Supporting Information

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SI Text

Research Sites. Site location information is summarized in Dataset S1. Radiocarbon and calendar ages of black mats are given in Dataset S2. All ages discussed below are presented in calendar ages.

Sites in the American Southwest. ***Murray Springs, Arizona.*** Famous for its remarkable Clovis-age Paleoindian artifacts, megafauna remains, and exposures of arid-land stratigraphy, Murray Springs contains one of the most photogenic black mats in the Desert Southwest (Fig. 2*A*). Dating to 12.9 ka, the black mat at Murray Springs has been sampled repeatedly by both the "pro" and "con" sides of the impact debate. At two locations, we sampled sediments from three distinct profiles separated laterally by approximately 10 m to determine the amount of variation in the concentration of impact markers over a given area. Note that our sample set "Murray Springs 1b" was taken from the exact location that was sampled by Firestone et al. (1) and later by Haynes et al. (2).

Dove Spring, CA. Sediments at Dove Spring, CA, just outside of Red Rocks State Park, contain alternating sequences of alluvial/colluvial sands and gravels that are interbedded with multiple thin (5–20 cm) organic-rich silty clay units (black mats) that contain fossil gastropod shells and ostracodes. Fossil shells of the terrestrial gastropod family Succineidae were used for ^{14}C dating (see rationale below), and yielded ages that range from 11.4 to 12.5 ka. We sampled sediments at Dove Spring at multiple depth intervals, including three of the most pronounced black mats exposed in the outcrop.

South Sierra, CA. A 3-m section of paleowetland sediments is exposed approximately 200-m upslope of an active spring mound adjacent to California State Highway 178. The sediments include a well-developed black mat that dates to 10.8 ka. As with other sites, we collected sediment samples from above and below the black mat for background purposes, as well as the basal sediments and the black mat itself.

Sites in the Atacama Desert of Northern Chile. ***Quebrada del Chaco.*** Quebrada del Chaco (or Chaco Canyon) consists of two distinct branches, Chaco Norte and Chaco Sur (3). We sampled three sections in the Chaco system, Chaco 12 in the norte branch and Chaco 2 and 5 in the sur branch (3). We sampled a total of eight black mats at three locations that dated to the late Pleistocene that ranged in age from 11.5 ka at Chaco 5 to 16.6 ka at Chaco 12.

El Salto. Extensive wetland deposits that fed into the now-dry Salar de Punta Negra were first reported by Quade et al. (4). We sampled five black mats at two sections in the "El Salto" area of these deposits, El Salto 1 (Quade's Station 49) and El Salto 2 (Quade's Station 43). Similar in age to the Chaco deposits, the black mats at El Salto ranged in age from 12.7 to 15.6 ka.

Quebrada Agua de Cascabel (QAC). This site contains two distinct wetland deposits dating to the late Pleistocene (QAC 2; 13.7 ka) and the Pleistocene-Holocene transition (QAC 4; 10.6 ka), as well as an active spring mound.

Rio Salado. Originally studied by Rech et al. (5), wetland deposits at Rio Salado include an approximately 3-m section that contains alternating thin beds of organic-rich silt (black mats) and diatomaceous silt and clay. The section sampled here was the same as Unit A of Rech's Station 21, and includes several black mats that are beyond the limit of ^{14}C dating (i.e., >40 ka). The three mats sampled in this study were the thickest, best-developed mats in the sedimentary sequence.

Tilomonte. Also studied originally by Rech et al. (5), wetland deposits at Tilomonte include an approximately 3-m section that contains multiple black mats. The section sampled here was the same location as Rech's Station 7, and dates to the mid-Holocene.

Radiocarbon Dating. Samples used for radiocarbon dating included terrestrial gastropod shells (Dove Spring, CA) and organic matter (all others). Multiple fossil shells of the Succineidae family were collected from fine-grained deposits at Dove Spring, CA for radiocarbon dating. Terrestrial gastropod shells are often avoided for ^{14}C dating because many taxa incorporate carbon derived from limestone or other carbonate rocks when building their shells (6). Recent studies, however, have shown that some small taxa, including Succineidae, avoid this "limestone problem" even when living in environments in which carbonate rocks are readily available (7). Moreover, these shells appear to act as closed systems with respect to carbon over geologic timescales and should yield reliable ^{14}C ages for the Holocene and late Pleistocene.

Fossil shells were cleaned with 3% H_2O_2 for 24–48 h at room temperature to remove residual organic material, washed repeatedly with ultrapure water (American Society for Testing and Materials type I, 18.2 MΩ), briefly leached in dilute HCl to remove adhering carbonate dust, and rinsed again before being dried in a vacuum oven at 70 °C. CO_2 was extracted from the shell aragonite by hydrolysis.

Samples of organic material in the form of plant macrofossils, carbonized wood, and undifferentiated organic matter were collected from black mats at all sites except Dove Spring, CA. Organic samples were treated subjected to the standard acid-base-acid pretreatment procedures used in radiocarbon laboratories worldwide. In most cases, the base-insoluble (A fraction) of the organic matter was submitted for analysis. In others, the base-soluble (or B fraction) was analyzed (Dataset S2). CO_2 was extracted from the treated materials by combustion.

For all samples, one aliquot of the CO_2 gas was converted to graphite either using an Fe catalyst in the presence of excess hydrogen or catalytic reduction of CO using a Zn catalyst. The resulting graphite was pressed into pellets (or targets) and analyzed by accelerator mass spectrometry. A second aliquot of CO_2 was submitted for $\delta^{13}C$ analysis to correct for isotopic fractionation. Radiocarbon ages were converted to calendar years using the IntCal09 dataset and CALIB v.6.0.0 (8, 9).

Magnetic Grains and Spherules. We followed the sample preparation procedures of the original Firestone et al. (1) as closely as possible to minimize any differences in our data due to laboratory procedures. We typically collected 200–500 g of sample material in the field, which was lightly disaggregated using a ceramic mortar and pestle. Samples were then homogenized and split using a standard laboratory splitter prior to physical and chemical analyses. In our view, systematic homogenization and subsampling is essential to ensure that sample bias based on grain size or density is not introduced or that trace elements/physical prop-

erties are not missed when analyzing the samples for the impact markers.

For each sample, magnetic grains were removed from approximately 100-g aliquots of bulk sediment using grade-42 neodymium magnets wrapped in plastic bags as described initially by Firestone et al. (1) and later by Surovell et al. (10). We also attempted to use a quantitative method to collect the magnetic grains (11), but the magnets used in the system were not as strong as the Nd magnets and the results did not show a clear correlation with the handheld magnet approach. Therefore, we report only the data collected using the Nd magnets to ensure direct comparison between our magnetic grain data and previous studies.

Magnetic spherules were counted using the conservative criteria described by Surovell et al. (10). We emphasize that implementing even the most conservative criteria to count magnetic spherules is made difficult by the issue of subdued facets that appear differently when observed under different levels of magnification (12). Like previous studies, we only counted spherules if they appeared rounded and polished under 100× magnification.

Iridium—Bulk Sediment. Bulk sediment samples were measured for iridium by instrumental neutron activation analysis (INAA) at the US Geological Survey in Denver, CO. INAA analysis was conducted on samples that were at least 10 g in mass to avoid any complications related to "nugget effects" (after ref. 13). Average measurement uncertainties for the bulk sediment samples were generally less than 0.1 ppb (Dataset S3).

Iridium—Magnetic Sediment. Magnetic sediment samples were analyzed by INAA when enough material was available (Dataset S3). Average measurement uncertainties for the magnetic sediment samples were significantly higher, averaging approximately 1 ppb, because the sample sizes were generally quite small and often near the practical limit of the technique.

Rare Earth Element Data. Rare earth elements (REEs) include the periodic row of lanthanides that range in atomic number from 57 to 71 (La to Hf). These elements are quite resistive to chemical exchange and only two, Ce^{4+} and Eu^{2+}, form different ions in nature (14). Thus, when normalized to chondritic ratios (15) and plotted in series against their atomic numbers, REEs of crustal rocks exhibit several predictable features, including enriched concentrations of lighter REEs, a negative Eu anomaly, and depleted concentrations of heavier REEs (16). Moreover, REE concentrations in crustal rocks are approximately two orders of magnitude higher than in chondrites and, presumably, cosmic dust (17). The samples measured by INAA in this study consistently exhibited all of these features, and fall squarely in the terrestrial realm (Fig. S1; Dataset S4 *A* and *B*).

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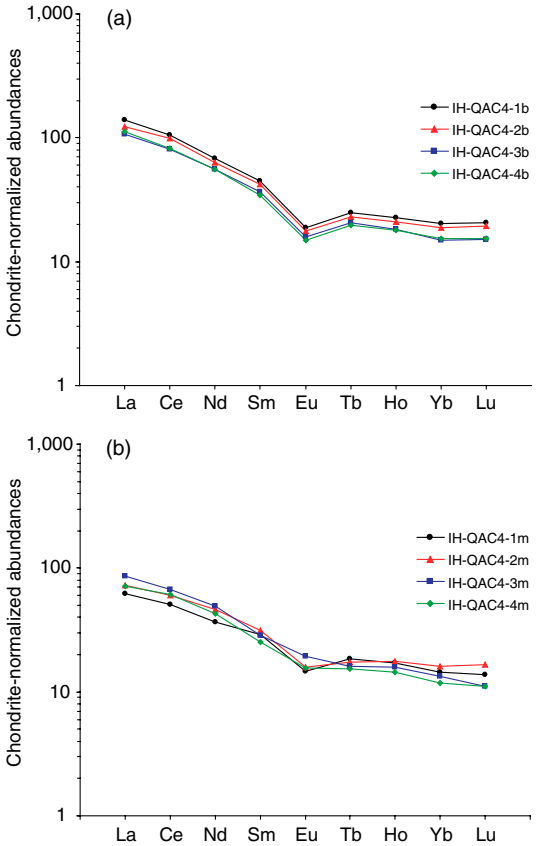

Fig. S1. Chondrite-normalized rare earth element (REE) abundances measured by INAA for (*A*) bulk (designated as "b") and (*B*) magnetic sediments ("m") for samples collected at QAC 4. In both sets, samples are numbered as 1, below the black mat; 2, basal contact; 3, within the black mat; and 4, above the black mat. All samples shown here exhibit REE concentrations typical of terrestrial (crustal) rocks, and are representative of most samples analyzed in this study.

Other Supporting Information Files

Dataset S1 (XLS)
Dataset S2 (XLS)
Dataset S3 (XLS)
Dataset S4 (XLS)