Supporting Information

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SI Text

Our laboratory procedures were based on those used in the original study (1) and followed a detailed laboratory manual, titled "Separation of YD Event Markers (8/10/2007)," which was provided by one of its authors (Allen West, GeoScience Consulting).

Magnetic Minerals. Air-dried samples were lightly disaggregated with a ceramic pestle in a plastic tub and passed through a no. 18 1-mm sieve to remove the coarse fraction (if present). Depending upon the available sample size, between 200 and 500 g of the fine fraction were placed in clean plastic tub filled with ample amounts of water to produce a slurry. A $2 \times 1 \times 0.5''$ grade-42 neodymium magnet was placed in a 4-mL plastic bag, and the slurry was circulated allowing magnetic particles to accumulate on the bag. At intervals of ≈1 min, the bag was removed, and the particles were transferred to a bath of clean water. We found that this process could be repeated for many hours without the yields ever dropping to zero. Initially, we repeated magnetic extraction until yields dropped to minimal levels, but for later sets of samples, we extracted magnetics for a standardized 30-min time interval. After extraction, magnetic grains were cleaned by transfer through a series of water baths (2–4 depending upon texture) to remove clays. Once clean, magnetic fractions were dried and weighed.

Magnetic Microspherules. To identify magnetic spherules, two to four aliquots of magnetic grains from each sample were dusted onto a standard microscope slide coated with adhesive white paper to create an opaque background for increased visual contrast. The mass of particles on each slide typically varied between 8 and 20 mg depending upon sediment texture and their density on the slide. Each sedimentary grain was examined at 100× magnification with a binocular compound microscope, which was top-lit with a dual-gooseneck fiber optic light source. A digital camera connected to a monitor was mounted to the microscope to speed the process. When possible microspherules were identified, we zoomed to 300×, using the optical zoom of the camera, to determine if the grain should be counted as a microspherule. We recorded the location of each microspherule on the graduated microscope stage to prevent double counting, and each microspherule was photographed. We typically examined 10–40 mg of sediment per sample, from which we extrapolated to the entire sample, to estimate the total concentration of microspherules per kg of sediment to make our results directly comparable with Firestone et al. (1). We found that a single slide could be scanned for microspherules in ≈30 min to 1 h.

After consultation with Allen West, an author of the original study (1), we used extremely conservative criteria for the identification of microspherules. Our counts of microspherules from the Lubbock Lake site are largely based on West's identifications. We only counted those grains that were unfaceted, well rounded, highly spherical, and exhibited a smooth glassy or metallic surface. We found that the most efficient and replicable method for microspherule identification was to use the reflective properties of highly spherical and shiny grains. With a dual light source, microspherules invariably show two very bright and circular reflections on their surfaces (see Fig. 2 for examples). Once a possible microspherule was identified, we manually manipulated the light sources to observe how their reflections migrated across the surface. If even slight faceting was present on the grain surface, the movement of surface reflections tended to "jump" rather than migrating smoothly. Possible microspherules were photographed at least twice with the light sources positioned at multiple angles, and by doing so, we were able to eliminate a number of particles that at first glance appeared to be highly spherical but were not.

Study Sites. In this section, we provide a brief background to the sites and stratigraphic sections used in the study. In addition to site-specific sampling methods, we briefly describe the geomorphology and geochronology of stratigraphic sections. Although the identification of the precise position of the Younger Dryas Boundary (YDB) in some sections is not known with a high degree of confidence, we are certain that it does occur within all sampled sections. From the perspective of testing the ET impact hypothesis, the exact location of the YDB within sections is not critical because all that is predicted is that the YDB samples should have enhanced concentrations of magnetic grains and microspherules, no matter where they fall stratigraphically.

Agate Basin, Wyoming. The Agate Basin site contains numerous localities of Paleoindian archaeology occurring in alluvial terraces of Moss Agate Creek and its tributaries in eastern Wyoming just to the southeast of the southern Black Hills (2). The site has seen numerous episodes of investigation by archaeologists over more than 60 years (2–5). Archaeological components at the site span much of the Paleoindian period ranging in age from Clovis through Hell Gap (Fig. S1). Agate Basin is the type site for the Agate Basin Paleoindian technocomplex.

Our sample column was taken from Area 1 stratigraphically beneath the Agate Basin complex bone bed originally investigated by Roberts (5). Paleoindian artifacts occur within fine-grained alluvium deposits within the second alluvial terrace (6, 7). Four well-developed dark colored horizons (or "black mats") are present (Fig. S1). Consistent with Reider's (7) description of a similar section at Area 1, gleying was observed throughout much of the profile with intermittent horizontal banding of redoximorphic mottling. From this section, we recovered a continuous 1-m sample column in 10-cm increments.

From each of the lowermost two black layers, we dated paired humic/humin soil organic matter samples by using an accelerator mass spectrometer (AMS) (Fig. S1). For both samples, the humin or residue fractions were considerably older than the humic acid fractions and were inconsistent with the known chronology of the site (2, 8). We suspect that humin fractions have been affected by the inclusion of particulate carbon contributed by local Cretaceous Carlile Shale. The humic acid dates are more reasonable but still somewhat problematic. The uncalibrated humic acid date on the lower most buried soil of 10,506 ± 82 BP (AA-81792) is consistent with the dating of Younger Dryas black mats elsewhere (9). Therefore, we consider the basal contact of the lowermost black layer to be the most likely position of the Younger Dryas Boundary (YDB). The upper humic acid age of 9,195 ± 48 BP (AA-82374) is likely too young as it is stratigraphically beneath the Agate Basin bone bed. Dates on Agate Basin components elsewhere in the site are generally older, but they have fairly low precision: 10430 ± 570 BP; 9,990 ± 225 BP (10, 11).

Although it is possible that we have incorrectly identified the exact location of the YDB at Agate Basin, additional stratigraphic evidence suggests that it is within the section we sampled. At Area 2 of the site <100 m to the west, the Younger Dryas aged Folsom component occurs ≈30–60 cm beneath the

Agate Basin complex and typically overlies organic-rich "dark" horizons (3, 12), and at the Sheaman locality of Agate Basin, the Clovis component appears to occur within or at the base of a black mat (4, 13). Therefore, the YDB occurs within this section even if our estimation of its exact position is incorrect.

Blackwater Draw, NM. The Blackwater Draw site (also known as the Clovis site and the type site for the Clovis technocomplex) is a stratified archaeological site on the west-central Southern High Plains in a paleo-basin that drains into upper Blackwater Draw (14–17). The Clovis archaeology is from spring-generated sandy alluvial deposits and from sandy slope deposits. Post-Clovis, typically Folsom archaeology is from overlying lacustrine and paludal diatomite, diatomaceous earth, and muds. Archaeology and geology of the basin fill were exposed since the 1930s as the basin was subjected to quarrying for gravel. The site was largely destroyed by the early 1970s. Today the most complete and accessible section is the "South Bank," where the paleo-basin once drained into the draw. This section is described, dated, and discussed by Haynes (17). This profile is where samples reported by Firestone et al. (1) and by us were collected (Fig. S2). Our sampling columns were within ≈10 cm of one another, grid unit N1151 E1028. We collected a 35-cm column in continuous 5-cm increments through the diatomite and into the underlying sands (Fig. S2), essentially reproducing the sequence reported by Firestone et al. (1).

No Clovis or Folsom archaeology is known from the sample section but is correlated stratigraphically with archaeological features found elsewhere in the site. A number of radiocarbon ages from the South Bank are reported and discussed by Haynes (14), but the dates for the Clovis and Folsom levels (including the YDB "black mat") illustrated by Firestone et al. (1) and mentioned by Kennett et al. (18) are from a section ≈320 m away on the "North Bank."

Lubbock Lake, TX. Lubbock Lake is a stratified archeological site on the east-central Southern High Plains on the northwest side of the city of Lubbock, TX, in a meander of Yellowhouse Draw (19). The site was discovered after excavation for a reservoir in 1936. The stratigraphy of the Paleoindian (Clovis and Folsom) levels is very similar to that described for Blackwater Draw (16, 20, 21). Clovis-age bone and artifacts are in the upper few tens of centimeters of alluvium (stratum 1C) from a stream that once meandered across the floor of the draw. Resting conformably on the alluvium is interbedded diatomite and mud (stratum 2A). Above is homogeneous mud (stratum 2B). These layers produced the Folsom and some of the other Paleoindian archaeological features. The samples reported in this article were collected from Trench 65 on the west side of the old reservoir cut (Fig. S3) Six samples were collected in a continuous sequence from the base of 2B through 2A into upper 1C. Samples were collected on the basis of microstratigraphic units. Dating of the section is based on stratigraphic correlation with other exposures and excavation areas that yielded archaeology and radiocarbon samples (22, 23). These correlations are reasonable because Clovis-age fauna is found only in the alluvium and Folsom archaeology is found only in the bedded diatomite/mud.

Paw Paw Cove, MD. The Paw Paw Cove site is located on a low Coastal Plain upland a short distance from the Chesapeake Bay on the west side of the Delmarva Peninsula. Paw Paw Cove consists of a complex of sites that were identified through a survey of eroded shorelines along Tilghman Island, MD (24). Throughout the area, a conspicuous buried A-horizon is commonly present, marking late to terminal Pleistocene deposits that are then buried by loess. Clovis artifacts have been found at the top of this buried surface at Paw Paw Cove and other locations, providing a chronological marker for the start of YD age sediments (24). Therefore, we consider the Younger Dryas Boundary (YDB) to be marked by the overlying mantle of loess that buries this distinctive land surface used by Clovis.

Excavations at Paw Paw Cove have confirmed the existence of intact Clovis deposits resting atop the buried A-horizon (2BAtgb), and Early Archaic deposits in some areas just below the plow zone (24), thus effectively bracketing the loess mantle within the YD. In 2007, soil samples were collected near the site by auger. These samples were collected in 10-cm increments starting at 38 cm below the surface and extending to 98 cm (Table S1). In this profile we define the YDB at 68 cm resting at the top of the buried surface (2BAtgb).

San Jon, NM. San Jon is a stratified archaeological site in a playa basin on the northwest escarpment of the Southern High Plains (16, 26–28). Erosion exposed both a large playa with stratified basin fill and a smaller "subplaya" (29) with weakly stratified fill. The fill in the basins is a gray to dark gray mud, typical of most playa basins in the region (Fig. S4) (29). The samples for both magnetic extraction and radiocarbon dating were collected directly from the exposed section of the smaller subplaya. The radiocarbon ages were determined on bulk decalcified mud by conventional methods. Our radiocarbon samples bracketed the YDB zone. We estimated the position of the YDB zone based on calculated sedimentation rates, but the exact position is not especially important, because the dates show that it is near the middle of our sampling column (Fig. S4). Samples for separation of magnetic materials were collected through a 1-m column in continuous 10-cm increments.

Shawnee-Minisink, PA. The Shawnee-Minisink site in the Upper Delaware Valley of northeastern Pennsylvania has a thick well-stratified geological and archaeological record with Clovis, Late Paleoindian, and Early Archaic through Woodland occupations (30, 31). At a height of 6.5 m above the Delaware River at the confluence of Brodhead Creek, Shawnee-Minisink remains one of the most spatially intact Clovis deposits known in eastern North America (30, 32, 33). The Paleoindian deposits are buried by ≈240 cm of alluvial and eolian sediments. The cultural zone that contains the Clovis-age occupation has been tentatively interpreted as a silt loam loess deposit (33–35). During the Holocene, overbank alluvium was responsible for much of the deposition in the upper 2 m of the profile (Fig. S5).

The Clovis occupation at Shawnee-Minisink is well dated with six AMS radiocarbon assays from three hearth features, directly associated with Paleoindian artifacts (32). Using the protocol described by Long and Rippeteau (36), these six dates produce an average age of 10,935 ± 15 BP (*ca*. 12,900 Cal yr BP). Based on these dates and the location of artifacts, which occur only within the central portion of stratum 7Bwb (240–268 cm), we consider the upper portion of this level to represent the Younger Dryas Boundary (YDB). Although no other radiocarbon dates have been obtained from the lower levels of the profile, a Late Paleoindian deposit resting at the top of 5Bwb in some of the excavation units (31) may represent the end of the Younger Dryas dating to approximately 10,000 ^{14}C BP (*ca*. 11.6 kyr BP) (32) (Fig. S5).

Our sample column was taken from Unit 1 of the new excavation block (32, 33, 38) (Fig. S5). Samples were collected by stratigraphic horizon beginning at a depth of 199 cm below surface and ending at a depth of 350 cm. This strategy allowed for an even number of samples to be collected both from above and below the YDB (Fig. S5). Only one sample from this sequence was not collected, stratum 8C. Stratum 8C is a 10-cm sand lens and did not provide sufficient sediment for analysis.

Topper, SC. The Topper site is a multicomponent site in Allendale County, SC in the Savannah River Valley. The site contains a relatively complete cultural sequence, including Clovis and a possible pre-Clovis component (39). Our sample column was collected from a profile in an excavation unit in the 2008 Upper Firebreak excavations within colluvial sands that bury the Clovis occupation. The sediment column includes 11 samples continuously spanning a depth of 92 cm (Fig. S6). Limited chronological control is available beyond the presence of time-diagnostic cultural materials. An OSL date taken in association with the Clovis component in another area of the site produced an age of 13.5 ± 1.0 kyr BP (35), consistent with the dating of Clovis elsewhere (25). In our sample column, the Clovis component occurs at a depth of ≈80–90 cm beneath the surface, and, like Firestone et al. (1), we assume that the YDB falls within this interval.

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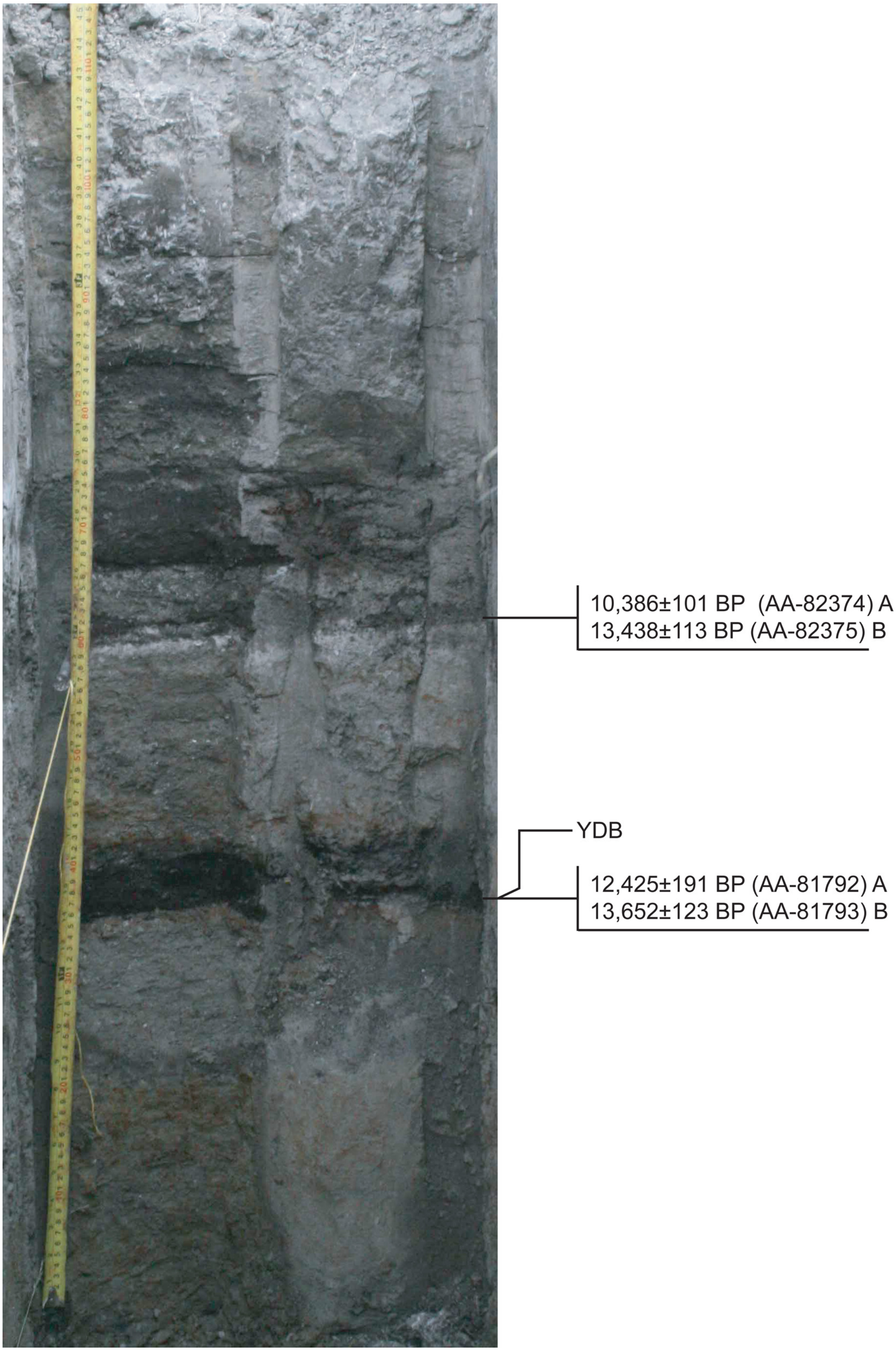

Fig. S1. The sampled section from Agate Basin Area 1, stratigraphically beneath the Agate Basin complex bison bone bed with uncalibrated radiocarbon ages. Abbreviations: YDB, estimated position of the Younger Dryas Boundary; A, humic acid fraction; B, humin fraction.

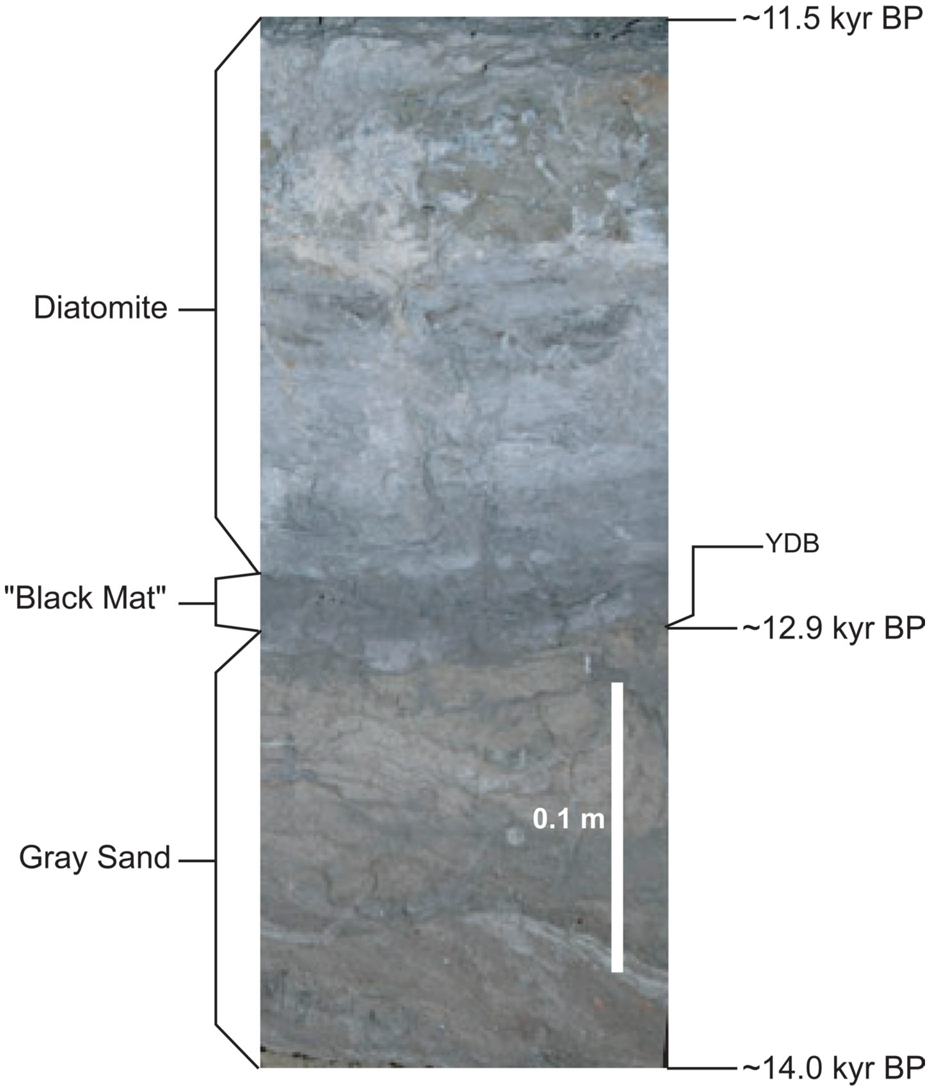

Fig. S2. The sampled section from Blackwater Draw. YDB marks the estimated position of the Younger Dryas Boundary.

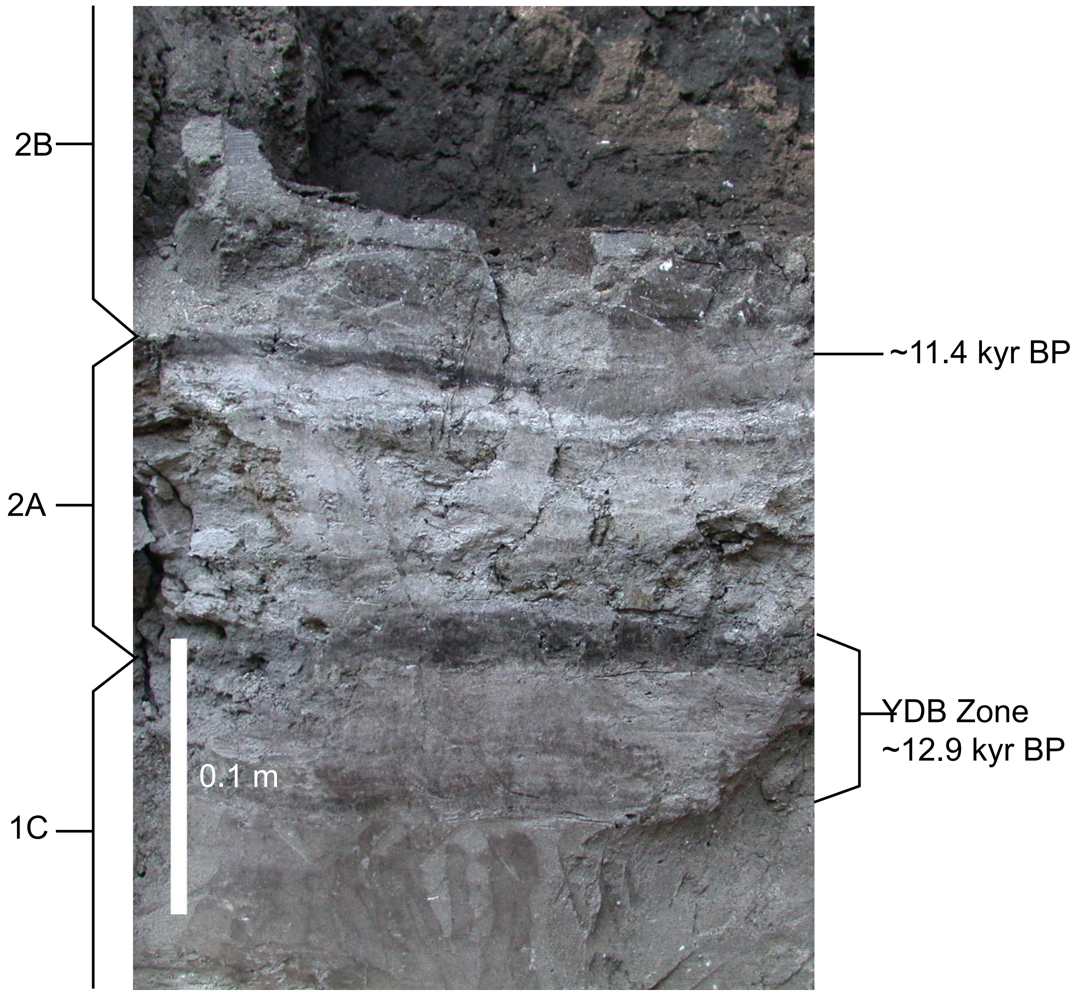

Fig. S3. The sampled section from Lubbock Lake. YDB Zone marks the approximate position of the Younger Dryas Boundary. Stratigraphic designations (*Left*) are taken from Holliday (20).

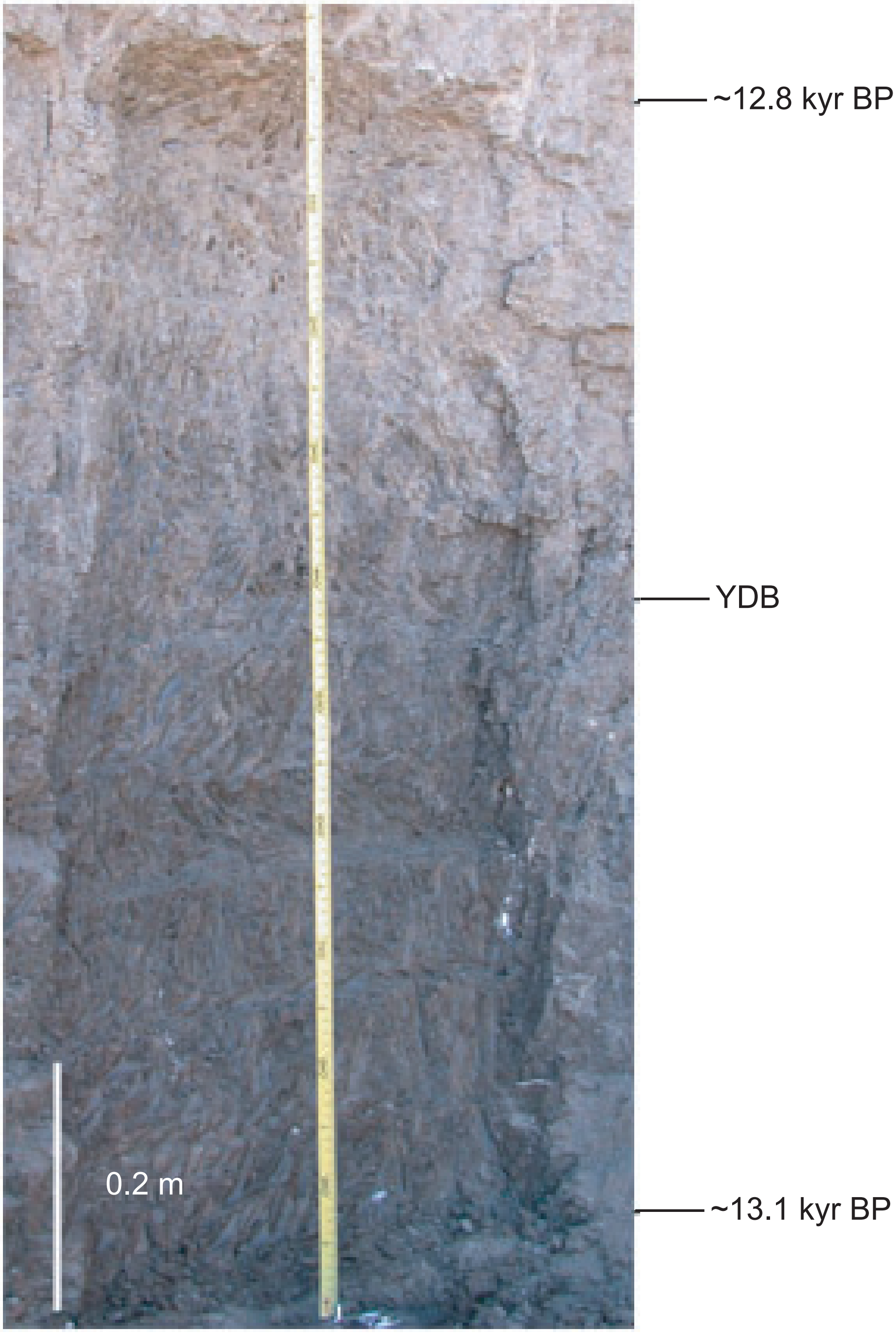

Fig. S4. The sampled section from the San Jon site. YDB marks the approximate position of the Younger Dryas Boundary.

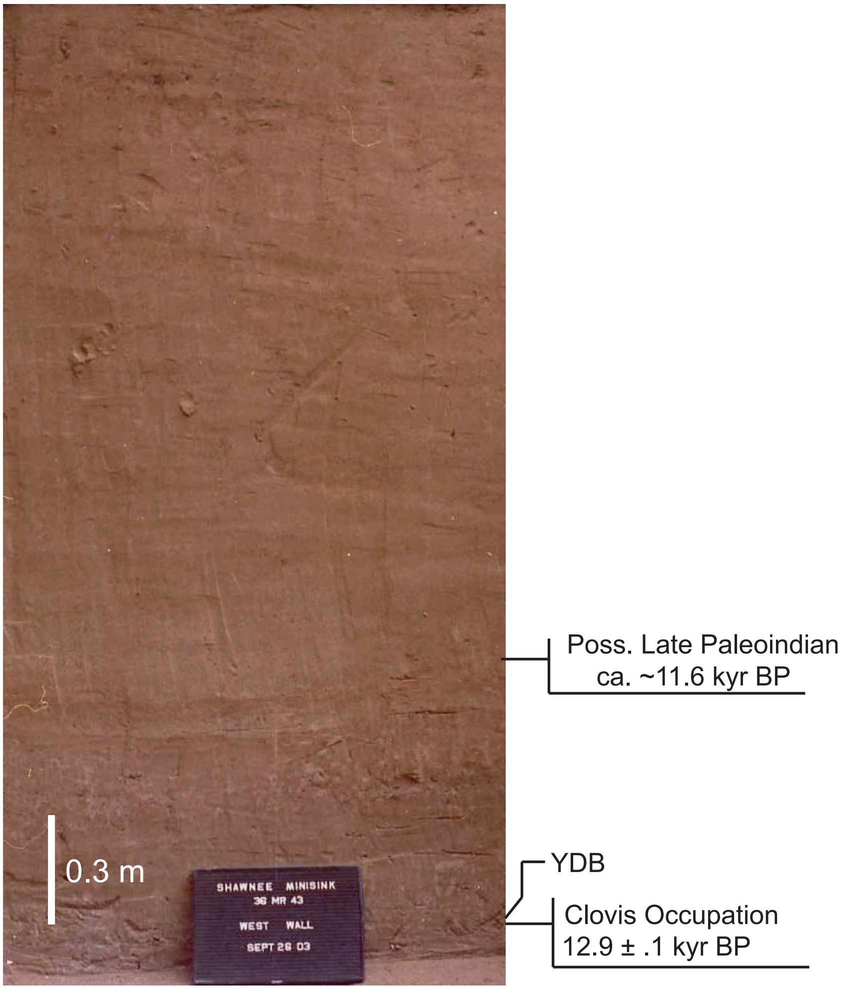

Fig. S5. Stratigraphic section from Shawnee-Minisink, PA. The sampled section was from the same excavation unit. Age control for the Clovis occupation is based on an average of six radiocarbon dates.

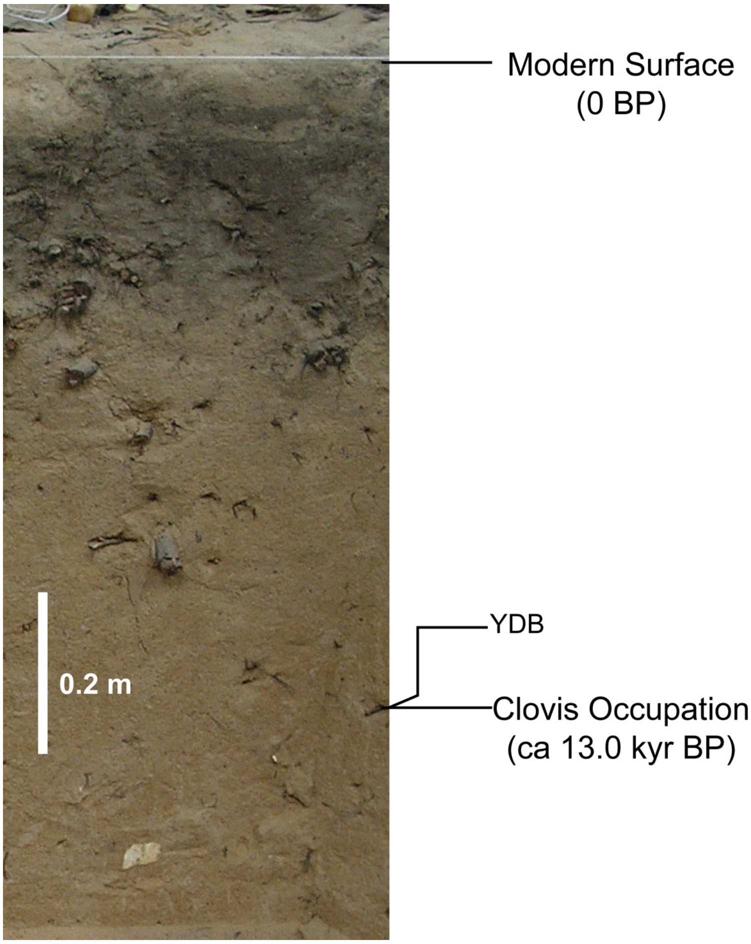

Fig. S6. The sampled section from the Topper site. YDB marks the estimated position of the Younger Dryas Boundary.

Table S1. Concentrations of magnetic grains and microspherules by site and sample

Site	Depth, cm	Magnetic grains, g/kg	Magnetic spherules, no./kg
Agate Basin, WY	165–175	1.222	217
Agate Basin, WY	175–185	1.261	139
Agate Basin, WY	185–195	3.063	88
Agate Basin, WY	195–205	2.198	0
Agate Basin, WY	205–215	2.286	0
Agate Basin, WY	215–225	3.137	255
Agate Basin, WY*	225–235	1.480	141
Agate Basin, WY	235–245	1.698	124
Agate Basin, WY	245–255	2.322	0
Agate Basin, WY	255–265	1.801	0
Blackwater Draw, NM	0–5	0.363	11
Blackwater Draw, NM	5–10	0.388	17
Blackwater Draw, NM	10–15	0.352	14
Blackwater Draw, NM*	15–20	0.256	0
Blackwater Draw, NM	20–25	0.579	0
Blackwater Draw, NM	25–30	0.602	0
Blackwater Draw, NM	30–35	0.598	0
Topper, SC	0–5	1.461	0
Topper, SC	5–10	1.390	0
Topper, SC	10–20	0.794	0
Topper, SC	20–30	1.327	0
Topper, SC	30–40	0.991	0
Topper, SC	40–50	0.986	0
Topper, SC	50–60	1.334	0
Topper, SC	60–70	1.288	0
Topper, SC	70–80	1.436	0
Topper, SC*	80–90	1.111	0
Topper, SC	90–92	1.033	0
Paw Paw Cove, MD	38–48	2.228	0
Paw Paw Cove, MD	48–58	2.525	0
Paw Paw Cove, MD*	58–68	1.099	0
Paw Paw Cove, MD	68–78	0.815	0
Paw Paw Cove, MD	78–88	0.567	0
Paw Paw Cove, MD	88–98	0.493	0
Lubbock Lake, TX	40–49	0.285	0
Lubbock Lake, TX	49–53	0.064	20
Lubbock Lake, TX	53–60	0.075	17
Lubbock Lake, TX	60–67	0.053	0
Lubbock Lake, TX*	67–73	0.132	13
Lubbock Lake, TX	73–75	0.357	0
San Jon, NM	140–150	0.552	0
San Jon, NM	200–210	0.613	0
San Jon, NM	210–220	0.602	0
San Jon, NM	220–230	0.587	22
San Jon, NM*	230–240	0.520	0
San Jon, NM	240–250	0.630	24
San Jon, NM	250–260	0.658	0
San Jon, NM	260–270	0.544	0
San Jon, NM	270–280	0.691	24
San Jon, NM	280–290	0.473	0
San Jon, NM	290–300	0.576	17
Shawnee-Minisink, PA	199–212	3.568	0
Shawnee-Minisink, PA	212–229	5.798	0
Shawnee-Minisink, PA	229–240	10.081	0
Shawnee-Minisink, PA*	240–268	7.1284	0
Shawnee-Minisink, PA	273–299	3.117	0
Shawnee-Minisink, PA	299–311	7.970	0
Shawnee-Minisink, PA	311–350	7.721	0

*Younger Dryas boundary sample.