquartile range below the first quartile or higher than the third quartile (Fenner 2007). These specimens are identified in Table 2 as having very low (negative) δ^{13}C values. No statistical outliers were identified based on δ^{15}N. Outliers such as these are often reported from archeological bison herds such as at Folsom (Meltzer 2006:Table 6.19) and Jones-Miller (Tieszen et al. 1997), and elsewhere we have speculated that these may represent sexually mature bulls that had migrated into the study area from elsewhere (Lohse et al. 2014b). We are not aware of any research to date that has focused specifically on explaining or interpreting these outliers, but they are not uncommon in archeological studies of prehistoric bison isotopes.

We define periods of bison presence (also called temporal groups) based on the clustering of calibrated ^{14}C dates. In addition to standard calibration we calculate the duration of each period as the *Difference* of the earliest and latest samples in each group using OxCal, and summarize the range with means of those dates. Because we are unlikely to have directly dated the earliest or latest bison for any of our temporal groups, future dating is likely to affect the span of one or more groups. OxCal's *Sum* command is used to visually summarize the distributions within each group of dates, but this is merely a heuristic rather than an analytical tool. Because of the high density of samples taken from 41HY160, 41HY165, and 41HY188, it is possible that the same animals from these sites may have been dated more than once. If such cases exist, however, they do not adversely affect our chronology, since assays are only used to indicate when bison were hunted, and are not used to reconstruct herd population dynamics. Evaluating the individual carbon and nitrogen isotope measurements for each sample (shown in Table 2) shows that no two samples returned the same radiocarbon and isotope values. This suggests that any duplicate measurement of the same animal is minimal.

As noted, one result of our analytical approach is that the resulting chronology has greater precision than temporal models based on traditional (i.e., non-pretreated) bone dating and/or those relying on archeological association. While such methods have long provided useful information about the general timing of events, they are not well suited for addressing the precise timing of prehistoric events or when researchers are interested in documenting periods of rapid or punctuated cultural adaptations. Precise chronologies, sometimes also called "short chronologies" (e.g., Denham et al. 2012; Kennett et al. 2011, 2014; Tzedakis 2003; Wilmshurst et al. 2011) because they cover shorter spans of time than "long chronologies" of the same phenomena, are based on careful selection and AMS ^{14}C measurement of short-lived, pretreated species that minimizes the difference between the dated and target events. This approach can be differentiated from simple "dating," which might include no particular strategy to help ensure greater chronometric precision, and "high precision" dating, which we see as efforts that begin with the kind of sample selection and treatment we use but that also employ appropriate statistical manipulation, such as Bayesian statistics, of constrained data

Table 2. XAD-purified bison dates by lab number and provenience and stable isotope measurements discussed in this study. All dates are calibrated using IntCal13 (Reimer et al. 2013) (from Lohse et al. 2014b:Table 2).

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15}N	delta^{13}C	2σ calibrated range (cal BP)
29246	41VT141, Area B, N376, E826, level 10	3.26	190 ± 20	5.5	-7.8	290-265 (19.6%), 215-145 (52.9%)
81005	41HY165, Unit 2, level 7	3.16	215 ± 15	8.6	-11.1	300-275 (34.5%), 175-150 (50.2%)
81002	41HY165, Unit 2, level 2	3.14	250 ± 15	8.9	-9.4	310-285 (86.7%), 165-155 (8.7%)
87921	41HY160, Unit 4, level 3	3.16	275 ± 15	6.9	-14.3	425-395 (27.6%), 320-290 (67.8%)
106463	41HY160, Unit 3, level 5	3.03	515 ± 15	6.72	-11.51	545-515
129247	41VT141, Area 5(B), N376, E826, Feature 2, level 10	3.26	515 ± 15	5.5	-7.8	545-515
81003	41HY165, Unit 2, level 3	3.14	520 ± 15	5.3	-9.0	545-515
80131	41HY165, Unit 7, level 2	3.16	535 ± 20	6.2	-9.8	625-605 (11.8%), 555-515 (83.6%)
87940	41HY188, Unit 35 SE, level 5	3.16	535 ± 15	5.9	-8.7	620-610 (4.6%), 555-520 (90.8%)
87929	41HY188, Unit 4, level 5	3.21	540 ± 15	5.7	-9.4	620-610 (10.0%), 555-520 (85.4%)
87926	41HY188, Unit 1 NE, level 4	3.21	545 ± 15	6.4	-10.8	625-605 (17.5%), 560-525 (77.9%)
87932	41HY188, Unit 11 NE, level 4	3.17	545 ± 15	6.1	-9.6	625-605 (17.5%), 560-525 (77.9%)
87928	41HY188, Unit 4 NW, level 3	3.19	545 ± 15	7.9	-10.2	625-605 (17.5%), 560-525 (77.9%)
87937	41HY188, Unit 22 SW, level 11	3.19	545 ± 15	6.2	-9.3	625-605 (17.5%), 560-525 (77.9%)
81007	41HY165, Unit 11, level 3	3.15	555 ± 15	6.7	-8.9	630-600 (34.7%), 560-530 (60.7%)

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15}N	delta^{13}C	2σ calibrated range (cal BP)
87930	41HY188, Unit 6 NE, level 8	3.15	555 ± 15	8.4	-10.5	630-600 (34.7%), 560-530 (60.7%)
111183	41ME147, N807 E629, level 3	3.07	560 ± 15	5.5	-8.6	630-600 (42.7%), 560-530 (52.7%)
80133	41HY165, Unit 7, level 4	3.11	565 ± 20	4.6	-7.3	635-595 (51.8%), 560-530 (43.6%)
87927	41HY188, Unit 2 SW, level 3	3.19	570 ± 15	5.9	-10.2	635-595 (56.1%), 560-535 (39.3%)
80132	41HY165, Unit 2, level 4	3.12	575 ± 20	5.1	-9.6	640-590 (61.2%), 565-535 (34.2%)
87935	41HY188, Unit 22 SE, level 5	3.21	580 ± 15	6.1	-10.9	635-590 (65.4%), 565-540 (30.0%)
87931	41HY188, Unit 7 NW/NE, level 3	3.19	580 ± 15	6.7	-10.2	635-590 (65.4%), 565-540 (30.0%)
87936	41HY188, Unit 22 NE, level 10	3.23	585 ± 15	6.1	-9.7	640-590 (68.5%), 565-540 (26.9%)
87933	41HY188, Unit 11 NE, level 5	3.21	595 ± 15	5.9	-10.2	645-585 (73.6%), 565-545 (21.8%)
80134	41HY165, Unit 11, level 7	3.12	2205 ± 20	6.6	-8.5	2310-2150
80137	41HY160, Unit 10, level 7	3.13	2210 ± 20	5.7	-7.6	2310-2155
80135	41HY160, Unit 13, level 5	3.12	2255 ± 20	5.5	-8.4	2345-2305 (41.3%), 2245-2180 (51.4%), 2170-2160 (2.7%)
87925	41HY160, Unit 23 SE, level 10	3.19	2270 ± 15	5.2	-8.6	2345-2305 (73.1%), 2235-2185 (22.3%)
87922	41HY160, Unit 4, level 8	3.26	2275 ± 15	5.0	-9.3	2350-2305 (82.4%), 2230-2205 (12.3%), 2195-2190 (0.7%)
106470	41HY160, Unit 3, level 14	3.04	2415 ± 20	7.4	-14.5	2680-2665 (2.1%), 2655-2645 (2.5%), 2490-2355 (90.8%)
87920	41HY160, Unit 1, level 2	3.21	2460 ± 15	6.0	-8.2	2705-2630 (41.5%), 2620-2560 (20.3%), 2545-2430 (32.8%), 2390-2385 (0.8%)
81004	41HY165, Unit 3, level 8	3.29	2460 ± 25	5.1	-9.0	2705-2630 (31.8%), 2620-2380 (63.6%)

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15} N	delta^{13}C	2σ calibrated range (cal BP)
87938	41HY188, Unit 23 SE, level 8	3.22	2470 ± 15	6.3	-8.6	2705-2630 (37.9%), 2620-2465 (57.5%)
87923	41HY160, Unit 6, level 10	3.20	2470 ± 15	5.6	-8.9	2705-2630 (37.9%), 2620-2465 (57.5%)
81006	41HY165, Unit 3, level 6	3.18	2475 ± 15	5.9	-8.1	2710-2485
106465	41HY160, Unit 3, level 6	3.05	2475 ± 20	5.3	-8.05	2715-2465
87924	41HY160, Unit 6, level 11	3.18	2480 ± 15	5.1	-8.4	2710-2490
87934	41HY188, Unit 20, level 12	3.21	2480 ± 15	5.6	-8.4	2710-2490
106464	41HY160, Unit 3, Level 6	3.08	2480 ± 15	5.41	-9.19	2710-2490
106471	41HY160, Unit 4, level 7	3.07	2490 ± 20	6.57	-9.25	2720-2650 (21.8%), 2645-2490 (73.6%)
80138	41HY160, Unit 13, level 13	3.11	2955 ± 20	5.5	-7.8	3210-3200 (1.1%), 3180-3060 (93.0%), 3050-3040 (1.2%)
80130	41HY165, Unit 8, level 11	3.15	2965 ± 20	5.1	-8.4	3210-3190 (4.4%), 3185-3065 (91.0%)
80140	41HY160, Unit 13, level 13	3.12	2985 ± 20	5.4	-9.5	3225-3075
87939	41HY188, Unit 25, level 14	3.24	2995 ± 15	5.2	9.3	3230-3140 (88.2%), 3130-3115 (2.8%), 3095-3080 (4.3%)
80129	41HY165, Unit 3, level 7	3.12	3000 ± 20	5.6	-7.8	3320-3310 (1.7%), 3240-3140 (85.4%), 3130-3110 (3.8%), 3095-3080 (4.4%)
106472	41HY160, Unit 4, level 7	3.11	3000 ± 20	7.18	-8.77	3320-3310 (1.7%), 3240-3140 (85.4%), 3130-3110 (3.8%), 3095-3080 (4.4%)
129245	41BL323, N1161, E1081, 94.4-94.37 elevation	3.32	3000 ± 15	5.6	-8.3	3235-3140 (91.6%), 3125-3115 (1.3%), 3095-3080 (2.5%)
95718	41HY165, Unit 11, level 10	3.24	3065 ± 15	4.9	-20.0	3350-3225

UCIAMS Number	Provenience	C:N Ratio	^{14}C Age	delta^{15} N	delta^{13}C	2σ calibrated range (cal BP)
80999	41HY160, Unit 9, level 14	Too small	5060 ± 40	-	-	5910-5715
95717	41HY160, Unit 14, level 13	3.21	5110 ± 15	8.1	-10.7	5915-5885 (47.2%), 5820-5760 (48.2%)
80139	41HY160, Unit 7, level 14	3.14	5115 ± 20	6.8	-9.8	5920-5880 (48.4%), 5825-5755 (47.0%)
80136	41HY160, Unit 7, level 15	3.15	5120 ± 20	9.3	-9.6	5925-5885 (56.4%), 5820-5760 (39.0%)
80998	41HY160, Unit 7, level 14	3.13	5120 ± 20	8.5	-10.5	5925-3935 (56.4%), 5820-5760 (39.0%)
129248	41WM267, Area D, E-6, level 120-121, 93.3-93.2 elevation	3.28	5135 ± 20	5.7	-8.6	5935-5890 (81.4%), 5810-5765 (14.0%)
106473	41HY160, Unit 13, level 13	3.14	5140 ± 20	9.38	-11.9	5935-5890 (87.3%), 5805-5770 (8.1%)
106468	41HY160, Unit 3, level 14	3.11	5140 ± 20	7.43	-19.0	5935-5890 (87.3%), 5805-5770 (8.1%)
106469	41HY160, Unit 3, level 14	3.17	5145 ± 20	9.59	-11.9	5940-5890 (91.3%), 5805-5795 (1.8%), 5785-5770 (2.3%)
81000	41HY160, Unit 16, level 13	3.25	5155 ± 15	8.7	-11.1	5935-5900
81001	41HY160, Unit 16, level 13	3.19	5165 ± 15	8.3	-11.5	5980-5980 (1.8%), 5940-5905 (93.6%)
80997	41HY160, Unit 7, level 9	3.12	5180 ± 15	8.5	-9.4	5990-5970 (16.4%), 5945-5910 (79.0%)
111182	41ME147, N802 E631, level 4	3.46	5205 ± 20	3.6	-16.7	5990-5920

to construct or build chronological models characterized by greatly reduced age range probabilities. While this study focuses on precisely dating bison, we include an example of high-precision chronology, below, based on our work with the Calf Creek archeological component at Spring Lake.

RADIOCARBON RESULTS

Prehistoric bison exploitation is dated to four main periods in our study area, the first lasting from ca. 5955-5815 cal B.P.; the second and third involving two pulses between 3295-3130 cal B.P. and

2700-2150 cal B.P. separated by a 400+ year hiatus from ca. 3130 to 2700 cal B.P.; and the fourth consisting of a short Late Prehistoric interval from 650 to 530 cal B.P (Figure 3). Four historic period dates range from approximately 400-150 cal B.P. This last interval is hard to date precisely because of variations in atmospheric radiocarbon concentration during this period. However, historic documents record widespread bison hunting across Texas and nearby regions (e.g., Speth 2004; Wade 2003), and this period is critical for understanding regional culture historical events for the preceding three or four centuries. The prehistoric periods include the widespread Calf Creek horizon, found across the Southern Plains (Thurmond and Wyckoff 1999); two different periods in the regional Late Archaic (termed Late Archaic Bison 1 and Late Archaic Bison 2, LA_B1 and LA_B2, to distinguish these bison periods from subdivisions in the regional chronology); and what appears to be an early facet of the Toyah phase or horizon (Kenmotsu and Boyd 2012).

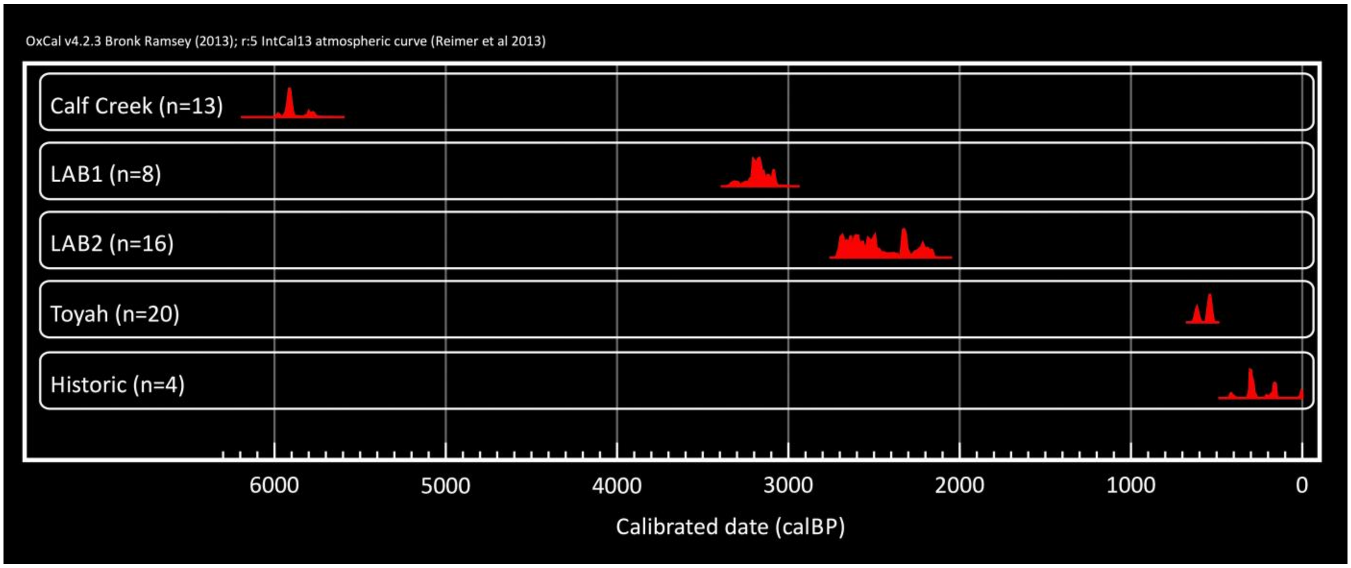

Figure 3. Summed probabilities for 61 XAD-purified AMS dates on bison bone from archeological contexts in Central and South Texas.

Calf Creek: ca. 5955-5815 cal B.P.

The earliest period of bison presence in our study is associated with the Calf Creek horizon. This period, which marks the end of the Early Archaic in Central Texas (Lohse et al. 2014a), is defined by the widespread occurrence of distinctive basally notched Bell and Andice points (Figure 4) often found in direct association with bison. Calf Creek materials are reported across Oklahoma (Bement et al. 2005; Duncan 1996; Neal 1999; Neal and Duncan 1998; Thurmond and Wyckoff 1999; Wyckoff 1994, 1995; Wyckoff et al. 2009); Central and South Texas, the Trans Pecos, and northern Tamaulipas (Calame et al. 2002; Collins 1994; Gray 2013; McReynolds 2002; Prewitt 1983; Ricklis 1988; Ross 1965; Sorrow et al. 1967; Walter 2013); western Arkansas (Dickson 1970); and into eastern New Mexico (Carmichael 1986). They are also present but less well documented in eastern Colorado, Missouri (O'Brien and Wood 1998), and Kansas (Stites 2006). Two Calf Creek points have recently been reported as far north as southern Utah (Wyckoff and Richens 2010). The brevity of this period has made it difficult to date these deposits with any precision. For example, this horizon is not represented in Dillehay's (1974) model for the Southern Plains (see Table 1), and is only poorly resolved at many sites (e.g., Wilson-Leonard). Stable carbon and nitrogen isotope data from samples in this study indicate that Calf Creek climates were among the coldest and perhaps driest experienced in the entire Holocene (Lohse et al. 2014b).

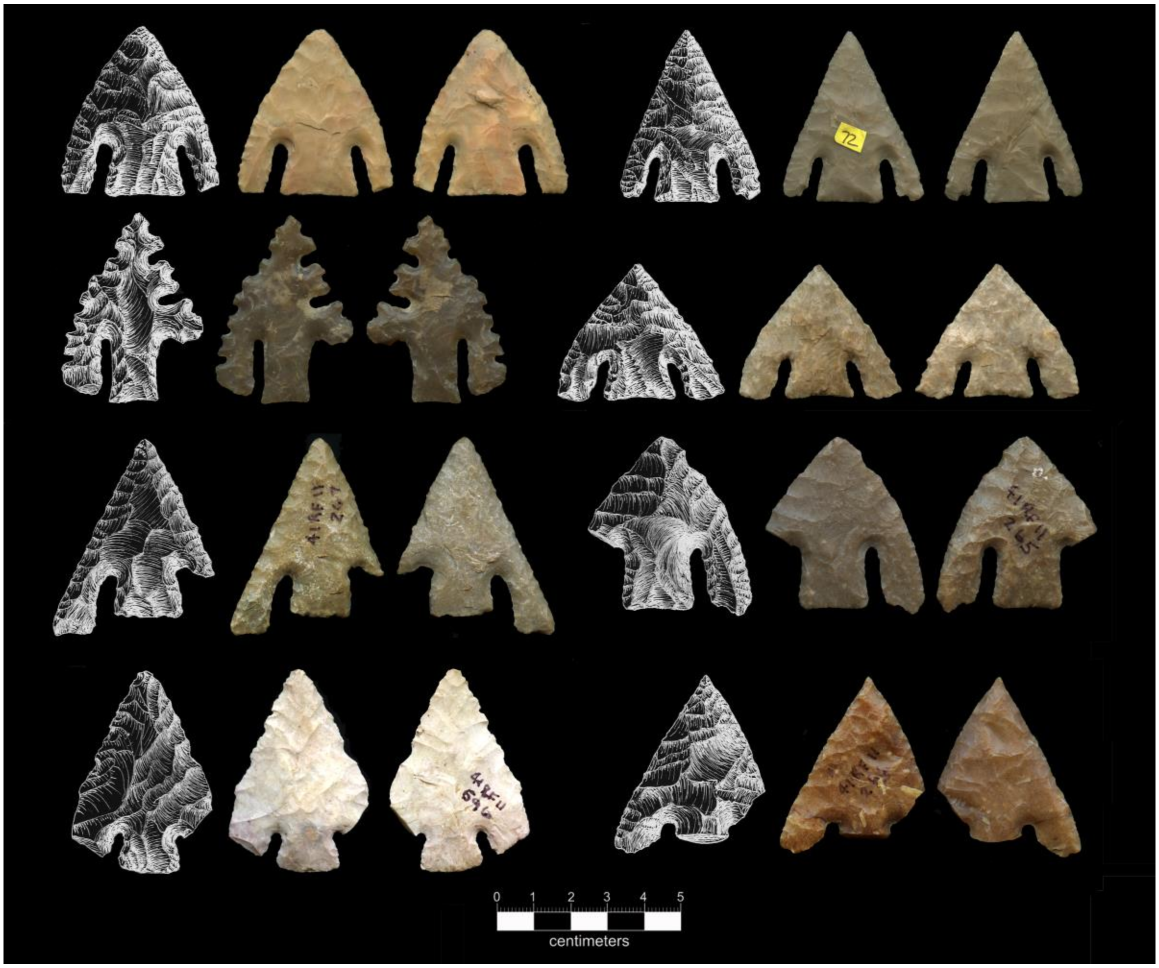

Figure 4. Examples of basally notched Calf Creek horizon points (Bell type). Top two rows are from Zapata County in South Texas (courtesy of Richard McReynolds). Bottom two rows are from the Hopper's Landing site (41RF11) (courtesy of the Museum of the Coastal Bend). All line drawings by Richard McReynolds.

Our Calf Creek bison data derive from three sites: Spring Lake (41HY160), Eagle Bluff, and Cervenka; the latter two have only a single date each. A bison bone sample associated with a Bell point from Feature 2 at the Landslide site (41BL85; Sorrow et al. 1967) was curated at the Texas Archeological Research Laboratory and was submitted for dating as part of this study, but did not yield enough collagen to be reliably measured. Two separate contexts at Spring Lake, over 40 m apart, have yielded Calf Creek remains including 11 AMS dates on bison (Lohse et al. 2013). Conservatively, the 13 dates together span the interval from 5990-5715 cal B.P., taking the extreme 2 sigma ranges for the earliest and latest dates. However, most dates fall onto an ideal part of the calibration curve, centering around 5900 cal B.P., between a modest reversal at about 5960 cal B.P. and a minor plateau spanning from approximately 5850-5770 cal B.P. (Figure 5). The effect of these two parts of the curve is to draw out or extend the calibrated probabilities of the earliest and last dates.

However, the difference of the earliest and latest dates allows us to estimate the duration of the Calf Creek components to be between 25 and 260 calibrated years (mean=140 cal years).

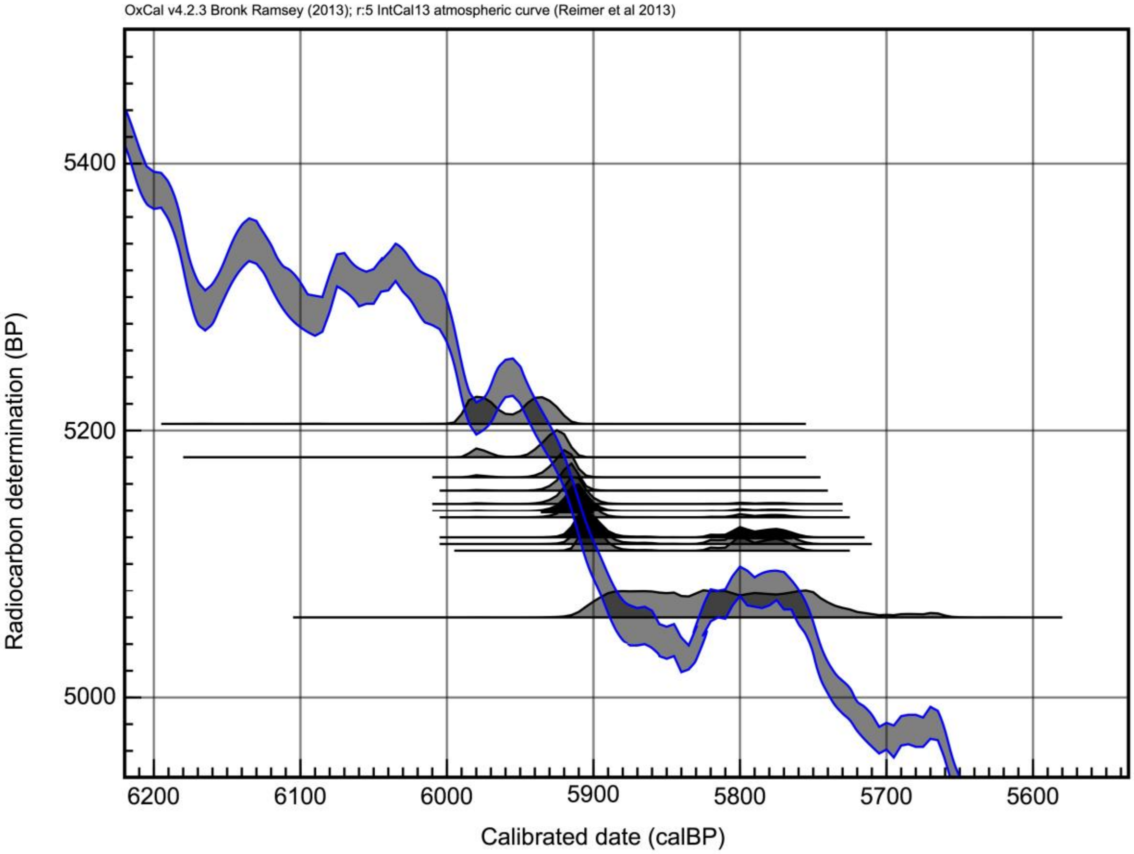

Figure 5. Calibrated probabilities for 13 Calf Creek dates superimposed on IntCal13 calibration curve.

Radiocarbon dates reported in association with Calf Creek materials commonly span over seven hundred years (see Wyckoff et al. 2009), and some "long" chronologies ascribe as much as a thousand years to this period (e.g., Collins 2004). Based on our results, however, we argue that this horizon may have been considerably shorter in duration. A moderately conservative treatment of these dates suggests a period of about 140 years. However, Bayesian modeling of the calibrated dates from Spring Lake suggests the presence of bison during a very short interval of no more than about 40 years (Figure 6), from 5937-5897 cal B.P. (A_{model}=122.3). This model indicates the short duration that can be identified with calibrated radiocarbon dates under ideal circumstances and with high-density sampling. The single date from Eagle Bluff is slightly earlier than this range, indicating regional variation in terms of timing and age of different site components. This model substantially narrows the overall age span for Calf Creek, and creates an opportunity to develop and test hypotheses relating to the overall chronology of bison movements and cultural responses during this period.

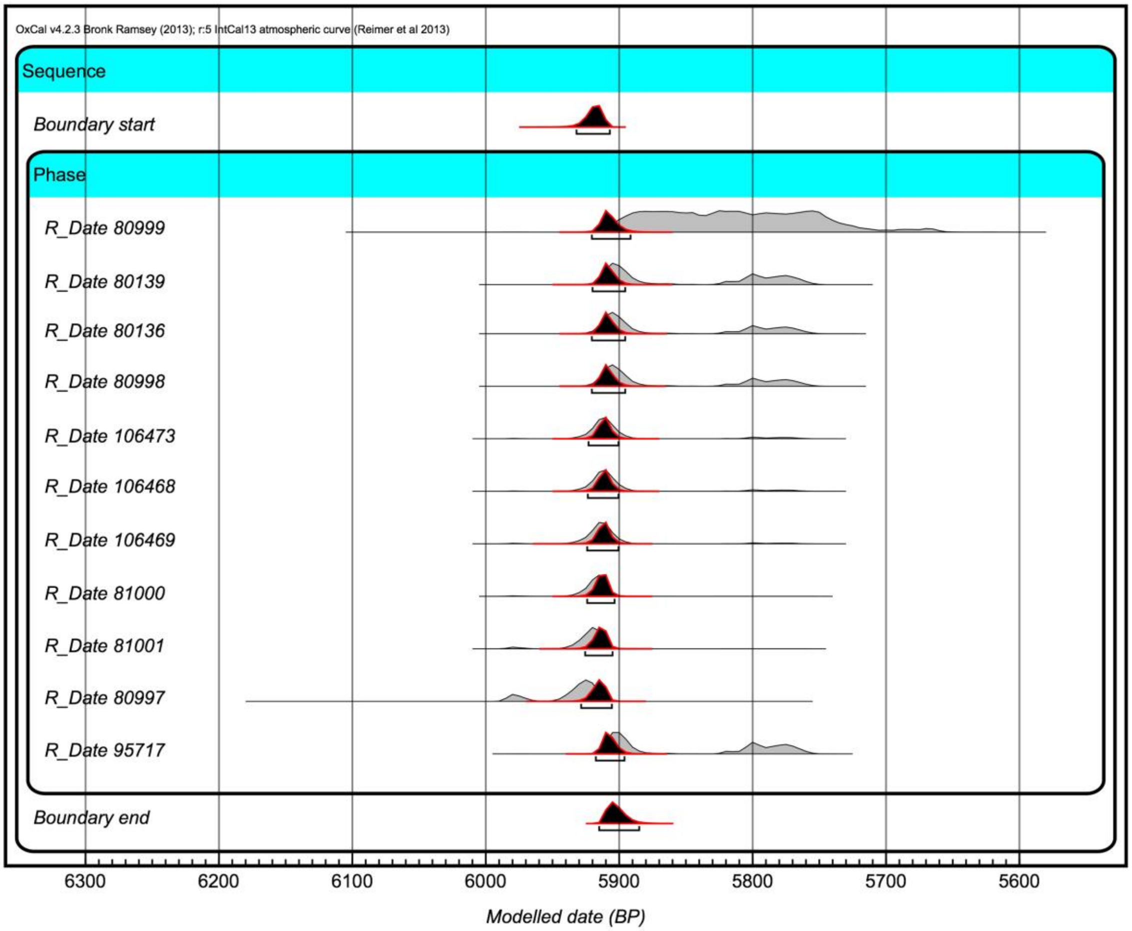

Figure 6. Simple Bayesian phase model of AMS ^{14}C from Calf Creek deposits at Spring Lake. These data suggest that the occupation during this horizon may have been limited to only a single event or a few rapid visitations.

Other than our data, very few precise assays are available for this time period. A Calf Creek point embedded in a juvenile bison (*B. occidentalis*) skull found in river gravels near Tulsa, Oklahoma (Bement et al. 2005) and dated at 5120 ± 20 ^{14}C years B.P. (approximately 5925-5760 cal B.P.) falls squarely within the range of dates we report. The Calf Creek component at the Kubik site, also in Oklahoma, has produced three dates: 4990 ± 100 (NZA6601) (5950-5465 cal B.P.), 5020 ± 120 (NZA6602), and 5050 ± 60 (Beta 98146) radiocarbon years B.P. (Neal 1999). The latter two dates, from a split nut hull, average to about 5895-5735 cal B.P. All three partially overlap with but are generally younger than our bison dates by a couple of centuries. The large 2 sigma probabilities of the Kubik dates relate to their large standard deviations compared with samples in our study, and also partly to a reversal in the calibration curve that occurs at ca. 5800 cal B.P. (see Figure 5). However, the nutshell dates are considered highly reliable, and the Kubik data suggest that the Calf Creek horizon extended later in Oklahoma than in our study area. Additional sampling using precision dating protocols will be necessary to define the temporal extent of the Calf Creek horizon as it occurred elsewhere on the Southern Plains.

Late Archaic: ca. 3295-3130 and 2700-2150 cal B.P.

Following Calf Creek, bison appear to have been absent from the landscape for more than two thousand years, from ca. 5750-3300 cal B.P. Regional models (see Table 1) show bison throughout the Late Archaic, but are vague about when they appear and tend to treat the Late Archaic as a single undifferentiated period. Single component sites with bison dating to this time are uncommon. Most sites, like Wilson-Leonard, have mixed or compressed Late Archaic components. Our Late Archaic bison dates come from four sites: two Spring Lake sites (41HY160 and 41HY165), 41HY188, and Gault.

Our data suggest that Late Archaic bison exploitation took place over two distinct intervals. The first period (LA_B1) began by 3295 cal B.P. (mean of 3355-3220 cal B.P., UCIAMS-95718) and continued until approximately 3130 cal B.P. (mean of 3215-3005 cal B.P., UCIAMS-80138). The duration of the period is estimated at between 55 and 270 cal years, with a mean of 165 cal years. This bison pulse is followed by a hiatus of at least 400 years (the 2 sigma difference is 380-700 cal years) after which a subsequent pulse, LA_B2, lasts from about 2700-2150 cal B.P. The more than 400 year hiatus after 3130 cal B.P. is previously unreported, likely as a result of the reliance on archeological associations for reconstructing cultural patterns (Figure 7). Stable carbon and nitrogen isotope data indicate that Late Archaic climates were relatively stable for the entire LA_B1 and LA_B2 periods, and that both periods were somewhat warmer and had more effective moisture than the earlier Calf Creek or later Toyah periods (Lohse et al. 2014b). However, both also correspond with a period of globally cool climates (Wanner et al. 2011). Importantly, Viau et al. (2006) identify the period around 3000 B.P., approximately the middle of our postulated hiatus, as among the warmest of the entire North American Holocene and van Geel et al. (1996) identify a cool, moist period in Europe and North America starting by around 2650 cal B.P. If verified, these temperature changes could help explain or contextualize bison movements into and out of the study area at different times during the Late Archaic period.

Although there appears to be a gap in bison exploitation in LA_B2 between ca. 2275 and 2415 ^{14}C B.P. (see Table 2), this gap is likely an artifact of the calibration curve. A plateau in the curve occurs during LA_B2, followed by a steep decline and then another mild reversal. These statistical plateaus affect the interpretation of radiocarbon data most obviously by creating very broad calibrated distributions for the dates in these groups. Indeed, the estimated length of LA_B2 (200-550 cal years) is the longest in our study, and it is possible that the duration of this period is overestimated because of fluctuations in the calibration curve during this interval.

A less obvious effect of the plateaus and associated steep segments of the curve is that even with precise measurements and very dense sampling, conventional ages corresponding to plateaus will be overrepresented, and those during steep sections may tend to be underrepresented (Calf Creek is an

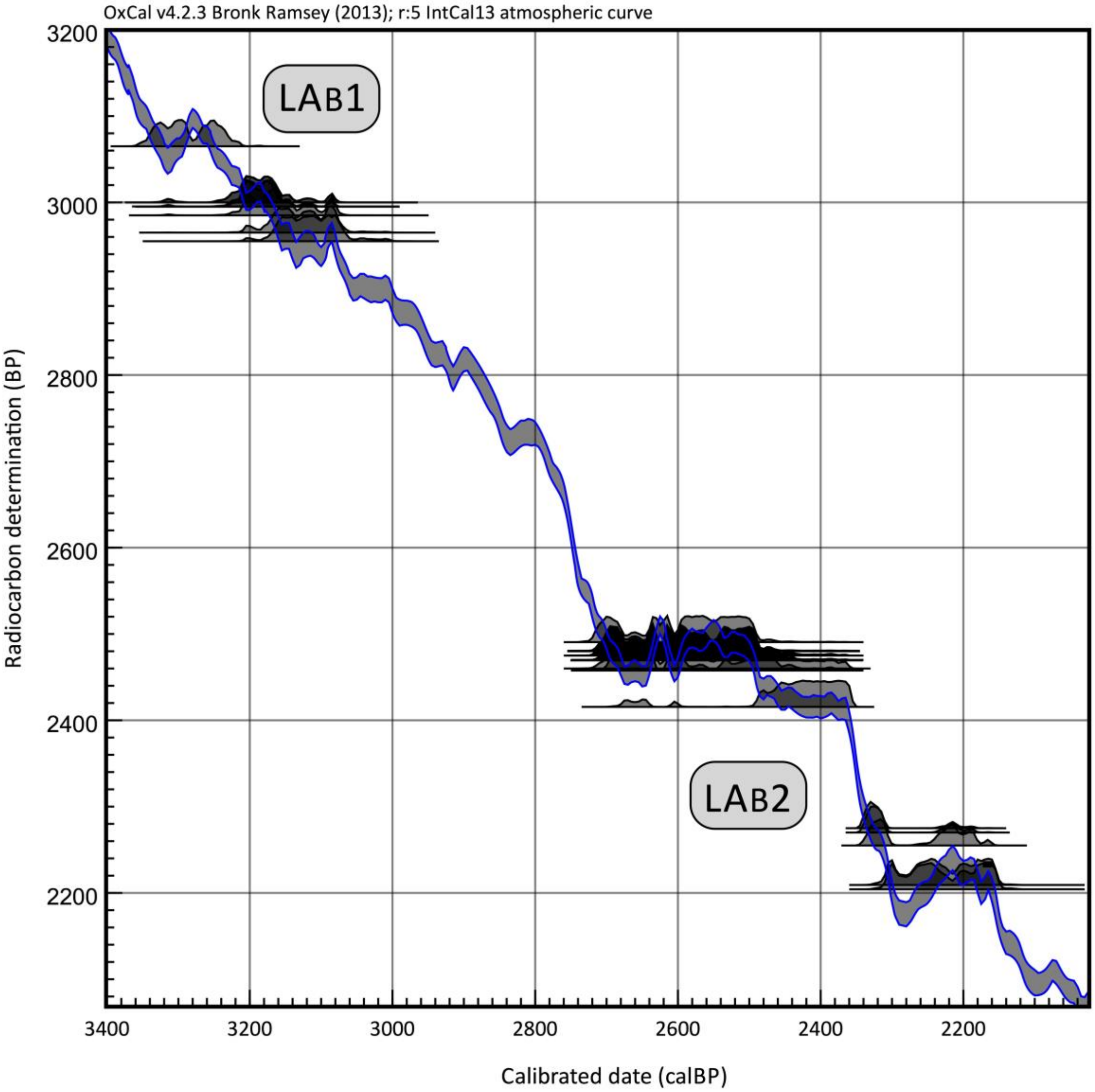

Figure 7. Calibrated probability distributions for 24 Late Archaic AMS ^{14}C bison dates. The LAB2 occupies a relatively flat part of the curve from about 2700-2360 cal B.P., which contributes to temporal imprecision during this interval. The steep decline following this plateau creates the appearance that a brief hiatus separates this period from a third Late Archaic period of bison exploitation.

exception; see Figure 5). This phenomenon can be modeled with OxCal using the *R_Simulate* command, which produces a conventional age from a calendar age with a given measurement error, and then calibrates it. To better understand the effect of the curve on our calibrated sample, we simulated a group of 170 dates (10 dates every 25 years) from 2500 to 2100 cal B.P. assuming a measurement precision of ± 20 ^{14}C years to mirror the precision of our study. This very dense dataset is analogous to recovering and dating 40 bison per century from the archeological record, or roughly 10 times what we have sampled for the period. Plotting the frequency of conventional ages demonstrates that even at this density, conventional ages from ca. 2380 to 2260 cal B.P. are relatively unlikely (roughly 10-20 percent as likely) to be sampled compared with ages on the plateaus before and after that time (Figure 8). The congruence between the distributions of simulated and observed conventional ages through this period suggests that the apparent gap is an artifact of the calibration curve, and that further sampling is unlikely to produce many more conventional ages between 2415 and 2275 ca. B.P.

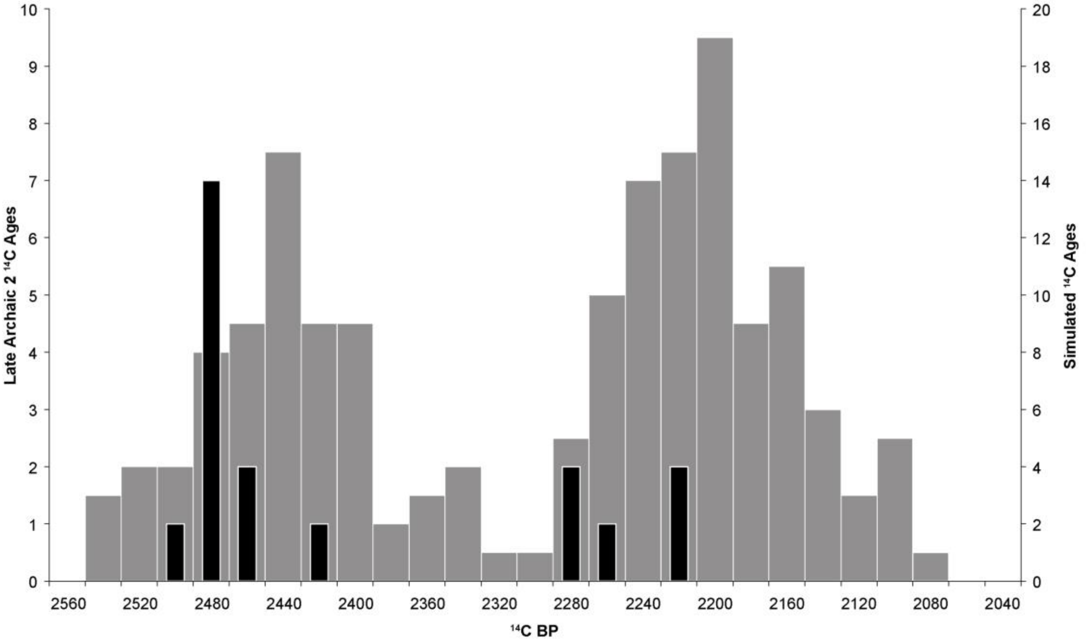

Figure 8. Frequency of simulated ^{14}C ages (gray columns) versus measured ^{14}C ages (black columns) on bison across two plateaus in the Late Archaic from 2500-2100 cal B.P. (2560-2040 14C yr B.P.) and the apparent gap in ^{14}C ages that is an artifact of the calibration curve. Simulated ages were generated in OxCal 4.17 (Bronk Ramsey 2010) using R_Simulate, assuming 10 dates every 25 cal years and a precision of ± 20 ^{14}C yr, comparable to the precision of the dates in this study. The "gap" in LAB2 ^{14}C ages is likely not a true hiatus in bison exploitation.

Toyah: 650-530 cal B.P.

Following the Late Archaic, bison again appear to have been absent from the study area for approximately 1500 years, until ca. 650 cal B.P. They reappeared suddenly and may have been present for less than 120 cal years before once again disappearing. This Toyah bison interval is the shortest in our study. Climatically, our early Toyah bison period occurred immediately after the onset of the Little Ice Age (LIA), a prolonged cool and dry period, the beginning of which corresponds with one of the largest volcanic events of the entire Holocene as well as severely reduced solar activity (Mayewski et al. 2004; Wanner et al. 2011). Stable carbon and nitrogen isotope data (Lohse et al. 2014b) indicate that temperatures during this brief interval were not as cool as the Calf Creek period, and that effective moisture was slightly greater than in the Calf Creek period. However, the period was still cooler and drier than either LA$_B$1 or LA$_B$2. The LIA was complex climatologically, and significant variation has been documented within it. Based on over a thousand tree-ring, ice core, coral, sediment, and other proxy records, Mann et al. (2009) reconstruct a brief cold period in the northern hemisphere centering around A.D. 1340 (ca. 610 cal B.P.) that precedes a short warm interval before temperatures decline once again just prior to ca. A.D. 1500 (ca. 450 cal B.P.). The reconstructed cool periods correspond with the Wolf and Spöer grand solar minima, respectively

(Bard et al., 2000; Steinhilber and Beer 2011), brief intervals of reduced solar activity (e.g., sun spots, solar flares, etc.) that are associated with global cooling.

The bimodal calibrated distributions of our 20 dates from this period (Figure 9) partially reflect the shape of the calibration curve during this interval, which exhibits a sharp reversal resulting in paired intercepts for each assay. Taking the difference of the oldest and youngest dates in our Toyah bison period, the period lasted between 10 and 120 cal years, with a mean of 70 cal years. Toyah dates come from five sites: two Spring Lake sites (41HY160 and 41HY165), 41HY188, Eagle Bluff, and McNeill.

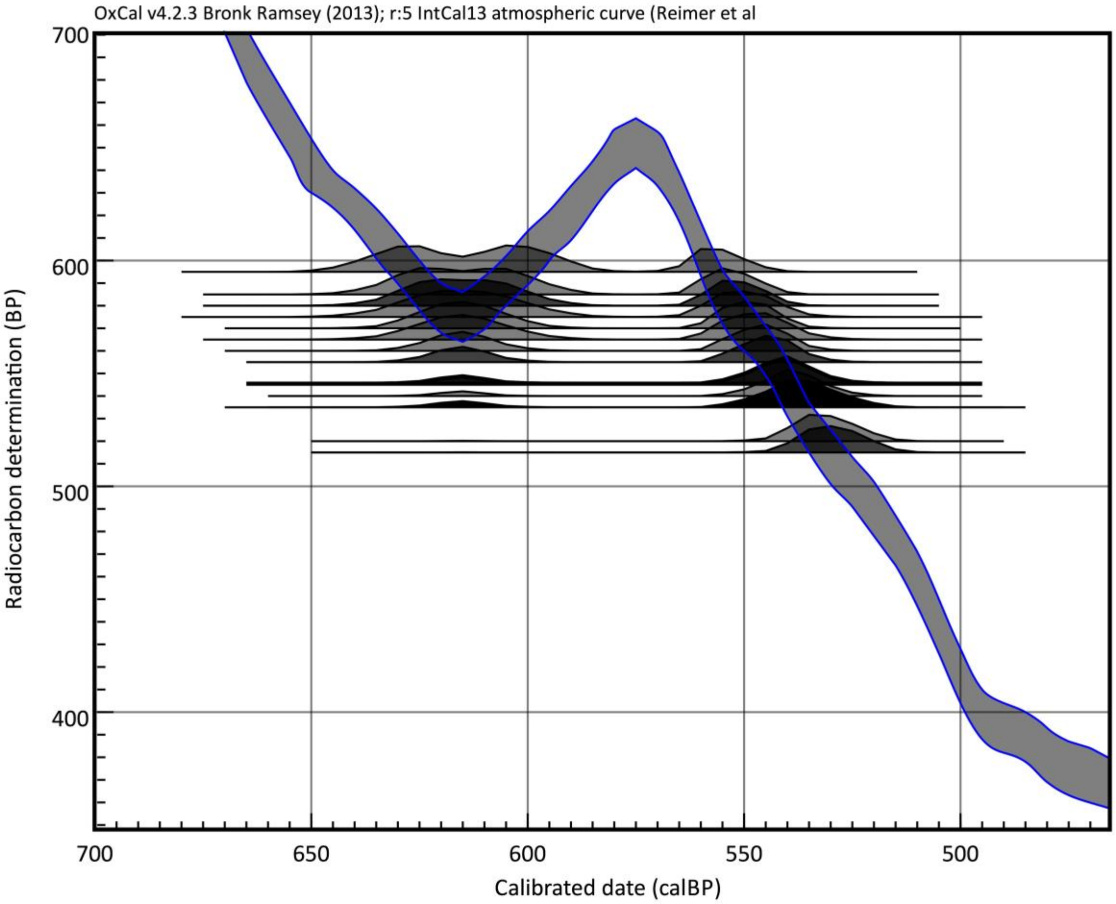

Figure 9. Calibrated probability distributions for 20 early Toyah AMS 14C bison dates. The reversal at ca. 575 cal B.P., resulting in bimodal distributions, causes the calibrated span of time to cover a longer period than is likely. Nonetheless, this is the shortest period of bison exploitation documented in our study.

The brevity of this period of bison exploitation is significant in the culture history of North America. In the regional sequence, the Toyah horizon begins by approximately 650 cal B.P. or A.D. 1300, and lasts as late as A.D. 1700. Native American cultural practices extending to the end of this sequence are difficult to link with earlier prehistoric antecedents because of the influences of Spanish *entradas and* colonization, not to mention population declines and social disruptions due to European diseases and group displacement practices that started in the early 1500s (Arnn 2012; Kenmotsu and

Hester 2001). Nonetheless, Toyah culture has typically been defined as exhibiting a technological focus on the exploitation of bison (Johnson 1994; Kenmotsu and Boyd 2012; Prewitt 2012; Ricklis 1994) and artiodactyls generally (Black 1986). Some have noted variation in Toyah subsistence practices (e.g., Dering 2008; Mauldin et al. 2013), including what appears as a decreased emphasis in bison, but temporal controls frequently lack the precision needed to demonstrate whether this variation is temporal or geographic in nature.

Archeologists argue that Toyah is important for our broader anthropological understanding of hunter-gatherer cultural patterns just prior to ethnographically-documented foragers that occupied the region when the Spanish arrived (Collins 1995). Our data suggest that the Toyah horizon may have been characterized by more varied subsistence practices and associated social and technological adaptations than conventional views suggest. From the early A.D. 1500s through the late 1700s, historical groups were recorded pursuing bison across Texas (Arnn 2012; Speth 2004; Wade 2003), and it has been widely presumed that this pattern is an extension of practices that began as early as A.D. 1300 (ca. 650 cal. B.P.). Prior research on the southern Plains has documented widespread trade between Puebloan settlements to the west and Plains groups focusing on bison meat, hide, and other products (Boyd 1997; Creel 1991; Krieger 1946; Prewitt 1982; Speth and Newlander 2012; Spielmann 1991; Vehik 1990, 2002). Considering the sudden appearance of bison and their role in both subsistence and economic patterns, we suggest that early Toyah (ca. A.D. 1300-1420, or 650-530 cal B.P.) can be partly understood as a southern extension of this interregional system. Our findings suggest, however, that middle Toyah sites, those dating after around 530 cal B.P. (A.D. 1420), but pre-dating the reappearance of bison in the mid-1500s, may have maintained an altogether different orientation, with significantly less reliance on bison than previously thought. Although sites with late Toyah material such as the Rush site (41TG346, ca. A.D. 1575; Quigg 1997) or the upper Toyah component at Rowe Valley (41WM437; Prewitt 2012) contain bison and appear to support this three-part model of Toyah chronology, dating resolution is so far lacking to demonstrate the postulated middle Toyah facet. However, the four historic dates in our sample provide partial support for this model. More dates are needed from this late period before this model can be further developed.

DISCUSSIONS AND CONCLUSIONS

Our record of 61 AMS dates on bison bone recovered from archeological contexts from the southeastern periphery of the Great Plains adds to what is known about the exploitation of a top-ranked resource starting approximately 6000 years ago. We show that bison were present only occasionally since the Early-Middle Holocene. While our study is generally consistent with previous regional models, it adds important precision to the overall understanding of these periods. It is well known that bison were present in the region prior to 6000 cal B.P., but this part of the record has not been directly dated using the XAD-based protocols we report here. Because the early sequence for bison exploitation is dated primarily by archeological association, in our view it remains imprecise.

In spite of its limitations in terms of geographic and temporal coverage, our record of XAD-purified AMS ^{14}C dates on bison offers one of the most precise models for the presence and prehistoric exploitation of this key resource anywhere in North America. In addition to refining local and regional chronologies, our findings also contribute to hypotheses about fluctuations in "Plains-like" cultural patterns that depended, in part, on environmental and climatic change and the subsequent exploitation of bison for subsistence and economic purposes. For example, what appears as the sudden onset of bison-related cultural patterns, especially Calf Creek and Toyah, may have been associated with rapid climate change (Mayewski et al. 2004). This important possibility, which deserves further attention, would have significant implications for how archeologists understand the nature and timing of prehistoric culture change. Additionally, the rapid appearance of widespread horizons associated with the Calf Creek and early Toyah periods is ostensibly linked to the sharing of weapons- and processing-related technologies involved with logistically organized bison hunting at these times. Projectile point styles associated with these intervals are among the most widespread post-Paleoindian styles in Texas (cf. Prewitt 1995), and may reflect the distances traveled by bison hunters and the kinds of social encounters that occurred as part of these forays.

More than only subsistence practices are implicated as well. Trade patterns beginning by A.D. 1250 (ca. 700 cal B.P.) in the Southern Plains and focused on bison are also well known (e.g., Creel 1991; Speth 2004). Toyah sites commonly show a sharp increase in exotic materials compared with earlier periods (Kibler 2012), suggesting that exchange networks also extended south into Central and southern Texas. Like connections with climate change, this proposition also requires much additional research before these economic processes are fully understood. Future AMS radiocarbon dating work on Toyah sites should be mindful of our evidence suggesting a three-part bison chronology. Sample selection should avoid large carbonized wood fragments susceptible to the old wood effect and focus instead on annuals or perennials. Radiocarbon results should be matched against zooarcheological assemblages indicating the presence or absence of bison.

Our study highlights the research value of adding to the record of XAD-purified AMS dates of bison remains. Adding samples with greater time depth and from additional sites will help improve the bison record and increase its usefulness as a means for understanding larger cultural and environmental processes at the southern extent of the far Southern Plains.

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