Independent evaluation of conflicting microspherule results from different investigations of the Younger Dryas impact hypothesis

Malcolm A. LeCompte*,†, Albert C. Goodyear‡, Mark N. Demitroff‡, Dale Batchelor‡, Edward K. Vogel‡, Charles Mooney§, Barrett N. Rockf, and Alfred W. Seidelg

*Center of Excellence in Remote Sensing Education and Research, Elizabeth City State University, Elizabeth City, NC 27921; ‡South Carolina Institute of Archaeology and Anthropology, University of South Carolina, Columbia, SC 29208; †Department of Geography, University of Delaware, Newark, DE 19716; gAnalytical Instrumentation Facility, North Carolina State University, Raleigh, NC 27695; ‡Department of Psychology, University of Oregon, Eugene, OR 97403; †Institute for the Study of Earth, Oceans and Space, University of New Hampshire, Durham, NH 03824; and Seidel Research, Camden, NC 27921

AUTHOR SUMMARY

Firestone et al. (1) proposed that a cosmic impact event occurred at the onset of the Younger Dryas (YD) cooling, 12,900 years ago. They reported discovery of enhanced numbers of magnetic microspherules at numerous, widely distributed sites in sediment dating to the YD Boundary (YDB). Spherules were proposed to be either ablated impactor material or terrestrial ejecta from one or more impacts centered on the Laurentide Ice Sheet. Surovell et al. (2) attempted to replicate these results, but found few or no spherules, and Pinter et al. (3) dismissed the spherules as misidentified products of non-impact related processes. Sedimentary iron- and silica-rich spherules can form by meteoritic ablation, sudden cooling of molten terrestrial ejecta from an extraterrestrial (ET) impact (4), volcanism, industrial processes, or slow biological and physical processes.

Surovell et al., asserting adherence to the Firestone et al. protocol, examined YDB and adjacent sediment sequences at seven North American archeological sites. They observed no YDB layer abundance peaks at all sites, and at five sites, they found zero spherules in YDB strata. Investigating the discrepant findings of Firestone et al. and Surovell et al., we conducted a blind study of a discontinuous sequence of four strata, one at the YDB and three bracketing it, from two archeological sites common to both studies. We also examined a single sample of YDB stratum at a site common only to Surovell et al. Our research was limited to investigating: (i) spherule stratigraphic abundances; (ii) spherule morphology and elemental abundances; (iii) research methodology differences; and (iv) microspherule evidence that might be archeologically relevant to Firestone et al.’s predicted post-YDB human population decline. Samples were collected from sites associated chronologically with a prehistoric Paleo-Indian culture known as Clovis, four each at Topper (TPR), Allendale, SC and Black Water Draw (BWD), NM, and one at Paw Paw Cove (PPC), MD.

Using the Firestone et al. protocol, magnetic grains were extracted from sediment samples using a neodymium-boron super magnet. Magnetic grains were sorted into size-fractions, the smallest with dimensions <53 μm, and we report spherule abundances from only that smallest fraction. Several portions of each site’s grains were examined for spherules using an optical microscope at approximately 130 power magnification.

At TPR, a stratum containing extensive stone-tool production debris was found. Immediately above the debris were very few human artifacts indicating a quarry dormant for 600–1200 years, then reoccupied. Sediment directly atop the layer of debris was removed, and pieces of Clovis debris were uplifted to collect underlying sediment to test the possibility of a ‘chert shadow’ effect. TPR spherule concentrations exhibited a peak of approximately 260 spherules/kg in the thin YDB layer above the debitage, decreasing significantly below their shadowing debris. The lowest spherule abundance coincided with high quarry usage while spherule abundance peaked in the layer corresponding to the start of a period of quarry dormancy. A similar procedure was not possible at the other two sites. At BWD, spherule abundance in the YDB stratum was 624 spherules/kg. An abundance peak in the stratum just above YDB yielded twice that number, perhaps due to fluvial enrichment. Spherule abundance in the single PPC sample of YDB age was 317 spherules/kg. YDB spherule diameters averaged approximately 30 μm. Unlike the other two sites, the TPR YDB-layer contained abundant (≥1000/kg) terrestrial spheroidal framboids, although it is unclear why. YDB-layer spherule abundances reported by the three studies are summarized in Fig. P1B.

The authors declare no conflict of interest.

This Direct Submission article had a prearranged editor.

†To whom correspondence should be addressed. E-mail: malcolm.lecompte@ceser.ecsu.edu.

See full research article on page E2960 of www.pnas.org.

Cite this Author Summary as: PNAS.10.1073/pnas.1208603109.
Scanning electron microscope (SEM) imaging and energy-dispersive X-ray spectroscopic (EDS) analysis were performed on approximately 50 YDB spherules (≥6 from each YDB layer) were extracted to determine their surface. While magnetic spherule surface morphology due to meteoritic ablation, terrestrial impact ejecta, or anthropogenic sources are nearly indistinguishable (4, 5), it is differentiable from those produced by other natural terrestrial processes. We were thus able to distinguish YDB-layer spherules from other possible spherule populations using electron microscopic imagery (Fig. P1A) and spectroscopic analyses. Essentially all YDB spherules displayed features indicative of melting and rapid cooling, and spherules were frequently perforated, exposing interior voids.

Geochemical analyses showed spherules typically exhibited high iron oxide with varying amounts of silicon, aluminum, and titanium. About 20% of the spherules recovered at TPR and BWD and 83% of those at PPC were titanium enriched, and a few spherules at TPR were aluminosilicate glass. One PPC spherule was enriched in rare earth elements (REEs), which are well-known constituents of chondritic (stony) meteorites and have been reported in YDB strata. YDB-layer spherules do not appear cosmic in origin, because their abundances of magnesium, iron, and titanium oxides are quite different than those observed in Antarctic cosmic microspherules. Cosmic spherules are typically enriched in MgO and depleted in TiO$_2$, while YDB-layer spherules are depleted in MgO and enriched in TiO$_2$. YDB-layer spherule concentrations peak at depths in very stratified, chronologically-distinct, sedimentary layers, making anthropogenic contamination unlikely.

YDB-layer spherules appear enriched in FeO, SiO$_2$, or TiO$_2$, and these oxides melt at 1550°C, 1730°C, and 1650°C, respectively. The high temperatures inferred from the YDB spherules’ morphology are consistent with the melting and rapid cooling of an energetic and transient process. Wide spherule spatial distribution may be due to a few very energetic event(s) or many dispersed events of lesser magnitude. Spherule stratigraphy indicates deposition occurred over a brief period proximate to YD onset. With the exception of one PPC magnetic spherule enriched in REEs, the compositions of YDB-layer spherules are similar to terrestrial metamorphic rocks and different from those associated with ET objects.

Firestone et al. proposed that a YDB impact triggered a decline in Clovis populations. At TPR, spherule abundance diminished in the “shadow” beneath chert fragments. Reduction in Clovis debris indicated that the quarry became dormant roughly contemporary with spherule deposition. The TPR quarry was one of the region’s most important sources of high-quality chert. Quarry dormancy may thus indicate a population reduction coincident with whatever phenomenon created and deposited the spherules.

Our results are consistent with those reported by Firestone et al. and inconsistent with those reported by Surovell et al. We find the latter’s methodology deviated in three critical respects from Firestone et al.: (i) inadequate size-sorting of the magnetic fraction; (ii) examination of insufficient magnetic material; and (iii) no SEM or EDS analyses of candidate spherules. These protocol deviations are cumulative in their effect, dramatically reducing the probability of successful spherule detection. Our results are consistent with, but do not prove, the YD Impact Hypothesis. The ultimate source of the magnetic microspherules and their apparent concentration in YDB-layer sediment remains a mystery warranting further investigation.