ANTHROPOLOGY

The age of Clovis—13,050 to 12,750 cal yr B.P.

Michael R. Waters[1,2]*, Thomas W. Stafford Jr.[3]*, David L. Carlson[1]

Thirty-two radiocarbon ages on bone, charcoal, and carbonized plant remains from 10 Clovis sites range from 11,110 ± 40 to 10,820 ± 10 ^{14}C years before the present (yr B.P.). These radiocarbon ages provide a maximum calibrated (cal) age range for Clovis of ~13,050 to ~12,750 cal yr B.P. This radiocarbon record suggests that Clovis first appeared at the end of the Allerød and is one of at least three contemporary archaeological complexes in the Western Hemisphere during the terminal Pleistocene. Stemmed projectile points in western North America are coeval and even older than Clovis, and the Fishtail point complex is well established in the southern cone of South America by ~12,900 cal yr B.P. Clovis disappeared ~12,750 cal yr B.P. at the beginning of the Younger Dryas, coincident with the extinction of the remaining North American megafauna (Proboscideans) and the appearance of multiple North American regional archaeological complexes.

INTRODUCTION

For decades, Clovis was considered to represent the basal archaeological horizon in North America and that later technologies in North and South America were believed to be derived from it. Clovis is characterized by a tool assemblage that includes bifaces and a distinctive lanceolate fluted projectile point, blade cores and blades, and osseous points and tools (*1*–*3*). The belief that Clovis tools were left behind by the first people to enter the Americas has changed with the discovery of sites predating Clovis in North and South America, and genetic studies that show North America was occupied a few millennia before Clovis appeared on the landscape (*4*).

That said, dating archaeological sites of the Clovis complex is important to understand how Clovis fits into the process of the Late Pleistocene settlement of the Americas and the extinction of megafauna. In 2007, Waters *et al.* (*5*) evaluated the radiocarbon ages reported from Clovis sites and generated new, accurate, and precise age measurements for many sites. Their evaluation included 11 Clovis sites with 43 radiocarbon ages and concluded that Clovis occupied a narrow time window between ~13,000 and ~12,600 calendar years before the present (cal yr B.P.). This generated much discussion about the age and duration of Clovis. Computer simulations and age estimates from five sites were championed to show that Clovis appeared before 13,000 cal yr B.P. This led to the formulation of a "long" chronology for Clovis (*2*), variously reported as 13,495–13,400 to 12,700 cal yr B.P. (*6*), 13,400 to 12,700 cal yr B.P. (*3*), and 13,500 to 12,500 cal yr B.P. (*7*). Some researchers (*2*) suggest that the duration of Clovis could have been as long as 1500 years, based on model simulations in (*8*); if so, Clovis first appeared over 14,000 years ago.

Since 2007, additional radiocarbon ages have been generated from different sites, and new information is available for some of the sites that we previously evaluated. New radiocarbon ages are available for Sheriden Cave, Ohio; Cactus Hill, Virginia; La Prele, Wyoming; Dent, Colorado; Shawnee-Minisink, Pennsylvania; Jake Bluff, Oklahoma; Anzick, Montana; and Blackwater Draw, New Mexico. New information on the radiocarbon ages and site geology is available for Lange-Ferguson, South Dakota; Paleo Crossing, Ohio; and Murray Springs, Arizona.

There also have been major advances in the chemical pretreatment and physical measurement of radiocarbon samples since 2007—advances that have improved the accuracy and precision of radiocarbon measurements. Furthermore, radiocarbon calibration, especially for the Clovis time period, has gone through major changes. Calibrated ages reported in 2007 were based on a provisionally anchored European tree-ring chronology in IntCal04 that replaced a large portion of the calibration curve previously based on ^{14}C-dated marine foraminifera. Three radiocarbon calibration iterations later, we can now accurately calibrate Clovis ages using the IntCal20 database, where the Clovis time period is calibrated directly on dendrochronological derived ages (*9*). These combined improvements allow us to evaluate the radiocarbon ages associated with Clovis sites and provide a revised age range for Clovis based on credible radiocarbon ages. The primary objective of this paper is to reassess the age and duration of Clovis based on the most current information and best radiocarbon dating practices for individual Clovis sites.

RESULTS

Credible radiocarbon ages

We define samples providing "credible" ages as bone, ivory, teeth, antler, and wood and charcoal, whose radiocarbon dates pass rigorous considerations of site formation and geological context, sample type, level of purification chemistry used, and the physics of the ^{14}C measurement. The radiocarbon sample must come from an undisturbed geological context. If bone, it must be in close association with artifacts. If charcoal, the sample should preferably come from a human-made feature such as a hearth. Ideally, dates from bounding strata would bracket and confirm the age of the site. Equally important is identifying erroneous stratigraphic associations created by time averaging, deflation, and the formation of palimpsests as fossils and artifacts accumulate on surfaces having no deposition for years.

Sample type determines what level of chemical purification is possible, if the sample's carbon accumulated over short or long periods of time, and how closely the material can be linked to the presence of humans. Wood can be purified and foreign debris eliminated by isolating α-cellulose. Hard, well-carbonized charcoal is wet oxidized with hot nitric acid or chromic acid–sulfuric acid mixtures that oxidize nonelemental carbon such as rootlets, chitin, humins,

[1]Department of Anthropology, Texas A&M University, College Station, TX 77843-4352, USA. [2]Center for the Study of the First Americans, Texas A&M University, College Station, TX 77843-4352, USA. [3]Stafford Research Laboratories, 200 Acadia Avenue, Lafayette, CO 80026-1845, USA.
*Corresponding author. Email: mwaters@tamu.edu (M.R.W.); twstafford@stafford-research.com (T.W.S.J.)

and similar organic compounds that are not removed during routine acid-base-acid treatment. For both wood and charcoal, identification to genus or species is a prerequisite whenever possible because accurate taxonomic attribution to a terrestrial or aquatic origin helps assess if reservoir effects may be an issue. Osseous materials such as bone, antler, teeth, and ivory yield the protein collagen that is purified using multiple chemical steps that culminate in isolation and dating of XAD-purified total amino acids or the specific amino acid hydroxyproline (*10*). Each of these sample groups yields radiocarbon dates that are accurate because either a specific compound can be isolated (α-cellulose or an amino acid) or the rigorous nature of the chemical purification precludes contaminants remaining in the sample.

In contrast, ^{14}C dates on sediments, soils, shells, and carbonized organic matter are not suitable for accurate dating of short-interval archaeological technologies or cultures. Soils and sediments are dated using at least five different chemical fractions—bulk soil or sediment, fulvic acids, humic acids, humins, or entrained charcoal ranging from a few micrometers to 1- to 2-mm diameter. Obtaining valid ^{14}C ages from sediments and soils is hindered, if not precluded by residence time effects, sedimentary reworking of older deposits, reservoir effects in pond and marsh environments, pedogenic overprinting from overlying soils, vertical movement of humates, and bioturbation by fossorial animals and deeply rooted plants.

Terrestrial and aquatic mollusk shells are susceptible to postdepositional carbonate exchange with groundwaters that may have ancient, geological (limestone/dolomite) origins or CO_2 and carbonic acids in modern rainwater. $CaCO_3$ in both terrestrial and aquatic mollusk shells can have ^{14}C ages different from their time of death due to aquatic reservoir effects and the animal's diet. While shell protein, conchiolin, can be dated to avoid postdepositional carbonate exchange, the protein's ^{14}C age is still affected by aquatic reservoir effects.

Carbonized organic material commonly occurs in pond, lake, and marsh environments due to the bacterial and fungal decomposition of plant and animal matter under anaerobic conditions. With the exception of infrequent leaves, twigs, and similar morphologically distinct remains, typical carbonized organic matter is not taxonomically identifiable and is often erroneously attributed to human activity rather than natural diagenetic processes. In addition, determining if aquatic reservoir effects cause the plant matter to date older than its actual age is virtually impossible. Only crude estimates of reservoir effects are measurable when modern groundwaters are tested, and even then, relating modern groundwater compositions to those thousands of years ago is futile.

As described previously, some sample types can be dated more accurately than others because specific compounds or molecular components can be isolated. Osseous materials—bone, teeth, antler, and ivory—are especially useful for providing the most direct, accurate, and precise chronologies for Clovis or any other archaeological and paleontological discovery. Collagen is unique because its identification and purification follow well-established protocols based on molecular biology. Quantitative amino acid and liquid chromatography–tandem mass spectrometry (LC-MS/MS) analyses establish that the protein collagen is present. Sequential, methodical chemical purification assures that scores of geological and preservation contaminants are removed and that the final ^{14}C date is on one or more molecular fractions unique to bone collagen.

The isolation, purification, and ^{14}C dating of bone collagen has been well described in (*10*–*12*). The minimum level of collagen purification must be either the 0.45-μm filtration or ultrafiltration (>30 kDa) of gelatin derived from decalcified collagen leached with alkali (NaOH or KOH) (*10*). Any lesser purification is unacceptable, and the resulting data cannot be used for chronologies. The goal should be the ^{14}C dating of either collagen amino acids purified through XAD-2 resins or by using the ultimate gold standard of purity, the amino acid hydroxyproline (*10*, *12*). In contrast, bone apatite will not yield accurate radiocarbon dates because the inorganic CO_3^{-2} in bone bioapatite (carbonate hydroxy calcium phosphate) readily exchanges with carbonates and bicarbonates in groundwaters, springs, and rainfall. These sources have unknown proportions of geologically ancient and modern carbon depending on the geological and atmospheric source of the $CaCO_3$, HCO_3^{-2}, and CO_2.

The final component of a ^{14}C date's credibility and use in Clovis dating and other research is the physics of the ^{14}C measurement. While the chemical purification controls the accuracy of a date by removing exogenous carbon, the physics of the measurement controls accuracy by the use of standards, backgrounds, and blanks; precision is based exclusively on sample size and the ion source's behavior and efficiency—the number of ^{14}C ions counted.

Standards and backgrounds should ideally comprise known-age and infinitely old (>60,000 cal yr B.P.) materials that are identical to the sample type being dated. Bone, teeth, ivory, chitin, wood, charcoal, shell, humates, and all other sample types dated should have known-age and background materials that are subjected to the same chemistry as the unknown sample. Laboratory reports should state the ^{14}C measurements on these accessory materials and if backgrounds or known-age materials are different than the unknown.

Precision is based on the number of ^{14}C ions counted, and other than causing longer or shorter calibration ranges, it has no effect on accuracy. Samples that approach the practical limit of ^{14}C dating (~48,000 to 52,000 cal yr B.P. depending on sample type), ones yielding <50 μg (0.05 mg) of carbon and ones ionized in the cesium source for a short time or in a less efficient ion source will all have larger errors. AMS targets containing large (>0.5 to 1.0 mg) amounts of graphitized carbon will yield high precision results (±10 to 30 years) regardless of the actual purity and chemical specificity of the material. High-precision measurements are due to counting statistics, not chemical purity. Due strictly to constant improvements in accelerator mass spectrometry since its inception in 1978–1980, overall precision has improved enormously, with Clovis-age (11,000 ^{14}C yr B.P.) samples having precisions of ±400 to 500 years in 1982 (*11*, *13*) compared with ±20 to 30 years in 2020 (e.g., *14*).

Clovis radiocarbon record

To determine an accurate age for Clovis, we must first determine if a dated Late Pleistocene site is Clovis. The only way unequivocally to identify Clovis at a site is by the presence of its diagnostic projectile point—a lanceolate point with a concave base and distinctive basal flute scars. Clovis points are distinct from later fluted point forms (e.g., Barnes, Gainey, and Redstone) based on their morphology, flaking patterns, and the methods used to make them. Here, we define a Clovis point as having the characteristics specified in (*1*). If a Clovis projectile point is not present at a site, the site cannot be unequivocally assigned to Clovis. For example, the presence of overshot debitage or bifaces with overshot flake scars commonly associated with Clovis technology (*1*) is not by itself diagnostic of Clovis (*15*). Sites that date to the Clovis time period but lack a Clovis point are here designated "Clovis-age" sites, and these are described in (*5*).

The radiocarbon record for Clovis is divided into two categories: those sites with credible radiocarbon ages and those sites with equivocal radiocarbon ages. As discussed in the previous section, the credibility of a ^{14}C date and whether or not it is included in our analysis is strictly based on physical and quantitative data—the archaeology, geology, chemistry, and physics for each radiocarbon measurement. Previous age determinations for Clovis and preference for a long or short chronology have no effect on our conclusion.

We have used a maximum one-sigma precision of ±100 radiocarbon years as the largest acceptable SD when evaluating the age of Clovis. This precision applied for the period between 11,000 and 10,800 ^{14}C yr B.P. yields calibrated dates with ranges between 150 and 230 calendar years. In our sample, the SDs of 29 of the 32 radiocarbon ages at one sigma range from ±25 to ±50 years, and the remaining 3 ages have one-sigma SDs ranging from ±55 to ±90 years. Ideally, precisions on all Clovis radiocarbon ages should be ±25 to 30 radiocarbon years for this time period, which translates to calibrated dates with ranges between 25 and 130 years. Basing a credible date on one-sigma precisions of ±100 years or less forces us to delete many radiocarbon dates, regardless if they pass all other standards for credibility. In the future, researchers should strive to determine the age of Clovis only using ages with one-sigma precisions of ±25 to 30 radiocarbon years.

Clovis sites with credible radiocarbon ages

Clovis sites with credible radiocarbon ages include Lange-Ferguson, South Dakota; Dent, Colorado; Domebo, Oklahoma; Shawnee-Minisink, Pennsylvania; Sheriden Cave, Ohio; La Prele, Wyoming; Colby, Wyoming; Jake Bluff, Oklahoma; Anzick, Montana; and Cactus Hill, Virginia (Fig. 1). At each of these sites, Clovis projectile points occur in a geological context that is accurately dated. From these sites, a total of 32 radiocarbon dates have been generated. Five ages are derived from hearth charcoal, 6 ages from carbonized plant remains from hearths, 4 from bone artifacts, 1 from human bone, and 16 from animal bone and teeth associated with Clovis artifacts (Table 1).

Lange-Ferguson, South Dakota

New information for the Lange-Ferguson site provides a better understanding of its age. Charcoal dated to 11,140 ± 140 ^{14}C yr B.P. (AA-905) and reportedly from the Clovis horizon (*16*) actually was from stratum C, 10 cm above the mammoth bones, and thus post-dates the Clovis occupation (*17*). Only the two ages on XAD-purified collagen from two different mammoth bones found with artifacts in stratum B_3 date the Clovis activity at the site. These ages are 10,710 ± 130 ^{14}C yr B.P. (UCIAMS-11344) and 11,110 ± 40 ^{14}C yr B.P. (UCIAMS-11345). The age with the large SD (UCIAMS-11344) is disregarded in favor of the age with the lower SD. This equates to an age of 13,095 to 12,990 cal yr B.P. for Lange-Ferguson.

Dent, Colorado

In 2007, two XAD-purified collagen ages on mammoth bone associated with Clovis artifacts provided the best age estimate for the Clovis activity at the Dent site (*5*). Since then, an XAD-purified collagen age of 10,960 ± 35 ^{14}C yr B.P. (UCIAMS-116403) (*18*) and two ages on hydroxyproline of 11,055 ± 50 ^{14}C yr B.P. (OxA-X-2736-11) and 11,155 ± 50 ^{14}C yr B.P. (OxA-X-2736-12) (*10*) were obtained on the same bone. These five ages average 11,010 ± 15 ^{14}C yr B.P. or 12,970 to 12,845 cal yr B.P.

Domebo, Oklahoma

Most radiocarbon ages from the Domebo site provide bracketing dates for this Clovis site. A single date of 10,960 ± 30 ^{14}C yr B.P. (UCIAMS-11341) or 12,905 to 12,820 cal yr B.P. was obtained on XAD-purified collagen from mammoth bone directly associated with the Clovis artifacts from this site (*5*).

Shawnee-Minisink, Pennsylvania

Previously, five radiocarbon ages on charred hawthorn (*Crataegus* sp.) seeds from two hearths associated with Clovis artifacts were reported for the Shawnee-Minisink site (*5*, *19*). One additional date of 10,970 ± 50 ^{14}C yr B.P. (OxA-1731) on seeds from a hearth close to a Clovis projectile point is reported (*19*). This new date overlaps the five other reported hawthorn seed ages at one sigma. The average of all six ages from the site is 10,940 ± 15 ^{14}C yr B.P. or 12,885 to 12,770 cal yr B.P.

Sheriden Cave, Ohio

In 2007, there were no ages directly associated with the Clovis artifacts from Sheriden Cave (*5*). Bracketing ages placed the Clovis artifacts between five radiocarbon ages averaging 10,600 ± 30 ^{14}C yr B.P. (12,685 to 12,620 cal yr B.P.) and two radiocarbon ages averaging 10,920 ± 50 ^{14}C yr B.P. (12,880 to 12,760 cal yr B.P.) (*5*, *20*). To directly date the Clovis assemblage, a ^{14}C measurement on XAD collagen from one of the two bone projectile points associated with the Clovis lithic projectile point and other tools dated 10,915 ± 30 ^{14}C yr B.P. (UCIAMS-38249) and calibrates to 12,830 to 12,770 cal yr B.P. (*20*).

La Prele, Wyoming

Clovis artifacts are associated with mammoth bones at the La Prele (formerly named Fetterman) site, Wyoming (*21*). Fourteen radiocarbon ages have been obtained from the site, but only two of those dates provide an accurate age for the Clovis occupation. Contamination issues plague the other 10 dated samples—four dates on humins range from 10,323 ± 39 to 10,969 ± 52 ^{14}C yr B.P. (D-AMS-4329; AA-105498), three dates on unpurified mammoth bone collagen range from 8890 ± 60 to 10,760 ± 30 ^{14}C yr B.P. (CAMS-74661; UCIAMS-40174), two apatite ages on mammoth bone are 11,190 ± 130 and 13,997 ± 90 ^{14}C yr B.P. (AA-107104; AA-109297), and three ages on ultrafiltered collagen from mammoth bone range from 10,654 ± 58 to 11,066 ± 61 ^{14}C yr B.P. (AA-108894; AA-108893) (*21*). The ages we consider accurate are 10,965 ± 30 ^{14}C yr B.P. (UCIAMS-206764) on XAD-purified bone collagen and 11,035 ± 50 ^{14}C yr B.P. (OxA-X-2736-14) on hydroxyproline (*10*) derived from mammoth bone. These two ages average 10,985 ± 25 ^{14}C yr B.P. or 12,915 to 12,835 cal yr B.P. and, finally, provide an accurate age for the La Prele Clovis site.

Colby, Wyoming

Two radiocarbon ages averaging 10,870 ± 20 ^{14}C yr B.P. or 12,820 to 12,800 cal yr B.P. were obtained on XAD-purified collagen from mammoth bone associated with bone pile 2 and Clovis artifacts (*5*).

Jake Bluff, Oklahoma

In addition to the three radiocarbon ages on XAD-purified collagen from bison bones associated with Clovis artifacts at the site reported in 2007 (*5*), two additional XAD-purified collagen dates on bison were published (*22*). These five ages average 10,820 ± 10 ^{14}C yr B.P. or 12,755 to 12,745 cal yr B.P.

Anzick, Montana

In 2007, the most reliable age for the ochre-stained Anzick-1 human cranium was an XAD-purified collagen date of 10,705 ± 35 ^{14}C yr BP (CAMS-80538) (*5*). This age was younger than two dates on alkali-collagen from antler foreshafts associated with the human remains: 11,040 ± 60 ^{14}C yr B.P. (Beta-163832) and 11,040 ± 40 ^{14}C yr B.P. (Beta-168967) (*23*). These two dates should be considered minimum

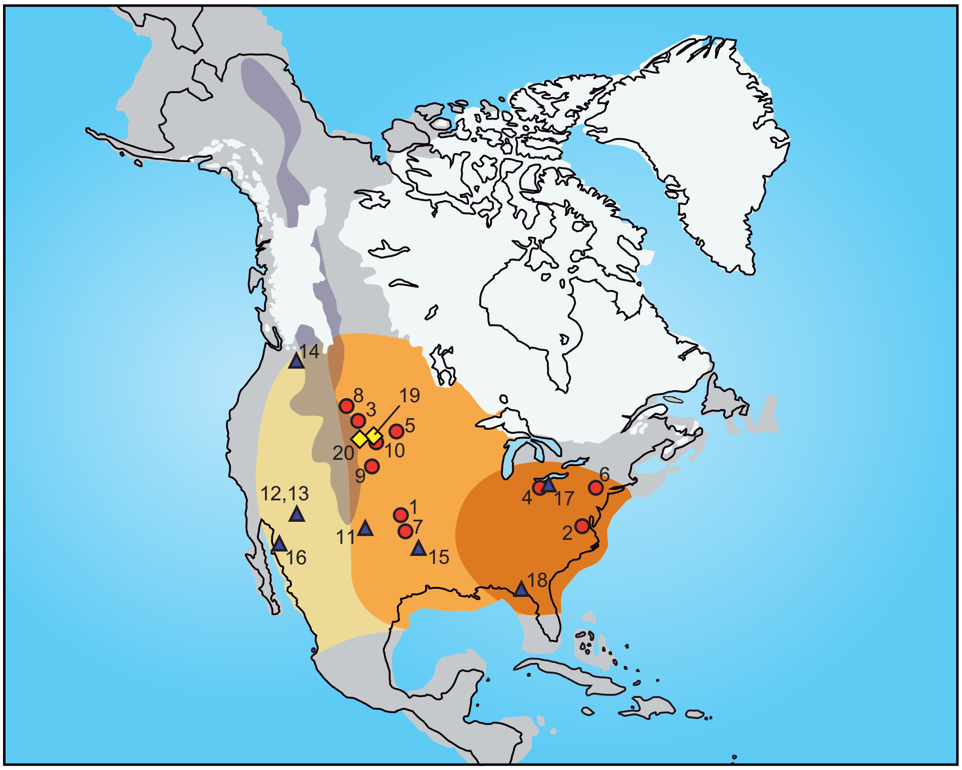

Fig. 1. Map of the location of dated Clovis sites. Clovis sites with credible ages (red circles): Jake Bluff, OK (1); Cactus Hill, VA (2); Colby, WY (3); Sheriden Cave, OH (4); Lange-Ferguson, SD (5); Shawnee-Minisink, PA (6); Domebo, OK (7); Anzick, MT (8); Dent, CO (9); La Prele, WY (10); Clovis sites with equivocal ages (blue triangles): Blackwater Draw, NM (11); Lehner, AZ (12); Murray Springs, AZ (13); East Wenatchee, WA (14); Aubrey, TX (15); El Fin Del Mundo, Mexico (16); Paleo Crossing, OH (17); Sloth Hole, FL (18). Dated sites proposed to be Clovis (yellow diamond): Casper, WY (19); Sheaman, WY (20). Color overlays on the North American map indicate high (brown), moderate (orange), and low (yellow) densities of Clovis occupations (*4*). Rocky Mountains (purple). Laurentide and Cordilleran Ice Sheets (white) at ~12,500 cal yr B.P. (*4*).

ages due to the low chemical specificity of alkali-collagen (*12*). In 2014, a new XAD-purified collagen age of 11,025 ± 30 ^{14}C yr B.P. (UCIAMS-61661) was reported for one of the antler foreshafts (*24*). In 2018, hydroxyproline isolated from two antler foreshafts yielded ages of 10,900 ± 50 ^{14}C yr B.P. (OxA-X-2739-55) and 11,050 ± 55 ^{14}C yr B.P. (OxA-X-2739-56) (*12*). These two ages overlap the XAD-derived antler foreshaft age at two sigmas. Hydroxyproline was also isolated from the Anzick-1 cranium and yielded an age of 10,915 ± 50 ^{14}C yr B.P. (OxA-X-2739-54) (*12*). This age is older than the XAD-derived age on the cranium by 210 radiocarbon years. The date on the hydroxyproline fraction should be considered the most accurate age for the human remains, and the XAD date should be disregarded. The reason for the failure of the XAD method to provide an accurate age for the human cranium is unknown, but could be due to the glue used to hold the cranial bones together or soaps used to remove ochre from the bones when first found. The new single–amino acid age on the human calvarium is now in agreement with the ages from the antler foreshafts and overlap by 1 SD. The average of the three foreshaft dates is 11,000 ± 25 ^{14}C yr B.P., which calibrates as 12,960 to 12,840 cal yr B.P. The calibrated age for the Anzick-1 cranium is 12,880 to 12,760 cal yr B.P. and indicates that the human remains and Clovis artifacts are contemporaneous. Averaging all four ages that overlap at one sigma yields a radiocarbon age of 10,985 ± 20 ^{14}C yr B.P., indicating that the Clovis burial occurred sometime between 12,905 and 12,840 cal yr B.P.

Cactus Hill, Virginia

Only one age, 10,920 ± 250 ^{14}C yr B.P. (Beta-81589) on hearth charcoal, was available from the Clovis horizon at the Cactus Hill site in 2007 (*5*, *25*). The large SD associated with this age precluded its use to accurately date the Clovis occupation at this site. Five new radiocarbon ages on charcoal from hearths and other features associated with the Clovis horizon are reported for the site (*25*). These ages are 10,860 ± 60 ^{14}C yr B.P. (Beta-266341), 10,840 ± 40 ^{14}C yr B.P. (Beta-233642), 10,810 ± 40 ^{14}C yr B.P. (Beta-233642), 10,890 ± 40 ^{14}C yr B.P. (Beta-233643), and 10,910 ± 40 ^{14}C yr B.P. (Beta-210651). The average of these five ages is 10,860 ± 20 ^{14}C yr B.P. or 12,820 to 12,745 cal yr B.P.

Equivocal radiocarbon-dated Clovis sites

In this section, we discuss sites where Clovis artifacts are found in secure geological contexts, but where the radiocarbon ages do not pass our testing criteria (Fig. 1). We have moved four sites—Murray Springs, Arizona; Lehner, Arizona; Paleo Crossing, Ohio; and Sloth Hole, Florida—from our previous list of well-dated Clovis sites (*5*) to equivocally dated sites because of a reexamination of the dates from them and new information about some of the sites. We also discuss the Aubrey site, Texas; El Fin Del Mundo site, Mexico; and Sheaman site, Wyoming, which are thought to be the oldest radiocarbon-dated Clovis sites. The East Wenatchee site, Washington, which is often cited as one of the oldest Clovis sites in North America (*26*), is not discussed. No radiocarbon dates have been obtained to substantiate

Table 1. Radiocarbon dates from Clovis sites.

Site	Date	Calibrated date	Laboratory number	Material dated	Remarks
	^{14}C yr B.P.	cal yr B.P.*			
Lange-Ferguson, SD	11,110 ± 40	13,095–12,990	UCIAMS-11345	Mammoth bone (XAD)	
Dent, CO	11,065 ± 35	13,075–12,930	UCIAMS-11339	Mammoth bone (XAD)	
	10,940 ± 30	12,885–12,770	UCIAMS-11340	Mammoth bone (XAD)	
	10,960 ± 35	12,905–12,780	UCIAMS-116403	Mammoth bone (XAD)	
	11,055 ± 50	13,070–12,925	OxA-X-2736-11	Mammoth bone (hydroxyproline)	
	11,155 ± 50	13,160–13,005	OxA-X-2736-12	Mammoth bone (hydroxyproline)	
Average	11,010 ± 15	12,970–12,845			
Domebo, OK	10,960 ± 30	12,905–12,820	UCIAMS-11341	Mammoth bone (XAD)	
Shawnee-Minisink, PA	10,940 ± 90	12,960–12,755	Beta-101935	Carbonized Hawthorn seed (*Crataegus*)	Hearth
	10,900 ± 40	12,830–12,760	Beta-127162	Carbonized Hawthorn seed (*Crataegus*)	Hearth
	10,820 ± 50	12,815–12,730	Beta-203865	Carbonized Hawthorn seed (*Crataegus*)	Hearth
	10,915 ± 25	12,830–12,770	UCIAMS-24865	Carbonized Hawthorn seed (*Crataegus*)	Hearth
	11,020 ± 30	13,050–12,850	UCIAMS-24866	Carbonized Hawthorn seed (*Crataegus*)	Hearth
	10,970 ± 50	12,925–12,770	OxA-1731	Carbonized Hawthorn seed (*Crataegus*)	Hearth
Average	10,940 ± 15	12,885–12,770			
Sheriden Cave, OH	10,915 ± 30	12,830–12,770	UCIAMS-38249	Bone (XAD)	Bone point
La Prele, WY	11,035 ± 50	13,065–12,900	OxA-X-2736-14	Mammoth bone (hydroxyproline)	
	10,965 ± 30	12,910–12,825	UCIAMS-206764	Mammoth bone (XAD)	
Average	10,985 ± 25	12,915–12,835			
Colby, WY	10,790 ± 30	12,750–12,735	UCIAMS-11342	Mammoth bone (XAD)	Bone pile 2
	10,950 ± 30	12,895–12,775	UCIAMS-11343	Mammoth bone (XAD)	Bone pile 2
Average	10,870 ± 20	12,820–12,800			
Jake Bluff, OK	10,750 ± 40	12,745–12,720	CAMS-79940	Bison tooth (XAD)	
	10,840 ± 45	12,820–12,735	CAMS-90968	Bison bone (XAD)	
	10,700 ± 45	12,735–12,690	CAMS-90969	Bison bone (XAD)	
	10,810 ± 25	12,755–12,740	UCIAMS-61657	Bison bone (XAD)	
	10,885 ± 35	12,820–12,760	UCIAMS-59874	Bison bone (XAD)	
Average	10,820 ± 10	12,755–12,745			
Anzick, MT	10,915 ± 50	12,880–12,760	OxA-X-2739-54	Human bone (hydroxyproline)	Anzick-1 cranium
	11,025 ± 30	13,055–12,895	UCIAMS-61661	Elk (XAD)	Foreshaft
	10,900 ± 50	12,835–12,755	OxA-X-2739-55	Elk (hydroxyproline)	Foreshaft
	11,050 ± 55	13,070–12,920	OxA-X-2739-56	Elk (hydroxyproline)	Foreshaft
Average	10,985 ± 20	12,905–12,840			
Cactus Hill, VA	10,860 ± 60	12,825–12,745	Beta-266341	Charcoal	Hearth
	10,840 ± 40	12,820–12,740	Beta-206060	Charcoal	Hearth
	10,810 ± 40	12,760–12,730	Beta-233642	Charcoal	Hearth

continued on next page

Site	Date	Calibrated date	Laboratory number	Material dated	Remarks
	^{14}C yr B.P.	cal yr B.P.*			
	10,890 ± 40	12,825–12,760	Beta-233643	Charcoal	Hearth
	10,910 ± 40	12,835–12,760	Beta-210651	Charcoal	Hearth
Average	10,860 ± 20	12,820–12,745			

*Ages calibrated using IntCal20, Calib 8.1 (*9*).

an old age for East Wenatchee, and the Glacier Peak Ash, which is dated elsewhere to ~11,600 ± 50 ^{14}C yr B.P. or 13,575 to 13,410 cal yr B.P., actually predates the deposition of the artifacts (*27*). We also discuss the Casper site, Wyoming, which is sometimes misrepresented as a Clovis site (*26*) and the new ages for the Clovis horizon at Blackwater Draw, New Mexico.

Murray Springs, Arizona

Clovis artifacts along with the bones of mammoth, bison, and other extinct animals were recovered from sand filling a channel known as the Graveyard Gulch member of the Murray Springs formation (stratum F_1) (*28*). Artifacts and bones were also found on the eroded surfaces adjacent to the channel. Interpretation of the archaeological and faunal remains suggests that the site likely represents two or more episodes of use over a few years (*28*). However, eight radiocarbon ages on dispersed charcoal from stratum F_1 range from 11,150 ± 450 ^{14}C yr B.P. (A-805) to 10,710 ± 160 ^{14}C yr B.P. (TX-1459) (Table 2) (*5*, *28*) and do not support a radiocarbon estimate of a short-duration event (see *14*). These eight ages do not overlap at one sigma, and the date means range over the entire span of Clovis. Seven of the radiocarbon ages have one-sigma SDs of ±450 to ±140 radiocarbon years. Despite this, the eight radiocarbon dates were averaged to 10,900 ± 50 ^{14}C yr B.P., a date commonly ascribed to the Clovis occupation at the site (*16*, *28*). However, as expected, by averaging dates that span the range of Clovis, a date mean in the middle of the Clovis range is obtained. The averaging of the ages from the Clovis horizon does not provide an accurate date for the occupation of the Murray Springs site by Clovis foragers. An overlooked age from the site of 10,760 ± 100 ^{14}C yr B.P. (A-1045; 12,825 to 12,675 cal yr B.P.) is reported on charcoal from a Clovis hearth (*28*). This age was rejected and considered to be contaminated by carbon from overlying deposits (*28*). This date, from a hearth, might not be contaminated and could actually represent the true age of the Clovis occupation at the Murray Springs site, thereby making Murray Springs a terminal Clovis occurrence. Given all these uncertainties, at present, we consider the Clovis occupation at the Murray Springs site to be insufficiently dated for inclusion in a Clovis chronology.

Lehner site, Arizona

Clovis artifacts with mammoth bone were excavated from a sand and gravel-filled channel known as Mammoth Kill Creek (unit F_1) (*16*). Archaeological and faunal interpretations suggest that this is a single kill event or, perhaps, a site that was revisited with mammoth kills occurring in the same location over a short period of time. Twelve radiocarbon ages on dispersed charcoal from unit F_1 range from 11,470 ± 110 ^{14}C yr B.P. (SMU-308) to 10,620 ± 300 ^{14}C yr B.P. (SMU-347) (Table 2) (*16*). These 12 ages do not overlap at one sigma and again range across the entire span of credible Clovis ages; this is not the chronological signature of a single, short-lived hunting event (see *14*). Despite these issues, the 12 ages were averaged to 10,930 ± 40 ^{14}C yr B.P., the date ascribed to the Clovis occupation at the site (*16*). As at the Murray Springs site, by averaging dates that span the entire range of Clovis, a date mean in the middle of the Clovis range is generated. We doubt that this is an accurate age for Clovis activity at the Lehner site. Only two of the radiocarbon ages have SDs <100 radiocarbon years, and these do not overlap at two sigmas. Given all these uncertainties, we consider the existing radiocarbon dates too imprecise to accurately determine when the Clovis activity took place at the Lehner site.

Paleo Crossing, Ohio

Radiocarbon ages reported on charcoal from the Paleo Crossing site, Ohio, seemed to provide credible and reliable chronological control for the site (*5*, *29*). However, recent excavations show that the reported radiocarbon ages do not accurately date the Clovis horizon (*30*). Most of the dated samples were collected from post-hole infillings that were described to be part of a prehistoric structure. Subsequent work at the site shows that the post molds are part of a historic structure (*30*). Furthermore, the original dates were reported to be on charcoal but were actually on bulk sediments that were a mixture of different strata of different ages. On the basis of this new understanding of the site, all previously reported ages for Paleo Crossing are disregarded and the site is defined as undated.

Sloth Hole, Florida

An ivory foreshaft from the Sloth Hole site yielded a radiocarbon age of 11,050 ± 50 ^{14}C yr B.P. (SL-2850) (*31*). At least one Clovis point was found at the site, but it was collected out of context and the point's relationship to the dated ivory artifact is unknown. Also uncertain is the exact geologic context of the dated ivory artifact. Last, because ancient ivory can be collected and used to make durable tools long after the death of the mammoth or mastodon (*32*), a radiocarbon age on ivory does not necessarily date the production of the artifact. Because of these uncertainties, the significance of the ivory foreshaft's age is equivocal.

Aubrey, Texas

The evidence for an early Clovis occupation at the Aubrey site, Texas, is based on two radiocarbon dates on material reported to be charcoal, 11,540 ± 110 ^{14}C yr B.P. (AA-5271) and 11,590 ± 90 ^{14}C yr B.P. (AA-5274); the dates average 11,570 ± 70 ^{14}C yr B.P. or 13,490 to 13,355 cal yr B.P. (*33*). This charcoal came from the Clovis occupation surface of camp B, which sits on the eroded surface of stratigraphic unit A2 and is overlain by unit G. The alluvial sediments underlying the Clovis surface are >17,000 years old, and the upper portion of the alluvium has been altered by pedogenesis and erosion. The age of the alluvium indicates that this erosional surface was exposed for thousands of years before the Clovis occupation. The age of the burial of the Clovis occupation surface is unknown, but a ^{14}C

Table 2. Radiocarbon dates from Murray Springs and Lehner, Arizona.

Site	Date	Calibrated date	Laboratory number	Material dated	Remarks
	^{14}C yr B.P.	cal yr B.P.*			
Murray Springs					
	11,190 ± 180	13,290–12,905	SMU-18	Charcoal	Dispersed
	11,150 ± 450	13,585–12,620	A-805	Charcoal	Dispersed
	11,080 ± 180	13,160–12,825	TX-1413	Charcoal	Dispersed
	10,930 ± 170	13,055–12,745	TX-1462	Charcoal	Dispersed
	10,890 ± 180	13,055–12,725	SMU-27	Charcoal	Dispersed
	10,840 ± 70	12,825–12,735	SMU-41	Charcoal	Dispersed
	10,840 ± 140	12,960–12,690	SMU-42	Charcoal	Dispersed
	10,710 ± 160	12,835–12,480	TX-1459	Charcoal	Dispersed
	10,760 ± 100	12,825–12,675	A-1045	Charcoal	Hearth
Lehner					
	11,470 ± 110	13,455–13,240	SMU-308	Charcoal	Dispersed
	11,170 ± 200	13,240–12,845	SMU-264	Charcoal	Dispersed
	11,080 ± 200	13,160–12,780	SMU-181	Charcoal	Dispersed
	11,080 ± 230	13,160–12,770	SMU-196	Charcoal	Dispersed
	10,950 ± 90	12,965–12,760	SMU-290	Charcoal	Dispersed
	10,950 ± 110	12,970–12,755	SMU-194	Charcoal	Dispersed
	10,940 ± 100	12,965–12,755	A-378	Charcoal	Dispersed
	10,860 ± 280	13,150–12,490	SMU-164	Charcoal	Dispersed
	10,770 ± 140	12,890–12,620	SMU-168	Charcoal	Dispersed
	10,710 ± 90	12,750–12,625	SMU-340	Charcoal	Dispersed
	10,700 ± 150	12,825–12,485	SMU-297	Charcoal	Dispersed
	10,620 ± 300	12,830–12,000	SMU-347	Charcoal	Dispersed

*Ages calibrated using IntCal20, Calib 8.1 (*9*).

measurement on humates from overlying unit G was 10,718 ± 90 ^{14}C yr B.P. (SMU-2338; 12,755 to 12625 cal yr B.P.). The exposure of the geological surface before and after Clovis occupation would have created a situation where geologically ancient carbon could have become commingled with and contaminated charcoal samples associated with the Clovis occupation. In addition, the Clovis-age samples may have been contaminated by older, soluble humates derived from underlying deposits. The Late Quaternary sediments at the Aubrey site are predominately derived from Cretaceous bedrock that contains large amounts of ^{14}C-free carbon. Large quantities of ^{14}C-depleted carbon in the form of recycled Cretaceous palynomorphs are documented in the late Pleistocene deposits at the Aubrey site (*34*). Furthermore, the Aubrey site is downstream from and adjacent to outcrops of the Late Cretaceous Woodbine Formation, which contains lignite. Just 20-km downstream from the Aubrey site is the Lewisville site (*35*), where charcoal samples from hearths associated with Clovis points yielded ages of >37,000 ^{14}C yr B.P. (O-235 and O-248). Reinvestigation of the Lewisville site in the 1980s revealed that small amounts of lignite contamination had skewed the radiocarbon dates to anomalously older ages (*35*). These chronological issues raise concern about the validity of the geologically early ages from the Aubrey site. Until more samples of chemically distinct and taxonomically identified charcoal and the soluble humate fractions from these charcoal samples are dated, the true age of the Aubrey site will remain unknown. If the current age estimates for the Aubrey site are confirmed, it would indicate that the oldest Clovis site occurs in the southern portion of the Clovis geographic range.

El Fin Del Mundo, Mexico

At El Fin del Mundo, Mexico, bones of a gomphothere (*Cuvieronius* sp.) are associated with Clovis lithics in the upper 15 cm of stratum 3B (*36*). A single sample identified as charcoal and associated with the gomphothere bones was dated as 11,560 ± 140 ^{14}C yr B.P. (AA-100181) or 13,590 to 13,300 cal yr B.P. This date was statistically manipulated to yield a similar date mean, but with a SD reduced by over 50%. This "calculated" age is 11,550 ± 60 ^{14}C yr B.P. (AA-100181A) or 13,470 to 13,350 cal yr B.P.

The dated "charcoal" from stratum 3B is described as "fragmented carbonaceous matter" that could not be taxonomically identified (*36*). Furthermore, the dated organics are geological; they are not from an archaeological feature such as a hearth. The organic matter that was dated was one of only two samples identified as charcoal with "woody tissue structure" from stratum 3B. Both were pretreated using standard acid-base-acid procedures. One sample dissolved completely during alkali treatment; its soluble organics yielded an age of 11,880 ± 200 ^{14}C yr B.P. (AA-100182). The other sample (AA-100181), which produced the 11,560 ± 140 ^{14}C yr B.P. age, yielded only 0.23 mg of carbon after pretreatment, a loss of 81% of its original mass (*36*). Three other samples of "fragmented carbonaceous matter" were collected from stratum 3B, but these lacked woody structure and were not dated. These laboratory observations—significant dissolution in alkali, and very small yields—are indicative of bacterially reduced organic matter, not combustion-derived charcoal. Alkaline springs deposited carbonates (marls) upslope of the site, and these marls are lateral facies of stratum 2 and 3 sediments (*36*). The dated sample from the site could have been derived from the spring deposits upslope of the site and could be any combination of terrestrial plants and emergent or submerged aquatic flora.

Furthermore, a carbonate reservoir effect may have made samples from the site date older than their true age. Dissolved inorganic carbon, (CO_3^{-2}) in the site's modern groundwater had a decreased ^{14}C content relative to the modern atmosphere and yielded an apparent ^{14}C age of 1180 ± 30 ^{14}C yr B.P. (AA-92972; no Fm value was reported) (*36*). Similar or larger carbonate reservoir effects may have existed during the Late Pleistocene and Early Holocene at the site. Aquatic organic matter in the sediments containing the gomphothere bones and overlying diatomites would have had their $^{14}C/^{12}C$ values significantly depleted by carbonate reservoir effects. Consequently, the 11,560 ^{14}C yr B.P. date on organic matter associated with the gomphothere may be 1000 ^{14}C years too old. The uncertainty of using dispersed organic matter to date the site, combined with the unknown biological origin of the organic matter and the potential for carbonate reservoir effects, forced us to disregard this 11,560 ^{14}C yr B.P. age.

We also question the recalculation of blanks and backgrounds used to modify the measured age to produce a revised age for the Clovis horizon with a smaller SD and a slightly younger date mean. The measured date mean and SD for AA-100181 is 11,560 ± 140 ^{14}C yr B.P. This age was modified to 11,550 ± 60 ^{14}C yr B.P. (AA-100181A).

For small samples, background values are inversely proportional to sample size. This is not the result of "machine-induced fractionation," as claimed in (*36*), because micrograms of modern carbon contamination will affect a small sample more than a large one. Because blank values in table S7 in (*36*) are high [about three times the values quoted in (*37*) for blanks of the same size], blanks for the larger samples are probably subject to inverse-mass dependence, contrary to what is stated in (*36*).

Blank values typically vary in a quasi-random fashion, and this scatter (*37*) should be taken into account when assigning an uncertainty to the blank correction. On the basis of long-term evaluation of run-to-run scatter in blanks (and in similar variations observed in different blank aliquots measured in the same run), many laboratories assign an uncertainty of approximately ±30% of the actual blank value.

One or both of these effects can be seen in the raw data shown in table S7 in (*36*), where the small (0.1 mg of carbon) blank run on 8 August 2013 was about one-half the size of blanks run on 19 and 20 November 2012 (0.16 and 0.23 mg), but the August blank gave an Fm value of 0.035, which is almost four times as high. Even assuming an inverse size dependence, one would have expected a value of just 0.018 based on the 2012 values. This raises the possibility that the relatively good agreement between the November 19 and 20 blank results is simply the result of random chance and suggests that it would be prudent to adopt the ±30% uncertainty throughout.

The equation for the blank subtraction is $F' = F - (1 - F) * B$, where F is the "raw" fraction modern value for the sample and B is the blank value. The $1 - F$ factor arises because the F values are ratios of carbon isotopes and the background adds stable carbon as well as ^{14}C (e.g., adding modern carbon contamination to a modern sample with $F = 1$ has absolutely no effect).

The first sample in table S7 in (*36*) has $F = 0.2443$, and the one sigma uncertainty based on the scatter is ±0.0024 (one should always take the larger of the scatter and statistical uncertainties). If we take $B = 0.009 \pm 0.003$ for samples of around 0.2 mg, then the background correction for a raw F value of 0.24 is (1 to 0.24)*(0.009 ± 0.003) or 0.0068 ± 0.0023. The uncertainty in the raw value and the correction should be added in quadrature (square, add, and take the square root), so the corrected value is 0.2375 ± 0.0033, and converting this to an age gives 11,550 ± 110 ^{14}C yr B.P. The uncertainty is therefore almost twice the value of the ±60 years reported in (*36*). Because of all these issues, we conclude that the Clovis activity at El Fin del Mundo remains undated.

Sheaman, Wyoming

A Clovis component is suggested to be present at the Sheaman site, Wyoming, based on the occurrence of overshot and overface flakes, and bifaces with overface flake scars. The only diagnostic artifact from the site is a stone projectile point that has been identified as either Goshen or Agate Basin, but not Clovis (*38*).

Dating the Sheaman site has been difficult. Two dates on charcoal, 10,140 ± 500 ^{14}C yr B.P. (RL-1241) and 10,100 ± 2800 ^{14}C yr B.P. (RL-1000), are believed to postdate the artifact-bearing horizon (*39*). A bison long bone fragment from the artifact zone yielded an age on chemically unspecified collagen of 10,030 ± 280 ^{14}C yr. B.P. (RL-1263) (*39*). To clarify the age of the site, two dates were measured on dispersed pieces of charcoal below the artifact zone and were 10,153 ± 90 ^{14}C yr B.P. (AA-42979) and 1820 ± 170 ^{14}C yr B.P. (AA-42535) (*39*). Another sample of dispersed charcoal was dated from the artifact-bearing zone and yielded an age of 10,250 ± 70 ^{14}C yr B.P. (AA-42533) on the HCL-insoluble charcoal fraction and an age of 10,025 ± 85 ^{14}C yr B.P. (AA-42534) on humates from the charcoal's alkali-soluble fraction (*39*). Another date on dispersed charcoal above the artifact layer yielded a date of 9085 ± 70 ^{14}C yr B.P. (AA-42532). A large volume of sediment was collected from the artifact-bearing zone and yielded charcoal and unidentified acid-insoluble organic matter that produced three dates: 11,040 ± 70 ^{14}C yr B.P. (AA-40989), 11,379 ± 70 ^{14}C yr B.P. (AA-40991), and 11,810 ± 300 ^{14}C yr B.P. (AA-40988) (*39*). Despite these three ages not overlapping at one sigma and one having a SD of 300 ^{14}C years, all three were averaged as 11,225 ± 50 ^{14}C yr B.P.—the age assigned to the Sheaman site (*39*). To reassess the site's age, we dated the osseous projectile point that was associated with the reported Clovis artifacts and the stone projectile point. The osseous point was made from cervid bone or antler, which had previously been identified as ivory. Three dates on XAD-purified collagen from this osseous artifact yielded an average age of 10,305 ± 15 ^{14}C yr B.P. or 12,095 to 11,950 cal yr B.P. (*5*). Considering all the ages from Sheaman, we believe the most accurate ages are those derived from the osseous artifact because the dates were obtained on an artifact directly associated with the cultural horizon and the ages were derived from XAD purified collagen. The artifact technology and new ages suggest that the Sheaman site is either a physically mixed assemblage of Clovis and Goshen/Agate Basin artifacts or there is no Clovis presence at the site and all the artifacts are Late Paleoindian Goshen or Agate Basin. If the latter is true, many of the diagnostic flaking methods that we associate with Clovis bifaces, e.g., overface flaking, overshot flaking, and alternate opposed flaking, may not inherently define Clovis and may have been used in later Paleoindian times.

Casper, Wyoming

At the Casper site, Wyoming, a single Clovis point was found by two avocational archaeologists in loose, disturbed sand in an area where 8 m of dune sand had been removed by mechanical equipment. After recovery of the artifact, the discoverers dug into the sand and found bison bones. This discovery led to further investigations that uncovered numerous Hell Gap–style projectile points associated with the remains of over 100 bison (*40*). Two dates from the bone bed, one on charcoal of 9830 ± 350 ^{14}C yr B.P. (RL-125) and the other on a bison bone of 10,060 ± 170 ^{14}C yr B.P. (RL-208), place the Hell Gap bison kill sometime between 11,850 and 11,300 cal yr B.P. Below the bison remains, several long bones and other skeletal elements of camel (*Camelops* sp.) were found. XAD-purified collagen from the *Camelops* bone dated 11,190 ± 50 ^{14}C yr B.P. (CAMS-61899) or 13,160 to 13,090 cal yr B.P. (*40*). No artifacts were associated with the *Camelops*, but the bones showed several green bone fractures (*40*). There is no stratigraphic association between the *Camelops* bone and the isolated Clovis point found above the layer with Hell Gap projectile points and bison bones. However, some believe the taphonomy of the camel skeleton confirms an early human presence at the site (*26*). They associate this early activity to Clovis based on the age of the camel bones and the presence of an out-of-context Clovis point. Because there is no association between the Clovis point found at the surface above the Hell Gap horizon and the *Camelops* bones stratigraphically below the Hell Gap horizon, the Clovis-age ^{14}C date from the camel cannot be assigned to the unassociated Clovis projectile point. Consequently, the date on the camel provides no information for the age of Clovis.

Blackwater Draw, New Mexico

In 2007, no credible age was available for the type locality of Clovis at Blackwater Draw, New Mexico. In 2012, "black charcoal–like plant remains" from the Clovis horizon, stratum B3, were dated (*41*). During chemical pretreatment, these samples dissolved 100% during alkali pretreatment. Upon adding HCl, a black precipitate formed, and upon drying and combustion, this black residue ("humic acids") was dated in triplicate as 9920 ± 80 (AA-30453B2), 10,915 ± 70 (AA-30454B), and 10,935 ± 55 ^{14}C yr B.P. (AA-87917). The 9920 ± 80 age was disregarded as too young, while the two oldest ages were accepted as accurately dating the Clovis horizon despite all three ages having been obtained on the same precipitate. None of the radiocarbon measurements on humic acids provide an unequivocal age for the Blackwater Draw Clovis horizon.

DISCUSSION

We propose here a chronology for the Clovis complex based on unequivocal data—reproducible radiocarbon ages from sites with diagnostic Clovis projectile points. Now, only 32 radiocarbon ages from 10 sites provide credible chronological control for the Clovis complex (Fig. 2 and Table 1). All radiocarbon ages are on bones associated with Clovis artifacts, tools made of bone, human bone, or charcoal and seeds from hearths.

These dates indicate that Clovis first appeared at the very end of the Allerød ~13,050 cal yr B.P. Three radiocarbon ages from Aubrey and El Fin del Mundo may indicate that Clovis first appeared

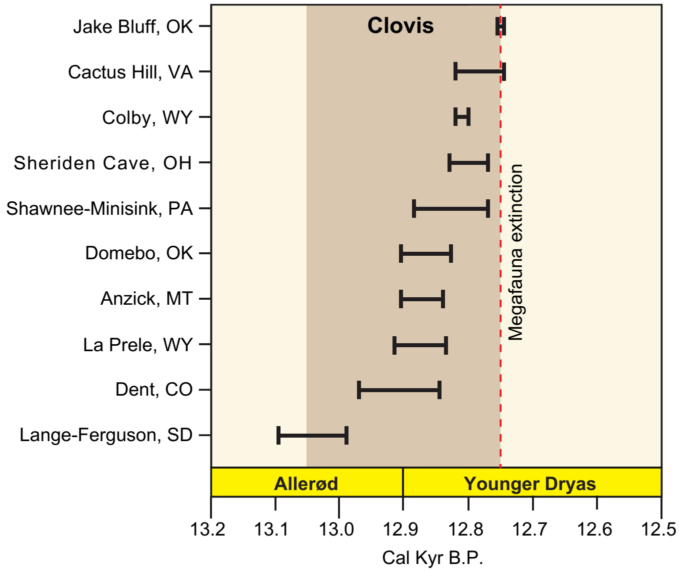

Fig. 2. Calibrated ages for the 10 well-dated Clovis sites. Calibrated ages shown at one sigma and Clovis range (~13,050 to 12,750 cal yr B.P.) in brown. Allerød and Younger Dryas climate periods shown. Red dashed line indicates age of Late Pleistocene megafauna extinction.

~13,400 to 13,300 cal yr B.P.; however, these ages remain equivocal because of geological and biogeochemical issues.

The earliest Clovis sites at ~13,050 cal yr B.P. are contemporaneous with non-Clovis lithic complexes in western North America and South America. In the Intermountain West, the Western Stemmed Tradition, characterized by lanceolate points with basal stems, are minimally dated to ~13,000 cal yr B.P. at Paisley Caves, Oregon (*42*), and ~13,400 cal yr B.P. at Coopers Ferry, Idaho (*43*). In the southern cone of South America, distinctive stemmed Fishtail projectile points occur in sites dated to ~12,900 cal yr B.P. (*4*, *44*). These data are evidence that Clovis is one of at least three contemporaneous lithic complexes present in the Western Hemisphere at the end of the Pleistocene (*4*). Even if Clovis began earlier, at ~13,400 to 13,300 cal yr B.P., as suggested by Aubrey and El Fin Del Mundo, Clovis still would be contemporaneous with North American stemmed points.

The origin of Clovis technology remains unknown, but the evidence clearly indicates that Clovis developed south of the continental ice sheets during a time of extreme climatic and biotic change. Current human genetic models suggest that there was a single early migration into the Americas during the Late Pleistocene. Archaeological evidence from many sites now indicates that people were in the Americas by ~16,000 to 15,000 cal yr B.P. (*4*, *27*). This suggests that the origins of Clovis lie in the biface, blade, and osseous technologies of the earliest sites in North America (*4*, *45*).

Clovis—the technology—abruptly ends at ~12,750 cal yr B.P. and coincides temporally with the beginning of the Younger Dryas cooling event and paleontologically, with the extinction of *Mammut*, *Mammuthus*, and *Cuvieronius*. Archaeologically, Clovis terminates immediately before the emergence of Folsom technology on the Plains (*27*, *46*) and the eastern Fluted Point Tradition in the eastern United States (*47*). In contrast, the production of stemmed points in the western United States continues after Clovis ends (*48*).

This is the current status of Clovis dating based on a rigorous analysis of the radiocarbon ages from sites with Clovis artifacts. To learn more about Clovis origins and its spread, we must expand the radiocarbon record for this complex. We must continue to find and date more sites to determine if older Clovis sites exist. Future dating of Clovis sites must be held to rigorous standards. In so doing, we will enlarge the radiocarbon record of accurate and precise ages that will allow us to evaluate the meaning of Clovis.

MATERIALS AND METHODS

Since 2007, radiocarbon dates were obtained on osseous samples in direct association with Clovis artifacts at Sheriden Cave, Ohio; La Prele, Wyoming; Dent, Colorado; Jake Bluff, Oklahoma; and Anzick, Montana. The osseous materials from Sheriden Cave, La Prele, Jake Bluff, and Anzick were chemically purified using XAD-2 resins to extract total collagen amino acids using the protocols in (*10*–*12*) and dated by the W.M. Keck Carbon Cycle Accelerator Mass Spectrometer Facility at the University of California, Irvine. Osseous samples from the La Prele, Dent, and Anzick sites were also dated using a specific collagen amino acid (hydroxyproline) at the Oxford Radiocarbon Accelerator Unit using protocols outlined in (*10*, *12*). Other samples, charcoal and seeds from hearths, were pretreated using standard methodologies at the W.M. Keck Carbon Cycle Accelerator Mass Spectrometer Facility, Oxford Radiocarbon Accelerator Unit, and Beta Analytic (Miami, Florida). All radiocarbon ages were calibrated using the IntCal20 database Calib 8.1 (*9*). Ages used to define Clovis come from sites where diagnostic Clovis projectile points are present. Radiocarbon ages from Clovis sites were evaluated using the criteria outlined in the paper.

REFERENCES AND NOTES

1. B. A. Bradley, M. B. Collins, A. Hemmings, *Clovis Technology* (International Monographs in Prehistory, Ann Arbor, MI, 2010).
2. M. I. Eren, B. Buchanan, Clovis Technology, in *eLS* (John Wiley & Sons, 2016).
3. D. S. Miller, V. T. Holliday, J. Bright, Clovis across the continent, in *Paleoamerican Odyssey*, K. E. Graf, C. V. Ketron, M. R. Waters, Eds. (Texas A&M Univ. Press, College Station, 2014), pp. 207–220.
4. M. R. Waters, Late Pleistocene exploration and settlement of the Americas by modern humans. *Science* **365**, eaat5447 (2019).
5. M. R. Waters, T. W. Stafford Jr., Redefining the age of Clovis: Implications for the peopling of the Americas. *Science* **315**, 1122–1126 (2007).
6. G. Haynes, The millennium before Clovis. *PaleoAmerica* **1**, 134–162 (2015).
7. B. Buchanan, M. J. O'Brien, M. Collard, Continent-wide or region-specific? A geometric morphometrics-based assessment of variation in Clovis point shape. *Archaeol. Anthropol. Sci.* **6**, 145–162 (2014).
8. M. Prasciunas, T. A. Surovell, Reevaluating the duration of Clovis: The problem of non-representative radiocarbon dates age estimates for the duration of the Clovis complex, in *Clovis: On the Edge of a New Understanding*, A. M. Smallwood, T. A. Jennings, Eds. (Texas A&M Univ. Press, College Station, 2015), pp. 21–35.
9. P. J. Reimer, W. E. N. Austin, E. Bard, A. Bayliss, P. G. Blackwell, C. B. Ramsey, M. Butzin, H. Cheng, R. L. Edwards, M. Friedrich, P. M. Grootes, T. P. Guilderson, I. Hajdas, T. J. Heaton, A. G. Hogg, K. A. Hughen, B. Kromer, S. W. Manning, R. Muscheler, J. G. Palmer, C. Pearson, J. van der Plicht, R. W. Reimer, D. A. Richards, E. M. Scott, J. R. Southon, C. S. M. Turney, L. Wacker, F. Adolphi, U. Büntgen, M. Capano, S. M. Fahrni, A. Fogtmann-Schulz, R. Friedrich, P. Köhler, S. Kudsk, F. Miyake, J. Olsen, F. Reinig, M. Sakamoto, A. Sookdeo, S. Talamo, The IntCal20 northern hemisphere radiocarbon age calibration curve (0-55 cal kBP). *Radiocarbon*, 1–33 (2020).
10. T. Devièse, T. W. Stafford Jr., M. R. Waters, C. Wathen, D. Comeskey, L. Becerra-Valdivia, T. Higham, Increasing accuracy for the radiocarbon dating of sites occupied by the first Americans. *Quatern. Sci. Rev.* **198**, 171–180 (2018).
11. T. W. Stafford Jr., P. E. Hare, L. Currie, A. J. T. Jull, D. J. Donahue, Accelerator radiocarbon dating at the molecular level. *J. Archaeol. Sci.* **18**, 35–72 (1991).
12. L. Becerra-Valdivia, M. R. Waters, T. W. Stafford Jr., S. L. Anzick, D. Comeskey, T. Devièse, T. Higham, Reassessing the chronology of the archeological site of Anzick. *Proc. Natl. Acad. Sci. U.S.A.* **115**, 7000–7003 (2018).
13. T. W. Stafford Jr., A. J. T. Jull, K. Brendel, R. C. Duhamel, D. Donahue, Study of bone radiocarbon dating accuracy at the University of Arizona NSF accelerator facility for radioisotope analysis. *Radiocarbon* **29**, 24–44 (1987).
14. M. R. Waters, T. W. Stafford Jr., B. Kooyman, L. V. Hills, Late Pleistocene horse and camel hunting at the southern margin of the ice-free corridor: Reassessing the Age of Wally's Beach, Canada. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 4263–4267 (2015).
15. M. I. Eren, D. J. Meltzer, B. N. Andrews, Is Clovis technology unique to Clovis? *PaleoAmerica* **4**, 202–218 (2018).
16. C. V. Haynes Jr., Contributions of radiocarbon dating to the geochronology of the peopling of the new world, in *Radiocarbon After Four Decades: An International Perspective*, R. E. Taylor, A. Long, R. S. Kra, Eds. (Springer-Verlag, New York, 1992), pp. 355–375.
17. L. A. Hannus, *Clovis Mammoth Butchery: The Lange/Ferguson Site and Associated Bone Tool Technology* (Texas A&M Univ. Press, College Station, 2018).
18. T. W. Stafford Jr., Chronology of the Kennewick Man Skeleton, in *Kennewick Man: The Scientific Investigation of an Ancient American Skeleton*, D. W. Owsley, R. L. Jantz, Eds. (Texas A&M Univ. Press, College Station, 2014), pp. 59–89.
19. J. A. M. Gingerich, Revisiting Shawnee-Minisink, in *In the Eastern Fluted Point Tradition*, J. A. M. Gingerich, Ed. (University of Utah Press, Salt Lake City, 2013), pp. 218–256.
20. M. R. Waters, T. W. Stafford Jr., B. G. Redmond, K. B. Tankersley, The Age of the Paleoindian Assemblages at Sheriden Cave, Ohio. *Am. Antiq.* **74**, 107–111 (2009).
21. M. E. Mackie, T. A. Surovell, M. O'Brien, R. L. Kelly, S. Pelton, C. V. Haynes Jr., G. C. Frison, R. M. Yohe, S. Teteak, H. M. Rockwell, S. Mahan, Confirming a cultural association at the La Prele Mammoth site (48CO1401), Converse County, Wyoming. *Am. Antiq.* **85**, 554–572 (2020).
22. L. C. Bement, B. J. Carter, Jake Bluff: Clovis bison hunting on the southern Plains of North America. *Am. Antiq.* **75**, 907–933 (2010).
23. J. E. Morrow, S. J. Fiedel, New radiocarbon Dates for the Clovis Component of the Anzick Site, Park County, Montana, in *Paleoindian Archaeology: A Hemispheric Perspective*, J. E. Morrow, C. Gnecco, Eds. (University Press of Florida, Gainesville, 2006), pp. 123–138.
24. M. Rasmussen, S. L. Anzick, M. R. Waters, P. Skoglund, M. DeGiorgio, T. W. Stafford Jr., S. Rasmussen, L. Moltke, A. Albrechtsen, S. M. Doyle, G. D. Poznik, V. Gudmundsdottir, R. Yadav, A.-S. Malaspinas, S. S. White V, M. E. Allentoft, O. E. Cornejo, K. Tambets, A. Eriksson, P. D. Heintzman, M. Karmin, T. S. Korneliussen, D. J. Meltzer, T. L. Pierre, J. Stenderup, L. Saag, V. Warmuth, M. C. Lopes, R. S. Malhi, S. Brunak, T. Sicheritz-Ponten, I. Barnes, M. Collins, L. Orlando, F. Balloux, A. Manica, R. Gupta, M. Metspalu, C. D. Bustamante, M. Jakobsson, R. Nielsen, E. Willerslev, The genome of a Late Pleistocene human from a Clovis burial site in western Montana. *Nature* **506**, 225–229 (2014).
25. J. M. McAvoy, L. D. McAvoy, *Nottoway River Survey Part-II: Cactus Hill and Other Excavated Sites* (Nottoway River Survey Research Report No. 5, Petersburg, VA, 2015).
26. M. J. Hamilton, B. Buchanan, Spatial gradients on Clovis-age radiocarbon dates across North America suggest rapid colonization from the north. *Proc. Natl. Acad. Sci. U.S.A.* **104**, 15625–15630 (2007).
27. M. R. Waters, T. W. Stafford Jr., The First Americans: A Review of the Evidence for the Late-Pleistocene Peopling of the America, in *Paleoamerican Odyssey*, K. E. Graf, C. V. Ketron, M. R. Waters, Eds. (Texas A&M Univ. Press, College Station, 2014), pp. 541–560.
28. C. V. Haynes Jr., B. B. Huckell, *Murray Springs: A Clovis Site with Multiple Activity Areas in the San Pedro Valley, Arizona* (University of Arizona Press, Tucson, 2007).
29. D. S. Brose, Archaeological Investigations at the Paleo Crossing Site, A Paleoindian Occupation in Medina County, Ohio, in *The First Discovery of America: Archaeological Evidence of the Early Inhabitants of the Ohio Area*, W. S. Dancey, Ed. (Ohio Archaeological Council, Columbus, 1994), pp. 61–76.
30. M. I. Eren, B. Andrews, M. Bebber, A. Rutkoski, D. Meltzer, Year One of New Excavations at the Paleo Crossing (33ME274) Clovis Sites, Ohio: The 2017 Field Season, paper presented at 83rd Annual Meeting of the Society for American Archaeology, Washington, D.C. (2018).
31. C. A. Hemmings, dissertation, University of Florida (2004).
32. S. J. Pfeifer, W. L. Hartramph, R.-D. Kahlke, F. A. Müller, Mammoth ivory was the most suitable osseous raw material for the production of Late Pleistocene big game projectile points. *Sci. Rep.* **9**, 2303 (2019).
33. C. R. Ferring, *The Archaeology and Paleoecology of the Aubrey Clovis Site (41DN479) Denton County, Texas* (U.S. Army Corps of Engineers, Fort Worth District, 2001).
34. S. A. Hall, Late glacial aster prairie at the Aubrey Clovis site, North Texas, USA. *Quatern. Int.* **530-531**, 25–34 (2019).
35. D. Stanford, Pre-Clovis Occupation South of the Ice Sheets, in *Early Man in the New World*, R. Shutler Jr., Ed. (Sage Press, Beverly Hills), pp. 65–72.
36. G. Sanchez, V. T. Holliday, E. P. Gaines, J. Arroyo-Cabrales, N. Martínez-Tagüeña, A. Kowler, T. Lange, G. W. L. Hodgins, S. M. Mentzer, I. Sanchez-Marales, Human (Clovis)-gomphothere (*Cuvieronius* sp.) association ~13,390 calibrated yBP in Sonora, Mexico. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 10972–10977 (2014).
37. G. M. Santos, J. R. Southon, S. Griffin, S. R. Beaupre, E. R. M. Druffel, Ultra small-mass AMS ^{14}C sample preparation and analyses at KCCAMS/UCI facility. *Nucl. Instrum. Meth. B* **259**, 293–302 (2007).
38. F. Sellet, A fresh look at the age and cultural affiliation of the Sheaman site. *PaleoAmerica* **1**, 81–87 (2015).

39. C. V. Haynes Jr., M. Kornfeld, G. C. Frison, New geochronological and archaeological data for the Sheaman Clovis Site, Eastern Wyoming, U.S.A. *Geoarchaeology* **19**, 369–379 (2004).
40. G. C. Frison, A ^{14}C date on a Late-Pleistocene Camelops at the Casper-Hell Gap Site, Wyoming. *Curr. Res. Pleistocene* **17**, 28–29 (2000).
41. C. V. Haynes Jr., J. M. Warnica, *Geology, Archaeology and Climate Change in Blackwater Draw, New Mexico: F. Earl Green and the Geoarchaeology of the Clovis Type Site* (Eastern New Mexico University, Portales, 2012), vol. 15.
42. D. L. Jenkins, L. G. Davis, T. W. Stafford Jr., P. F. Campos, B. Hockett, G. T. Jones, L. S. Cummings, C. Yost, T. J. Connolly, R. M. Yohe II, S. C. Gibbons, M. Raghavan, M. Rasmussen, J. L. A. Paijmans, M. Hofreiter, B. M. Kemp, J. L. Barta, C. Monroe, M. T. P. Gilbert, E. Willerslev, Clovis age western stemmed projectile points and human coprolites at the Paisley Caves. *Science* **337**, 223–228 (2012).
43. L. G. Davis, D. B. Madsen, L. Becerra-Valdivia, T. Higham, D. A. Sisson, S. M. Skinner, D. Stueber, A. J. Nyers, A. Keen-Zebert, C. Neudorf, M. Cheyney, M. Izuho, F. Iizuka, S. R. Burn, C. W. Epps, S. C. Willis, I. Buvit, Late Upper Paleolithic occupation at Cooper's Ferry, Idaho, USA, ~16,000 years ago. *Science* **365**, 891–897 (2019).
44. M. R. Waters, T. Amorosi, T. W. Stafford Jr., Redating Fell's Cave, Chile and the chronological placement of the fishtail projectile point complex. *Am. Antiq.* **80**, 376–386 (2015).
45. M. R. Waters, J. L. Keene, S. L. Forman, E. R. Prewitt, D. L. Carlson, J. E. Wiederhold, Pre-Clovis projectile points at the Debra L. Friedkin site, Texas—Implications for the Late Pleistocene peopling of the Americas. *Sci. Adv.* **4**, eaat4505 (2018).
46. T. A. Surovell, J. R. Boyd, C. V. Haynes Jr., G. W. L. Hodgins, On the dating of the Folsom complex and its correlation with the Younger Dryas, the end of Clovis, and Megafaunal extinction. *PaleoAmerica* **2**, 81–89 (2016).
47. J. C. Lothrop, D. L. Lowery, A. E. Spiess, C. J. Ellis, Early human settlement of northeastern North America. *PaleoAmerica* **2**, 192–251 (2016).
48. T. Goebel, J. L. Keene, Are Great Basin Stemmed Points as Old as Clovis in the Intermountain West? A Review of the Geochronological Evidence, in *Archaeology in the Great Basin and Southwest: Papers in Honor of Don D. Fowler*, N. J. Parezo, J. C. Janetski, Eds. (University of Utah Press, Salt Lake City, 2014), pp. 35–60.

Acknowledgments

Funding: The North Star Archaeological Research Fund paid for many of the radiocarbon dates. **Author contributions:** M.R.W., T.W.S.J., and D.L.C. wrote the paper. D.L.C. conducted the statistical analyses. T.W.S.J. processed most of the radiocarbon samples, whose AMS ^{14}C measurements were performed under the direction of J. Southon, at the University of California–Irvine W.M. Keck Carbon Cycle Accelerator Mass Spectrometer facility. **Competing interests:** The authors declare that they have no conflicts of interest. **Data and materials availability:** All data needed to evaluate the conclusions in the paper are present in the paper. Additional data related to this paper may be requested from the authors.

Submitted 7 August 2019
Accepted 10 July 2020
Published 21 October 2020
10.1126/sciadv.aaz0455

Citation: M. R. Waters, T. W. Stafford Jr., D. L. Carlson, The age of Clovis—13,050 to 12,750 cal yr B.P. *Sci. Adv.* **6**, eaaz0455 (2020).

Science Advances

The age of Clovis—13,050 to 12,750 cal yr B.P.

Michael R. Waters, Thomas W. Stafford, Jr. and David L. Carlson

Sci Adv **6** (43), eaaz0455.
DOI: 10.1126/sciadv.aaz0455

Science Advances (ISSN 2375-2548) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title *Science Advances* is a registered trademark of AAAS.