Evidence from central Mexico supporting the Younger Dryas extraterrestrial impact hypothesis

Isabel Israde-Alcántara1, James L. Bischoff2, Gabriela Domínguez-Vázquez2, Hong-Chun Li3, Paul S. DeCarli4, Ted E. Bunch1, James H. Wittke1, James C. Weaver4, Richard B. Firestone1, Allen West1, James P. Kennett5, Chris Mercer5, Sujing Xie6, Eric K. Richman7, Charles R. Kinzie8, and Wendy S. Wolbach9

1Instituto de Investigaciones Metalúrgicas, Departamento de Geología y Mineralogía, Universidad Michoacana de San Nicolás de Hidalgo, C. P. 58060, Morelia, Michoacán, México; 2US Geological Survey, Menlo Park, CA, 94025; 3Facultad de Biología, Universidad Michoacana de San Nicolás Hidalgo C. P. 58060, Morelia, Michoacán, México; 4Department of Geosciences, National Taiwan University, Taipei 106, Taiwan, Republic of China; 5SRI International, Menlo Park, CA 94025; 5Geology Program, School of Earth Science and Environmental Sustainability, Northern Arizona University, Flagstaff AZ 86017; 6Wyss Institute for Biologically Inspired Engineering, Harvard University, Cambridge, MA 02138; 7Lawrence Berkeley National Laboratory, Berkeley, CA 94720; 8GeoScience Consulting, Dewey, AZ 86327; 9Department of Earth Science and Marine Science Institute, University of California, Santa Barbara, CA 93106; 10National Institute for Materials Science, 1-2-1 Sengen, Tsukuba, Ibaraki, 305-0047, Japan; 11CAMCOR High Resolution and MicroAnalytical Facilities, University of Oregon, Eugene, OR 97403; 12Materials Science Institute, University of Oregon, Eugene, OR 97403; and 13Department of Chemistry, DePaul University, Chicago, IL 60614

**AUTHOR SUMMARY**

We report the discovery of unusual materials in a 10-cm-thick layer of sediment obtained from Lake Cuitzeo in central Mexico consistent with extraterrestrial impacts and/or atmospheric airbursts at the onset of Younger Dryas (YD), a geologically brief period of cold climatic conditions and drought, caused by the collapse of the North American Ice Sheets 12,900 y before present (BP). Firestone et al. (1) first reported major abundance peaks in magnetic spherules and carbon spherules within a thin layer (0.5 to < 5 cm) called the Younger Dryas boundary layer (YDB), found across North America and Western Europe. This layer is commonly located beneath a broadly distributed, black, organic-rich layer, called the “black layer.” Subsequently, Kennett et al. (2) observed nanodiamonds in the YDB in North America; they were also reported in the Greenland Ice Sheet in a discrete layer dating approximately to the YD onset. The proposed impacts may have played a role in initiating the abrupt YD cooling at 12,900 BP; caused widespread biomass burning, and contributed to major declines in human populations and to the extinction of Late Pleistocene megafauna, such as mammoths, mastodons, and giant sloths.

Although some workers have been unable to replicate the YDB evidence, others have confirmed it, although sometimes suggesting alternate hypotheses. In Venezuela, Mahaney et al. (3) independently identified 12,900-year-old abundance peaks in high-temperature melt-rocks, shocked quartz, carbon spherules, and a carbon-rich black mat analogue, concluding that the cause was “either an asteroid or comet event that reached far into South America.” Haynes et al. (4) observed high concentrations of magnetic spherules and iridium in the YDB at Murray Springs, Arizona, and stated that their findings are “consistent with their [Firestone et al.’s] data.” Tian et al. (5) observed abundant YDB nanodiamonds in amorphous carbon from Lommel, Belgium, concluding “our findings confirm the existence of diamond nanoparticles also in this European YDB layer.”

The unusual materials were discovered in a 27-m-long lake core from Lake Cuitzeo, the second largest lake in Mexico. Our attention focused on an anomalous, 10-cm-thick, carbon-rich layer at 2.8 m that dates to the YD onset and contains a major fraction of carbon that is radiocarbon dead (i.e., older than 50,000 y). In this layer, we discovered a diverse, abundant assemblage of markers, including nanodiamonds, carbon spherules, and magnetic spherules with rapid melting/quenching textures. The markers peak at the same time immediately beneath a layer containing the largest charcoal peak in the core.

We utilized a total of 22 accelerator mass spectrometry (AMS) 14C dates and generated an age-depth curve that permitted identification of the Younger Dryas interval. The pollen, diatom, and algal records from Lake Cuitzeo correlate with the YD boundary layer.

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1To whom correspondence should be addressed. E-mail: jsbischoff@usgs.gov.

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well with records from several regional lakes in Guatemala, Costa Rica, and Panama, as well as with records from the Cariaco Basin and the Greenland Ice Sheet. These records indicate that dramatic environmental, geochemical, and biotic changes occurred throughout the region at the onset of the YD episode at 12,900 BP.

There is an anomalous interval at 2.8 m that dates to the YD onset and displays unusually high percentages of total organic carbon (TOC)—up to 15.8%. Carbon-rich material in this interval is not the normal plant-derived organic matter dominating the rest of the 27 m core; instead, it represents major contamination of the TOC by radiocarbon-dead or very old carbon (92 wt%). This material may be analogous to the carbon-rich black matter reported across North America that dates to the YD onset (4). Its source remains enigmatic and unclear.

Black carbon spherules reach a significant YDB peak of approximately 680/kg at 2.75 m (Fig. P1). These spherules are 20 to 260 μm in diameter (average of 90 μm), ovoid-to-round with cracked roughened surfaces, typically having a thin rind with a spongy interior containing vesicles within a smooth, homogeneous matrix. Charcoal microparticles (>125 μm) reached a major peak of 77,000 particles/kg (15 × background) beginning just after the onset of YD cooling, indicating a major episode in biomass burning.

Magnetic spherules range from 25 to 100 μm in diameter (averaging 60 μm), and typically appear as highly reflective, black spheroids. They display surface textures indicative of melting with rapid quenching that precludes typical terrestrial formation processes. These spherules are conspicuous and abundant at 2.8 m (2,000/kg), where they form a sharp peak in the YDB (Fig. P1).

Analysis by energy-dispersive X-ray spectroscopy (EDX) demonstrates that these spherules are geochemically distinct from volcanogenic and cosmic material. Instead, Cuitzeo magnetic spherules are consistent with the composition of >1,000 tektites (impact-related glass rocks) and magnetic spherules from eleven craters and large areas of tektites formed by extraterrestrial impact into terrestrial rocks.

Because of the controversial nature of the YD impact debate, we conducted more comprehensive analyses on YDB nanodiamonds than in previous investigations. Analyses included high-resolution transmission electron microscopy (HRTEM), scanning TEM (STEM), and EDX, all of which clearly revealed a single major peak in nanodiamonds centered across two samples at 2.8 and 2.75 m. This interval dates to the YD onset at 12,900 BP (Fig. P1) and is synchronous with the peak in magnetic spherules and carbon spherules. The nanodiamonds varied in diameter from approximately 1 to 10 nm, averaging to approximately 4 nm, and were often embedded in amorphous carbon, as previously reported from Belgium (5). They reached a maximum abundance of approximately 100 ± 50 ppb at 2.8 m. We identified three of four previously reported nanodiamond variants, of which n-diamond was most abundant, with lesser amounts of i-carbon and lonsdaleite, a widely accepted impact indicator, as previously reported in North America (2). NDs were rare below the 2.9 m layer (≤1 ppb), whereas they were observed at low concentrations of 4 to 10 ppb above the 2.75 m layer, probably due to the geological process of reworking.

Speculation that copper, graphene, and graphane had been misidentified as YDB nanodiamonds is refuted by our identification of characteristics consistent with nanodiamonds and inconsistent with those other materials.

We also observed carbon onions, nanometer-sized nanoparticles constructed of concentric carbon shells from 2 to 10 nm in diameter. Some carbon onions contained nanodiamonds in their cores, and these nanodiamonds could only have formed at high temperatures under oxygen-deficient conditions that are not known to exist on Earth naturally. Their presence is consistent with known conditions within a cosmic impact.

We propose the following impact model to explain the observed data. A comet or asteroid, greater than several hundred meters in diameter, entered Earth’s atmosphere at a relatively shallow angle (>5° and <30°). Thermal radiation from the air shock reached Earth’s surface and thermally decomposed terrestrial carbon, silica, and iron below the flight path of the impactor. Nanodiamonds, carbon spherules, and other carbon species formed through a chemical-vapor-deposition-like process similar to TNT detonation, and simultaneously, magnetic spherules formed from melted iron and silica. Seconds later, the air shock lofted the melted materials into the upper atmosphere and distributed them across the Northern Hemisphere.

Multiple hypotheses have been proposed to explain the assemblage of markers identified in the YDB, and all but one can be rejected. For example, the magnetic spherules and nanodiamonds cannot result from misidentification or from cosmic influx or any known terrestrial mechanism, including wildfires, volcanism, or anthropogenic processes. Currently, only an extraterrestrial impact is capable of explaining the many types and wide distribution of evidence. In the entire geologic record, there are only two known continent-wide layers containing nanodiamonds, magnetic spherules, carbon spherules, and aciniform soot: the Cretaceous-Paleogene impact boundary (KPg) at 65 Ma and the YD boundary at 12,900 BP. Thus, the YDB evidence is uniquely consistent with a major extraterrestrial impact event 12,900 y ago.