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On the Dating of the Folsom Complex and its Correlation with the Younger Dryas, the End of Clovis, and Megafaunal Extinction

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Using a set of high-quality radiocarbon dates, including three new dates from the Hanson site and one from the Folsom component of Hell Gap, we provide a revised estimate of the duration of the Folsom period. Limiting our sample to bone collagen samples pretreated using the XAD resin chromatographic or ultrafiltration techniques, calcined bone, and charcoal from hearth features, we show that Folsom sites fall within a limited range from 12,610 to 12,170 BP, or 440 years. This duration is considerably shorter than previous estimates. Additionally, we show that there is little correlation between the onset and termination of the Younger Dryas and the start and end of the Folsom complex. Finally, the youngest Clovis sites and the last of the Pleistocene megafauna correlate well in time, but are followed by a 100-year gap until the earliest Folsom sites, most likely a result of small sample size.

Keywords Folsom, Clovis, radiocarbon, Younger Dryas, Hanson site, Hell Gap site

1. Introduction

Because a large number of additional high-quality dates have been produced from Folsom contexts in recent years, we felt that a review of the chronology of the Folsom complex was overdue. The age range for Folsom provided by Haynes et al. (1992) of 10,950–10,250 14C yr BP (12,780–12,000 cal yr BP) is now more than 20 years old. Holliday’s (1997, 2000a) more recent works suggest a similar but slightly constricted range of 10,800–10,200 14C yr BP (12,710–11,910 cal yr BP) for the northern Plains and 10,800–10,100 14C yr BP (12,710–11,710 cal yr BP) for the southern Plains, but do not include any dates produced this millennium (see also Stanford 1999; Taylor et al. 1996). Moreover, it has been noted that the span represented by Folsom correlates to some degree in time with the Younger Dryas stadial (12,850–11,650 cal yr BP) (e.g., Holliday 2000b; Jodry 1999; LaBelle 2012; Meltzer and Holliday 2010; Stanford 1999; Surovell 2009). Using a refined set of high-quality dates from 12 Folsom components, we provide a revised age range for the Folsom complex and examine its correlation with the Younger Dryas, the end of Clovis, and megafaunal extinction.

This paper was also inspired by four new radiocarbon dates first reported herein from Folsom contexts, three on calcined bone from the Hanson Folsom site and one on ultrafiltered collagen from the Folsom component of the Hell Gap site. The Hanson and Hell Gap site Folsom components are important in Folsom dating because they have effectively served as chronological bookends for the complex (Collard et al. 2010; Haynes et al. 1992).

Dates from Hanson have long been problematic. Frison and Bradley (1980, 10) initially reported two dates on “small” charcoal samples. The sample from Area 1 of the site produced a date of 10,700 ± 670 14C yr BP (RL-374), and a sample from Area 2 yielded an age of 10,080 ± 330 14C yr BP (RL-558). These samples were not clearly associated with hearth features, and as such their relationship to the age of the Folsom occupation is unclear. They are also imprecise with large standard deviations. Three additional dates were produced, apparently in conjunction with Ingbar’s reinvestigation of the site in
the late 1980s (Frison 1991, 25; Haynes et al. 1992; Ingbar 1992, 1994). Ingbar (1992, 175) reported two new dates from Area 2, presumably on charcoal, of 10,300 ± 150 14C yr BP (Beta-22514, ETH-3329) and 9970 ± 340 14C yr BP (Beta-22513). A third date of uncertain material and provenience (most likely also charcoal from Area 2) was reported by Frison (1991) and Haynes et al. (1992); that date is 10,225 ± 125 14C yr BP (Beta-31072). In sum, dates from Hanson, all of which appear to be on charcoal stratigraphically associated with the Folsom occupation, are highly variable and span almost 1000 radiocarbon years. Most subsequent studies of Folsom chronology have relied on an average of the two older Beta dates to provide an age estimate for the site of 10,260 ± 90 14C yr BP or 12,022 ± 200 cal yr BP after calibration (Collard et al. 2010; Haynes et al. 1992; Holliday 2000a). If correct, this would make Hanson one of the youngest Folsom sites known to date.

Although there are numerous radiocarbon dates associated with the Folsom component at Hell Gap (Haynes 2009), all are somewhat problematic as they are charcoal or soil organic matter dates with only stratigraphic association. In other words, they may not directly date the Folsom occupation. Based on an average of three charcoal dates, Collard et al. (2010) estimated the age of the Folsom component to be 10,820 ± 170 14C yr BP or 12,740 ± 179 cal yr BP after calibration. Those samples, however, were derived from the Midland component at Locality 2, which occurs stratigraphically in the same level as the Folsom component at Locality I (Haynes et al. 1992, 96). If the Collard et al. (2010) Folsom date is accurate, it would make the Hell Gap site the oldest known occurrence of the Folsom complex, and Collard et al. (2010, 2514) used this date to argue that the Folsom complex originated in the vicinity of Hell Gap and spread to the north and south from there. Our new dates from Hanson and Hell Gap suggest significantly different ages for both sites and refine the chronology of Folsom considerably.

2. Methods and materials

2.1 Date selection criteria

There is a huge number of radiocarbon dates available from Folsom contexts, and those dates are highly variable ranging in age from modern (SMU-153) in the case of a date on bone apatite carbonate from the Folsom site (Haynes et al. 1992) to 13,340 ± 170 14C yr BP (NZA-1091) on a piece of charcoal recovered from gully fill at the Lipscomb site (Hofman 1995). The key to refining the age of the Folsom complex is to whittle down the entire set of available radiocarbon dates to isolate those that are most likely to accurately date Folsom occupations. In evaluating the quality of radiocarbon dates, we are most concerned with issues of pretreatment/contamination and context, by which we mean the relationship between the age of the sample and the age of the phenomenon it is intended to date.

If pretreatment could always successfully remove all contamination from a sample, bone should be a preferred material to date over charcoal. Dates on wood charcoal can suffer from the old wood problem, which adds unsystematic and potentially large errors to the measured age of samples (Schiffer 1986). Although an analogous “old bone” problem is theoretically possible, animal bone often retains cut marks, impact fractures, and/or other contextual clues that leave little doubt that its presence is due to human action and that the death of an animal was contemporaneous with the occupation of a site. Rarely can the same thing be said about charcoal, except for charcoal recovered from features like hearths, but even then, old wood should be a concern, except perhaps in the case of dating annual macrobotanical remains like seeds. Isolated flecks of charcoal from sedimentary contexts have the additional complication of having potentially been redeposited. For these reasons, when dating a bison kill, for example, if given the option to directly date bone or a fleck of charcoal recovered from the matrix within the bonebed, dating the bone should be an obvious choice. That choice, however, has not always been obvious because pretreatment cannot always remove contamination.

Comparing bone and charcoal with respect to pretreatment and contamination, charcoal has traditionally been a much more reliable material. Removing exogenous carbon from charcoal samples is usually fairly straightforward because common contaminants of charcoal (i.e., humic and fulvic acids and secondary carbonates) have chemical properties that differ sufficiently from the carbon native to the sample that they are easily separated. Separating contaminant from endogenous carbon from bone samples, by comparison, is considerably more complicated, whether dealing with its organic or inorganic components (Taylor 1994), and reliable dating of bone was not really possible until relatively recently. The development of XAD resin chromatographic (Stafford et al. 1988, 1991) and ultrafiltration (Brown et al. 1988) methods for removing contamination from bone collagen appears to have dramatically improved the accuracy of bone dates when collagen is well preserved. More recently, several studies have shown that although macroscopically friable, highly crystalline calcined bone can also produce reliable dates (Hüls et al. 2010; Lanting et al. 2001; Snoeck et al. 2014; Zazzo and Saliège 2011). When bone is calcined, atmospheric and/or combustion gas CO2 is incorporated into the apatite matrix, which becomes
impervious to the problems of ionic exchange that have plagued attempts to date bone apatite carbonate for decades. These improvements in pretreatment in combination with the development of AMS dating, in our opinion, have transformed bone from being one of the least reliable materials for dating, to one of the preferred materials. That said, in evaluating the quality of bone dates, pretreatment methods must be taken into account. We suggest that only bone collagen samples pretreated using the XAD and ultrafiltration methods should be considered reliable, although some samples still produce anomalously young results (e.g., Byers 2002). We also consider dates on apatite carbonate from calcined bone to be reliable, although more work testing the accuracy of this method is needed.

Given these considerations, to isolate the highest quality dates available from Folsom contexts, we limit our sample to bone collagen dates wherein the sample was pretreated using the XAD resin chromatographic and ultrafiltration techniques, bone apatite dates from calcined bone, and charcoal samples recovered from hearth features. By limiting our sample this way, we isolate those samples that are most likely to have directly resulted from human occupation of a site and minimize the effects of contamination. If there are systematic errors in these dates, we expect the bone collagen dates to be too young due to the presence of small amounts of young carbon contamination, and we expect hearth charcoal dates to be too old due to the possibility of old wood. It is unclear if systematically directional errors are expected for calcined bone dates, but experimental work has shown that a partial old wood effect might be expected if old wood was used and combustion gases contributed significant amounts of CO₂ to apatite carbonate (Hüls et al. 2010; Snoeck et al. 2014). We exclude from our analysis all charcoal dates unassociated with hearths, including samples with strong stratigraphic association. We also omit all dates on soil organic matter because they do not directly date archaeological occupations.

2.2 Sample
The total sample of Folsom radiocarbon dates meeting our selection criteria includes 37 dates from 12 components and 10 sites (Table 1). Of these, 29 dates are on bone collagen, three are on calcined bone, and five are on charcoal from hearth features. Sites with reliable dates are Agate Basin, Carter/Kerr-McGee, Hell Gap, and Hanson in Wyoming; Waugh, Badger Hole and all three components of Cooper in Oklahoma; Barger Gulch Locality B and Mountaineer in Colorado; and Folsom in New Mexico. Our process for date selection notably eliminates a number of sites from which additional dates are available including Black Mountain, Blackwater Draw, MacHaffie, the Lake Iló sites, and Lindenmeier. At present, none of these sites has high-quality bone or hearth charcoal dates.

2.3 Calibration and averaging methods
We calibrated all dates using OxCal version 4.2 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013). We report calibrated dates as 1σ ages with means and standard deviations as shown in Table 1. We averaged all calibrated dates from each site or component using the Long and Rippeteau (1974) method. Site-averaged dates are presented in Table 2.

3. Results
3.1 New dates from the Hanson site
As part of a project to analyze previously unexamined materials recovered during water screening in the 1970s excavations, we identified several lots of calcined bone of sufficient quantity for radiocarbon dating. It should be noted that we do not know with certainty if these samples are associated with hearth features, but we assume that they were burned during the Folsom occupation. We feel confident in that assumption since the probability of bone becoming calcined is much higher in a hearth than in a natural fire (Buenger 2003). In all, we submitted three samples to the University of Arizona AMS Laboratory. We submitted two samples from the central excavation block in Area 2; those samples produced dates of 10,626 ± 77 (AA-106384) and 10,600 ± 77 (AA-106385) 14C yr BP. A third sample taken from two adjacent one-foot squares from the northwestern excavation block of Area 2 dated to 10,688 ± 77 14C yr BP (AA-106386). All three dates are statistically indistinguishable and after calibration and averaging, suggest an age for the Folsom occupation at Hanson of 12,605 ± 45 cal yr BP. This is approximately 600 years older than the prior age estimate for the site, and as we argue below, it makes Hanson one of oldest, if not the oldest, known Folsom site. The variation seen in the entire set of dates from the Hanson site serves nicely as a microcosm of the problems inherent to dating the Folsom complex as a whole.

3.2 New date from Hell Gap
We submitted a bone sample from the Folsom component at Locality I of Hell Gap to the University of Arizona AMS Laboratory where the collagen fraction was isolated using the ultrafiltration method. This sample, collected by Vance Haynes in June of 1964, produced an age of 10,490 ± 62 14C yr BP (AA-77592UF) or 12,412 ± 127 cal yr BP, which would place the Folsom component at Locality I of Hell Gap roughly in the middle of the Folsom age range,
though it is important to note that this is a single date and has a fairly large standard deviation. Based on this date it would be difficult to argue that Hell Gap is positioned spatio-temporally near to the origin of the Folsom complex, although one might be able to make that argument for Hanson.

### 3.3 Folsom in time

For the entirety of our sample, Folsom dates range in age from 10,135 ± 45 to 10,780 ± 120 14C yr BP, or 11,809 ± 91 to 12,699 ± 116 cal yr BP after calibration (Table 1 and Figure 1). That range, however, is expanded greatly by the two oldest dates and the youngest date in the sample. If those ages are excluded, the great majority of Folsom dates (91.9 per cent of our sample) falls within a much narrower range of 10,295 ± 50 – 10,688 ± 77 14C yr BP, or 12,078 ± 72 – 12,631 ± 63 cal yr BP. Notably, the two oldest dates in the sample are charcoal dates from hearth features at Barger Gulch (10,770 ± 70 14C yr BP, Beta-173385) and Agate Basin (10,780 ± 120 14C yr BP, SI-3733) and may be affected by the old wood problem. In other words, Folsom peoples were likely burning Clovis-aged wood. This is almost certainly

#### Table 1

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample number</th>
<th>Material</th>
<th>14C age</th>
<th>14C σ</th>
<th>Cal age</th>
<th>Cal σ</th>
<th>Reference</th>
</tr>
</thead>
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<td>Collagen</td>
<td>10,450</td>
<td>50</td>
<td>12,348</td>
<td>124</td>
<td>Meltzer (2006)</td>
</tr>
<tr>
<td>Folsom</td>
<td>CAMS-74658</td>
<td>Collagen</td>
<td>10,450</td>
<td>50</td>
<td>12,348</td>
<td>124</td>
<td>Meltzer (2006)</td>
</tr>
<tr>
<td>Folsom</td>
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<td>Collagen</td>
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<td>86</td>
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</tr>
<tr>
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<td>12,462</td>
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<td>50</td>
<td>12,478</td>
<td>88</td>
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</tr>
<tr>
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<td>Collagen</td>
<td>10,520</td>
<td>50</td>
<td>12,478</td>
<td>88</td>
<td>Meltzer (2006)</td>
</tr>
<tr>
<td>Hanson</td>
<td>AA-106384</td>
<td>Calcined bone</td>
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<td>12,584</td>
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<tr>
<td>Hanson</td>
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<td>Calcined bone</td>
<td>10,600</td>
<td>77</td>
<td>12,558</td>
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<tr>
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<td>AA-106386</td>
<td>Calcined bone</td>
<td>10,688</td>
<td>77</td>
<td>12,631</td>
<td>63</td>
<td>This paper</td>
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<td>Hell Gap</td>
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<td>Collagen</td>
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<td>Mountaineer</td>
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<td>Collagen</td>
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<td>50</td>
<td>12,329</td>
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</tr>
<tr>
<td>Mountaineer</td>
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<td>Collagen</td>
<td>10,295</td>
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the case for the Barger Gulch date because another charcoal sample from the same feature yielded a date almost 300 calendar years younger \((10,470 \pm 40 \text{ yr BP, Beta-173381})\). On the opposite end of the spectrum, a recent bone date from Agate Basin \((10,135 \pm 25 \text{ yr BP, UCIAMS-122571})\) reported by Carlson (2015) stands as a clear outlier in the sample (Figure 1). This date might be affected by contamination or could be intrusive from the overlying Agate Basin component at the site.

By averaging multiple dates from sites or components, measurement error in mean age estimates and standard deviations are reduced. The averages we report include all of the dates, even those that appear to be outliers. After averaging, the age range represented by Folsom is shortened even more (Table 2 and Figure 2). The youngest Folsom component in the sample is from the Badger Hole site in Oklahoma at \(12,169 \pm 49 \text{ cal yr BP}\), and the oldest is Barger Gulch Locality B in Colorado at \(12,644 \pm 43 \text{ cal yr BP}\). If the older date from Barger Gulch is omitted, Hanson is the oldest site in the sample, dating to \(12,605 \pm 45 \text{ cal yr BP}\). Using the dates from Badger Hole and Hanson, therefore, the Folsom complex was at least \(\sim 440\) years in length and spanned the time period from approximately \(12,610\) to \(12,170\) cal yr BP. This is considerably shorter than the estimates provided by Haynes et al. (1992) and Holliday (2000a). Haynes et al. (1992), for example, estimated the Folsom period to have lasted \(\sim 780\) years from \(12,780\) to \(12,000\) cal yr BP.

Of course, a sample of dates from only 12 sites is unlikely to represent the entirety of the age range encompassed by the Folsom complex (Prasciunas and Surovell 2015). To refine the 436-year time span represented by the mean age difference between Hanson and Badger Hole, we performed a simple Monte Carlo experiment to allow an error estimate to be placed on our estimate of the Folsom time span. We drew 12 random ages from uniform distributions of hypothetical age ranges spanning 440–1000 years in

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**Figure 1** All high-quality calibrated radiocarbon dates from Folsom contexts plotted in rank order. Boxes indicate one sigma age ranges, and whiskers show two sigma age ranges. Gray boxes are bone dates and black boxes are charcoal dates.

**Figure 2** Site-averaged calibrated radiocarbon dates from Folsom contexts. Boxes indicate the one sigma calibrated age ranges, and whiskers show the two sigma calibrated age ranges.
10-year increments and examined the dated ranges of dates that resulted. Each experiment was repeated 10,000 times. We calculated probability as the percentage of randomized date ranges for which the difference between the oldest and youngest randomized dates was less than or equal to 436 years. In other words, we are examining the likelihood of observing an age range of 436 years or less in a sample of 12 sites from a phenomenon that actually lasted anywhere between 440 and 1000 years. We found that the Folsom complex might have lasted as long as 660 years (Supplementary Figure 1), but longer time spans are unlikely ($P < 0.05$). Furthermore, an observed age range of 436 years for this sample size is typical of a phenomenon that persisted for approximately 510 years (Supplementary Figure 2). In other words, with larger samples the time span represented by Folsom will undoubtedly increase but not significantly. At most, it will be expanded by around 200 years.

3.4 Correlation with the Younger Dryas, the end of Clovis, and megafaunal extinction

It is well known that the Folsom complex correlates in time with the Younger Dryas climatic event. That said, based on high resolution analysis of the Greenland NGRIP ice core, Younger Dryas cooling in the North Atlantic lasted approximately 1200 years from 12,850 to 11,650 cal yr BP (Steffensen et al. 2008), so it would be difficult to argue at this point in time that changes in material culture seen in Folsom compared to Clovis (e.g., changes in projectile point manufacture) are related to Younger Dryas climate change, as the oldest Folsom sites in our sample date to roughly 240 years after the onset of the Younger Dryas. Additionally, the Folsom period appears to have ended some 500 years before climatic warming at the end of the Younger Dryas. In other words, while Folsom hunter–gatherers had to cope with the climates of the Younger Dryas, there is no clear correlation between climate change and changes in material culture as reflected by the start or end of the Folsom complex (see Eren 2012; Melzer and Holliday 2010). Haynes has also noted that black mats and other contemporaneous sediments and soils with which Folsom components are often associated correlate in time with the Younger Dryas (Haynes 2008; c.f. Holliday et al. 2011; Taylor et al. 1996). If these deposits, as Haynes (2008) has argued, began accumulating at ca. 10,800 $^{14}$C yr BP, this is equivalent to a calendar age of approximately 12,700 cal yr BP (Figure 3). In other words, black mats may have begun accumulating roughly 150 years after the onset of the Younger Dryas. In fairness, much of this difference in interpretation results from improvements in the radiocarbon calibration curve for the terminal Pleistocene. Over the last 17 years, from IntCal98 to the IntCal13 calibration curves, a radiocarbon age of 10,800 $^{14}$C yr BP has decreased in calendar age from ca. 12,850 cal yr BP, at the start of the Younger Dryas, to 12,710 cal yr BP, almost 140 years after it.

Of similar age to the onset of black mat deposition are the youngest Clovis sites (Haynes 2008; Waters and Stafford 2007). The youngest well-dated Clovis site is Jake Bluff, from which five high-quality bone collagen dates are available (Bement and Carter 2010). Using our calibration and averaging methods, the age of Jake Bluff is 12,714 ± 11 cal yr BP, or approximately 100 years older than the Hanson site. Based on our reanalysis of Folsom radiocarbon dates, there is an apparent 100-year gap between Clovis and Folsom. Given our error analysis above, the simplest explanation for this gap is sample size in the statistical sense (Prasciunas and Surovell 2015). With increased numbers of dated sites, this gap will shrink and theoretically disappear entirely. For example, eliminating this gap could be accomplished by adding only 50 years to each of the Clovis and Folsom time ranges, and it is likely that this will happen as more Clovis and Folsom components are dated, possibly even with the sample of sites that have already been excavated. Nonetheless, from a statistical point of view, the apparent lack of chronological overlap between these two cultural complexes at current sample sizes would suggest that the transition between the two was likely rapid and abrupt (Taylor et al. 1996). It is also interesting to note the youngest dates on extinct Pleistocene megafauna correlate well in time with the youngest Clovis sites (Waters et al. 2015). In Figure 3, we plot our revised age range for Folsom relative to Clovis, the Younger Dryas, and the youngest dates on Pleistocene megafauna. It is now apparent that the Clovis-Folsom transition occurred at least a century after the onset of the Younger Dryas, as did Pleistocene extinction. In other words, strong climatic forcing of either of the Clovis-Folsom transition or megafaunal extinction seems unlikely, unless a lag effect was at play. The observed lag between the start of the Younger Dryas as recorded in Greenland ice cores, and the accumulation of black mats (Haynes 2008) might suggest that such a lag was in effect, also supported by the idea that the cooling at the onset of the YD was gradual, lasting some 200 years (Steffensen et al. 2008).

4. Discussion and conclusions

Several years ago, Waters and Stafford (2007) published a revised chronology for the Clovis complex based on a series of high-quality and site-averaged radiocarbon dates. Their primary conclusion was that dates on Clovis appeared to be highly clustered in time, and that the duration of the Clovis complex was considerably shorter than what was previously
believed. In this paper, we have undertaken a similar exercise and come to similar conclusions. Our methods for culling high from low quality radiocarbon dates are different from those of Waters and Stafford (2007), but our results are similar. In particular, we have excluded all radiocarbon dates on charcoal, except for those associated with hearth features. Radiocarbon dates on charcoal have been the bread and butter of Paleoindian geochronology for more than 60 years, but there is good reason to believe that many charcoal dates in stratigraphic association with archaeological occupations are in error. Instead of directly dating Folsom occupations, many charcoal dates are likely dating the litho—and pedostratigraphic units associated with those occupations. With improvements in pretreatment methods coupled with isotopic counting by accelerator mass spectrometry, bone dating is becoming the gold standard for the field, whether in dating collagen or calcined bone apatite. By limiting our sample to high-quality bone dates and only charcoal samples associated with hearth features, we suggest a limited age range for Folsom of at least 440 years from 12,610 to 12,170 cal yr BP, but we expect that age range to expand somewhat, likely on both margins.

There are a number of reasons why this new chronology is significant. It seems that the transition from Clovis to Folsom in western North America post-dated the onset of the Younger Dryas stadial significantly. The Younger Dryas also persisted well after the last Folsom point was manufactured, perhaps for as much as another 500 years. With our revised chronology, there is a gap between Clovis and Folsom of approximately 100 years, although we are confident that it will be eliminated as larger samples of both kinds of sites are dated. Finally, the Clovis-Folsom transition appears to correlate in time with the last of the Pleistocene megafauna.

Given that this paper was inspired by several dozen fragments of calcined bone found in vials containing materials pulled from 1/16-in. screens at the Hanson site in the 1970s and a bone sample collected at Hell Gap in 1964, it would be prudent to emphasize that there is considerable opportunity for additional dating of Folsom and other collections already on hand. Thousands of bone samples that could be dated are sitting in laboratories and curation facilities across the country. Thirty years ago, we could not regularly produce accurate radiocarbon dates from those samples, but now we can. Carlson’s (2015) recent efforts to date bone collagen from Folsom sites in combination with our new dates from Hanson and Hell Gap in large part made this study possible, and we hope to see similar efforts in the near future, which will undoubtedly improve upon our contribution to Folsom geochronology.

Figure 3  Our revised age range for Folsom and the end of Clovis (hatched polygons) plotted on the IntCal13 calibration curve (Reimer et al. 2013) relative to the Younger Dryas stadial (gray polygon) and youngest dates on Pleistocene megafauna (thick black line).
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References


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