American Geophysical Union, San Francisco, CA December 15 and 19, 2008

Younger Dryas Boundary Impact Abstracts

Oral Presentations (Tuesday, December 16)

1) Presence of all Three Allotropes of Impact-Diamonds in the Younger Dryas Onset Layer (YDB) Across N America and NW Europe

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We report the discovery of all three diamond allotropes (cubic diamond, lonsdaleite, and n-diamond) in an extraterrestrial (ET) impact layer (the YDB), dating to the Younger Dryas onset at 12.9 ka. YDB diamonds are distributed broadly across N America and NW Europe at 15 sites spanning 9,000 km or 23 percent of Earth's circumference. N-

diamonds and lonsdaleite, or hexagonal diamond, do not co-occur with terrestrial diamonds, but are found in meteorites. Lonsdaleite is found on Earth only in association with known ET impacts, and thus, is a definitive impact indicator.

The diamonds were identified by transmission electron microscopy (TEM) using selected area diffraction (SAED), which display reflections corresponding to the following lattice planar spacings definitive of diamond: (1) cubic: 2.06, 1.26, 1.07, and 0.89 A; (2) lonsdaleite: 2.184, 1.261, 1.092, and 0.826 A; and (3) n-diamond: 2.06, 1.26, 1.07, and 0.89 A, plus “forbidden” reflections of 1.78, 1.04, and 0.796 A.

Nanodiamonds are rounded to highly angular, and range in size from 1 to 1700 nm with most between 1 and 50 nm. Concentrations are up to 3700 ppb, equaling more than 1 billion diamonds per cm^3 of sediment (comparable to K/T levels of 3600 ppb). No diamonds were detected above or below the YDB layer at any site tested.

These diamonds could not have formed from volcanic activity, because they combust at temperatures above 500°C in the presence of atmospheric levels of oxygen, and micrometeoritic diamonds are similarly destroyed. Also, the diamonds could not have accumulated from the constant rain of micrometeoritic debris, because multi-billions occur in YDB layer samples, but yet none have been found in non-YDB strata dating from 55,000 RCYBP to present.

YDB diamonds are associated with abundance peaks in magnetic spherules, carbon spherules, soot, and iridium, which can peak in impact layers of known ET events, such as the K/T and the 1908 airburst at Tunguska, Siberia. Furthermore, a high proportion of the nanodiamonds are found deeply embedded within spherical particles of melted plant resins, a fact inexplicable by any normal terrestrial process. Altogether, this evidence strongly suggests that the widespread and abundant nanodiamonds constrained to the thin YDB layer resulted from a major ET impact/airburst at 12.9 ka.

2) Late Pleistocene Megafaunal Extinction Consistent With YDB Impact Hypothesis at Younger Dryas Onset

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At least 35 mammal and 19 bird genera became extinct across North America near the end of the Pleistocene. Modern increases in stratigraphic and dating resolution suggest that this extinction occurred relatively rapidly near 12.9 ka (11 radiocarbon kyrs). Within the context of a long-standing debate about its cause, Firestone et al., (2007) proposed that this extinction resulted from an extraterrestrial (ET) impact over North America at 12.9 ka. This hypothesis predicts that the extinction of most of these animals should have occurred abruptly at 12.9 ka. To test this hypothesis, we have critically examined radiocarbon ages and the extinction stratigraphy of these taxa. From a large data pool, we selected only radiocarbon dates with low error margins with a preference for directly dated biological materials (e.g., bone, dung, etc.) and modern chemical purification techniques. A relatively small number of acceptable dates indicate that at least 16 animal genera and several other species became extinct close to 12.9 ka. These taxa include the most common animals of the late Pleistocene such as horses, camels, and mammoths. Also, the remains of extinct taxa are reportedly found up to, but not above, the base of a widely distributed carbon-rich layer called the black mat. This stratum forms an abrupt, major biostratigraphic boundary at the Younger Dryas onset (12.9 ka), which also contains multiple ET markers comprising the impact layer (the YDB). Surviving animal populations were abruptly reduced at the YDB (e.g., Bison), with major range restrictions and apparent evolutionary bottlenecks. The abruptness of this major extinction is inconsistent with the hypotheses of human overkill and climatic change. We argue that extinction ages older than 12.9 ka for many less common species result from the Signor-Lipps effect, but the impact hypothesis predicts that as new dates are acquired, they will approach ever closer to 12.9 ka. The megafaunal extinction is strongly associated with abrupt and major vegetation changes, abrupt cooling, and widespread biomass burning at the onset of the Younger Dryas over North America. The stratigraphic and chronologic data are consistent with megafaunal extinction being caused by continental-scale ecosystem disruption due to an ET impact.

3) Evaluating the Paleoindian Radiocarbon Record at the Onset of the Younger Dryas: Sensitivity Analyses and Bayesian Chronology-Building

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The onset of the Younger Dryas (13.0-12.9 ka) in North America is marked in the archaeological record by the transition from Clovis to Folsom cultural assemblages, as well as the extinction of many megafauna species. The nature of the transition-gradual or abrupt, continuous or discontinuous, regionally uniform or variable - remains poorly understood because of: 1) low-precision and low-quality radiocarbon records; 2) concerns about the accuracy of the calibration curve before ca. 12.4 ka; and, 3) disagreement on the appropriate statistical models for chronology building. Here we evaluate two approaches to Paleoindian radiocarbon chronology, summed probability distributions and Bayesian phase/boundary models.

Summed probability frequencies have been used as demographic proxies recently, but the effects of sample quality, density, and the variations in the calibration curve are largely unexplored. Sensitivity analyses were done by simulating radiocarbon ages at 10, 25, 50 and 100 cal yr intervals with varying measurement errors, which were calibrated and summed to obtain a probability distribution function for each run. We find that dense, high-precision radiocarbon records are necessary to detect gaps as small as 100 years in the record. Currently available radiocarbon databases for the Paleoindian period can at best be characterized as sparse and of low- to medium-precision, arguing against the use of summed probabilities as a proxy for human activity during that period.

Bayesian statistical models incorporate *a priori* archaeological information (e.g., stratigraphic relationships, cultural assemblage) to constrain calibrated radiocarbon ages leading to more refined chronologies. Selected high-precision, reliable radiocarbon dates were used to build phase and boundary models for Clovis and post-Clovis periods, and to determine the likelihood of a gap between them consistent with depopulation consistent with an ET impact at the Younger Dryas boundary. Model results suggest the possibility of a hiatus, a hypothesis to be further tested with a comprehensive program of high-precision AMS ^{14}C dating at stratified Paleoindian sites.

4) Impact-shocked diamonds, Abrupt Ecosystem Disruption, and Mammoth Extinction on California's Northern Channel Islands at the Ållerød-Younger Dryas Boundary (13.0-12.9 ka)

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Sedimentary records from California's Northern Channel Islands and the adjacent Santa Barbara Basin (SBB) indicate intense regional biomass burning (wildfire) near the Ållerød-Younger Dryas boundary (YDB) at ~13.0-12.9 ka. Multiproxy records in SBB Ocean Drilling Project (ODP) Site 893 indicate that these wildfires coincided with the onset of regional cooling and an abrupt vegetational shift from closed montane forest to more open habitats. Here we report impact-shocked hexagonal diamonds (lonsdaleite) in an organic-rich, dark layer dating to the YDB and deeply buried in Arlington Canyon on Santa Rosa Island, California. Transmission electron microscopy (TEM) demonstrates that these diamonds are mono- and polycrystalline, and electron diffraction confirms the high-pressure hexagonal diamond polymorph. Lonsdaleite has never been found with mantle-derived diamond and is only known on Earth to occur in meteorites and in extraterrestrial impact craters. These crystals co-occur with high concentrations of other nanometer-sized diamond polymporphs (n-diamond; cubic). These discoveries provide strong supporting evidence for an extraterrestrial impact at the Ållerød-Younger Dryas Boundary. The age of these impact diamonds coincides with the last known occurrence of pygmy mammoths (*Mammuthus exilis*) on the Northern Channel Islands, intense regional biomass burning, landscape transformation, vegetational shifts, and an apparent 600-800 year gap in the archaeological record. Taken collectively these data are consistent with abrupt ecosystem disruption triggered by an extraterrestrial airburst/impact at ~12.9 ka, one of many distributed across North America as proposed by the YDB impact hypothesis.

Posters (Monday, December 15)

1) Hexagonal Diamonds (Lonsdaleite) Discovered in the K/T Impact Layer in Spain and New Zealand

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We present the first evidence from Cretaceous-Tertiary (K/T) boundary clay and rock for shocked hexagonal nanodiamonds (lonsdaleite), these being found in concentrations greater than 50 ppm at Needles Point, New Zealand, and Caravaca, Spain. This is also the first evidence for K/T diamonds of any kind outside of North America. No diamonds were detected immediately above or below the impact layer.

Cubic diamonds have been reported earlier from North American K/T sediments by Carlisle and Braman (1991; 45 ppm) and Hough et al. (1997; 18 ppm), but lonsdaleite was not detected. Carlisle and Braman suggested that the cubic diamonds arrived already formed within the impactor, but Hough argued that they were shock-produced by the impact with Earth. Hence, it is not yet clear that K/T cubic diamonds were formed through shock.

Lonsdaleite does not co-occur with terrestrial diamonds but is found with cubic diamonds in ET impact craters (e.g., Popigai, Sudbury). Both also have been reported in the impact layer of the proposed Younger Dryas impact event at 12.9 ka. Lonsdaleite is formed by shocking carbonaceous material, e. g., graphite, under extreme conditions of pressure and temperature (more than 15 GPa at more than 1000°C), thus making this mineral an excellent impact-shock indicator (DeCarli, 2002). Although lonsdaleite is also contained in meteorites, such as ureilites, there appears to be a consensus of opinion that crater-related lonsdaleite formed during ET impact.

K/T sediment samples were acquired from the boundary layer, as well as above and below. To extract the diamonds from the sediments, we utilized the protocol from Amari (1994) and Huss and Lewis (1995), but modified their methodology after determining that phosphoric and perchloric acids oxidize metastable lonsdaleite at 200C. We extracted the diamonds successfully after eliminating those acids, which may explain why lonsdaleite was not apparent in extractions by others. The extracted lonsdaleite was analyzed by transmission electron microscopy (TEM) and by selected area diffraction (SAED), which displayed characteristic reflections corresponding to lattice planar spacings of 2.18, 1.26, 1.09, and 0.82 A. A scanning electron microscope (SEM) with energy dispersive X-ray spectroscopy (EDS) confirmed their carbon composition. With exposure to long-wave ultraviolet (365 nm) radiation, clusters of lonsdaleite crystals exhibited a blue fluorescence that is characteristic of many diamonds. Individual crystals were angular to sub-rounded in shape and ranged in size from 20 to 1000 nm, with a mean size of about 50 nm.

This discovery represents (1) the strongest available evidence for K/T diamond formation during the impact; (2) the first discovery of K/T diamonds outside North America; and (3) the first occurrence of any form of K/T diamonds in the Southern Hemisphere, about 12,000 km from the Chicxulub Crater in Mexico.

The Effect of the Younger Dryas on Paleoindian Occupations in Eastern North America: Evidence from Artifactual, Pollen, and Radiocarbon Records

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The Younger Dryas appears to have been a period when human populations in Eastern North America were undergoing significant stress. Attribute and locational data on Paleoindian materials from across the continent is available from the Paleoindian Database of the Americas (PIDBA), available on-line at http://pidba.utk.edu. Tallying the diagnostic projectile point sample from PIDBA (on-line "entire sample" dated 24 April 2008) suggests that a population decline followed by a rebound may have occurred, particularly in southeastern North America. Following Clovis, fluted points with deeply indented bases and short to full flutes occur in many areas, such as the Redstone, Barnes, Cumberland, and Folsom types. In southeastern North America, these are thought to have been replaced by unfluted lanceolate and waisted forms, including the Beaver Lake, Suwannee/Simpson, and Quad types, which are in turn replaced by Dalton forms. Within the Southeast, a significant decline occurs between Clovis (N=1993 points) and presumably immediate post-Clovis full fluted forms (N=947 points). This may correspond to a similar decline in population, assuming the point types occurred for comparable periods of time, and were used in a similar fashion. Goodyear (*Current Research in the Pleistocene* 23[2006]:102), noted a similar pattern between Clovis (n=179) and presumed immediate post-Clovis Redstone (n=40) forms in South Carolina. Comparable declines have also been observed in North Carolina by Daniel and Goodyear (*Current Research in the Pleistocene* 23[2006]:102) and in Virginia by MacAvoy (*Nottoway River Survey Part I: Clovis Settlement Patterns: The 30 Year Study of a Late Ice Age Hunting Culture on the Southern Interior Coastal Plain of Virginia*. Archeological Society of Virginia Special Publication Number 28 [1992]:161-162). In the PIDBA database across the Southeast, projectile point numbers increase following the immediate post Clovis decline, from 947 full fluted to 1717 unfluted and then 2594 Dalton points. The increase in the latter part of the Younger Dryas may actually be even more pronounced, since Dalton points, which are quite widespread, are only systematically recorded in a few states. Radiocarbon dates from Paleoindian and Early Archaic assemblages reveal a similar pattern. Dates falling in the initial centuries of the Younger Dryas are decidedly uncommon in the Southeast and over the larger region. In a sample of 218 dates from the Southeast and adjoining areas, only seven fall between 10,900 and 10,570 ^{14}C yr BP or between ca. 12,850 and 12,600 cal yr BP, and all of these are at the recent end of this range, between 10,570 and 10,710 ^{14}C yr BP. In the Southeast, at least, there appears to be a ca. 250-300 year 'gap' in the distribution of radiocarbon dates, with few reported from ca. 12,900-12,600 cal yr BP. Finally, analyses of fossil pollen records from the southeastern United States, although admittedly few in number, indicate that major vegetational shifts (both abrupt and characterized by oscillations) were occurring across the region during the Pleistocene/Holocene transition and that these shifts appear to be synchronic or quasi-synchronic with the Younger Dryas. However, both the magnitudes and signatures of these vegetational shifts were not uniform across the region, suggesting that a variety of factors were influencing the responses of local vegetation. While this study is best viewed as a first approximation at identifying vegetational changes in the region during the Younger Dryas, the results suggests that the earliest inhabitants in the southeastern United States were faced with an environment that was anything but stable.

Bull Creek Environment and the ET Event

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A recent hypothesis states that an extra-terrestrial (ET) event, in this case a comet explosion over NE North America, initiated the Younger Dryas chronozone--~11,000-10,000 radiocarbon years before present (RCYBP)--and left event specific markers including magnetic grains with iridium, magnetic microspherules, charcoal, soot, carbon spherules, glass-like carbon containing nanodiamonds, and fullerenes with ET helium. This hypothesis results in several predictions, including shuffling of plant and animal communities, disruption of human cultural adaptations, and megafaunal extinctions immediately following the ET event. This poster investigates the question: Does evidence exist for a disruptive event centered at ~11,000 RCYBP in the paleoenvironmental proxy records within the Bull Creek project area, Oklahoma Panhandle, USA? Evidence from multiple proxies, including particle size distribution, stable carbon isotopes, pollen, and phytoliths, is employed to reconstruct the paleoenvironment and search for discontinuities in the data sets.

End-Pleistocene Soil Constituents from Selected Sites on the Mid-Atlantic Coastal Plain: First Results

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Stratigraphic analyses of soil samples taken from dated and undated sites located along the mid-Atlantic Coastal Plain have yielded evidence of increased contemporary biomass burning, compared to under and overlying strata. Host strata ages are known or projected

to bracket the onset of the Younger Dryas cooling episode at 12.9 cal ka. This ongoing investigation includes samples from: 1) a late-Pleistocene aged periglacial feature located within the Pine Barrens of southern New Jersey; 2) an artifact dated stratum (~12.9 ka) in an embankment on the Chesapeake Bay in Maryland; and 3) an as yet undated (C^{14} test results pending) embankment of the Perquimans River in northeastern North Carolina projected to be age-appropriate.

Sample analysis of scanning electron (SEM) micrographs from the Chesapeake Bay site revealed charred fragments of late-Wisconsinan birch (Betula) and species of spruce (Picea) and fir (Abies), which are not extant on the modern-day temperate Coastal Plain. In addition, organic faunal material is found in association with ancient charred boreal wood, including hollow hair and skin fragments that are as yet unidentified, perhaps from cold climate adapted animals as inferred from host sediment age. Charred wood fragments are found to be attracted to a neodymium magnet. Some aggregates of organic matter appear to contain magnetic spherule-like grains whose composition is awaiting geochemical analysis. Photomicrographs of all specimens and a stratigraphic breakdown in the relative amount of burned carbon associated with each site and strata will be presented, along with the results of various analyses that are currently underway.

A New Method for Producing Nanodiamonds Based on Research Into the Younger Dryas Extraterrestrial Impact

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Research into a proposed extraterrestrial (ET) event 12.9 ka ago at the onset of the Younger Dryas revealed that for impact sediments (the YDB) that were tested across N America and NW Europe, all contain impact-related nanodiamonds ranging in size from 1 to 1700 nm. They appear in bulk sediment, but mostly occur inside carbon spherules and glass-like carbon, which are the charred, melted, amorphous-carbon byproducts of

intense, impact-related wildfires. No diamonds were found stratigraphically above or below the impact layers. Selected area electron diffraction (SAED) by transmission electron microscopy (TEM) produced reflections of 2.06, 1.26, 1.07, and 0.89 A, which correspond to the lattice planar d-spacings of cubic diamonds. So-called "forbidden" reflections were also apparent at 1.78, 1.04, and 0.796 A, and these spacings are characteristic of a metastable cubic diamond polymorph called "n-diamond," the dominant form of diamond found in the YDB. N-diamonds have been produced under lab conditions and have been identified in meteorites, but they have never been found associated with mantle-derived diamonds.

We have been able to reverse-engineer the process by which the impact-related n-diamonds form. First, various carbon-rich materials (coal, coconut shells, and wood) were charred at about 500°C under low-oxygen conditions. Next, the char was heated to more than 1000°C in a partially sealed vessel, while introducing steam or nitrogen at near-atmospheric pressure. As a result, rounded, nanometer-sized domains of graphite formed in the char, to be then transformed into n-diamonds. To prevent combustion of the n-diamonds, the char was quenched under low-oxygen conditions. As it happens, this procedure is identical to the commercial process for producing activated charcoal, and in fact, samples of commercially available activated carbon manufactured by both Calgon Carbon Corporation and Norit Americas, Inc. were found to be enriched with n-diamonds.

The process of forming n-diamonds requires conditions unlike any that are normal to the surface of the Earth. However, the requirements match the extreme conditions that exist during an ET impact or airburst: (1) transient high temperatures; (2) an oxygen-poor (or steam-rich) atmosphere within the fireball and behind the shock front; and (3) the opportunity for quenching in a low-oxygen environment. Our research confirms that the YD nanodiamonds could not have formed under normal terrestrial conditions, and instead, required conditions consistent with an ET impact. Our research group has filed a provisional patent application for this previously unknown method of producing diamonds.

Soot as Evidence for Widespread Fires at the Younger Dryas Onset (YDB; 12.9 ka)

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Evidence continues to grow in support of a major extraterrestrial (ET) impact, which was the primary trigger for the late Pleistocene megafaunal extinction in North America at the onset of the Younger Dryas (12.9 ka). Sediment at the base of a carbon-rich, dark layer (the YDB) is marked by peaks in magnetic microspherules and grains, iridium, nanodiamonds, and other materials consistent with a major ET event (Firestone, 2007; Kennett, 2008). This layer also exhibits above-background levels in charcoal, carbon spherules, glass-like carbon, and polycyclic aromatic hydrocarbons indicative of continent-wide biomass burning, which is coeval with evidence for major abrupt increase in biomass burning in the Greenland Ice sheet (Mayewski, 1993; Legrand, 1997).

The synchronous, widespread presence of soot in high abundances is well-accepted as a marker for extensive, intense impact-related wildfires. By conducting a soot analysis, we tested the possibility that the explosion of the impactor triggered combustion of terrestrial biomass, as hypothesized for the Cretaceous-Tertiary (K/T) 65 Ma ago (Wolbach, 1985). Previous analyses of samples from North America, Germany, and Belgium yielded YDB soot at two sites in North America containing other impact markers: Murray Springs, AZ, with a soot content of 20 +/- 2 ppm; and at Blackville, SC, with a soot content of 2000 +/- 200 ppm (Wolbach, 2007).

In this study, we report results from analyzing twenty-two additional samples from six sites in North America and Europe: Arlington Canyon, and nearby Arlington Springs, CA; Bull Creek, OK; Hall’s Cave, TX; Murray Springs, AZ (new sampling); and Lommel, Belgium. Dissolution and analysis procedures were based on those used successfully for detecting soot from impact-produced wildfires at the K/T boundary, as previously described (Wolbach, 1985, 1988, 1989, 1990).

The YDB layer at four of these sites (nine total samples) contains significant quantities of soot: Arlington Canyon, CA, at 2000 +/- 200 ppm; Bull Creek, OK, at 500 +/- 50 ppm; Hall’s Cave, TX, at 2000 +/- 200 ppm; and Murray Springs, AZ, at 6000 +/- 600 ppm, thirty times higher than previously observed at this location. Samples from the other two sites (Arlington Springs; Lommel) lack detectable soot in the YDB layer, in spite of independent evidence for biomass burning, such as charcoal and carbon spherules, probably because local depositional conditions were too oxidizing for soot preservation. Samples from above and below the YDB layer at all sites displayed no detectable soot.

The presence of significant YDB soot at five separate locations up to 3500 km apart across North America (CA, AZ, OK, TX, and SC), in combination with other pervasive wildfire evidence, suggests major, widespread burning and aeolian transport of soot across North America ~12.9 ka ago. These results support a size and energy of impact sufficient to ignite continental-scale fires.

Nanodiamonds in a Stratigraphic Datum Layer Correlated with the Continent-Wide Younger Dryas Impact Stratum (YDB) at 12.9 ka

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Firestone et al. (2007) presented evidence for a latest Pleistocene extraterrestrial (ET) impact over North America at 12.9 ka (11,000 RCYBP), coinciding with the onset of the Younger Dryas Climatic Episode. This hypothesis was based on the identification of multiple markers of ET origin found in an impact layer (YDB) at many locations across North America and NW Europe. We present new evidence in support of a continent-wide stratigraphic datum layer based on widely distributed and abundant nanodiamonds formed during the ET impact and preserved in the YDB. Of several hundred samples analyzed from 16 sites on two continents, we have yet to find YDB sediments lacking nanodiamonds, and we have yet to find non-YDB late Pleistocene sediments containing nanodiamonds.

This widespread distribution of nanodiamonds is currently most clearly demonstrated in carbon spherules (mean diameter ~100 µm) found in the YDB layer at many locations across the continent and in NW Europe. The n-diamonds in these spherules are the most abundant diamond allotrope found. All three allotropes of diamond have been consistently identified using high-resolution scanning electron microscopy (SEM) and transmission electron microscopy (TEM) with confirmation by selected area diffraction (SAED). We also report a large abundance of nanodiamonds in bulk sediments from the YDB layer at sites in Michigan, North Carolina, South Carolina, Arizona, and Oklahoma.

Established protocols for acid-digestion were used to isolate the diamonds, except for eliminating the phosphoric and perchloric acid steps, which were found to oxidize the diamonds. Labor-intensive studies are underway on bulk sediments collected from stratigraphic transects at 11 additional sites across North America and NW Europe. We have found that residues resulting from the acid-digestion are significantly larger (i.e., heavier) in YDB samples, regardless of diamond abundance. The increased mass largely results from high concentrations of acid-resistant amorphous carbon, which itself appears to be an identifying characteristic of the YDB impact layer. Nanodiamonds in YDB sediments are widespread probably as a result of atmospheric transport of these nano-sized particles during the impact event.

The YDB layer thus appears to be an increasingly valuable and easily discernable datum layer of unusual continent-wide extent, as identified by an increasing array of ET proxies including nanodiamonds. Its value is further strengthened by its frequent stratigraphic position at the base of a widely dispersed and conspicuous, carbon-rich sedimentary layer. If confirmed, the presence of such a widespread, well-dated, and readily identifiable datum should assist with better understanding of human, biotic, climatic, and other environmental and ecological processes of the last deglacial episode on continental scales.

A New Method for Producing Nanodiamonds Based on Research Into the Younger Dryas Extraterrestrial Impact

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Research into a proposed extraterrestrial (ET) event 12.9 ka ago at the onset of the Younger Dryas revealed that for impact sediments (the YDB) that were tested across N America and NW Europe, all contain impact-related nanodiamonds ranging in size from 1 to 1700 nm. They appear in bulk sediment, but mostly occur inside carbon spherules and glass-like carbon, which are the charred, melted, amorphous-carbon byproducts of intense, impact-related wildfires. No diamonds were found stratigraphically above or

below the impact layers. Selected area electron diffraction (SAED) by transmission electron microscopy (TEM) produced reflections of 2.06, 1.26, 1.07, and 0.89 A, which correspond to the lattice planar d-spacings of cubic diamonds. So-called "forbidden" reflections were also apparent at 1.78, 1.04, and 0.796 A, and these spacings are characteristic of a metastable cubic diamond polymorph called "n-diamond," the dominant form of diamond found in the YDB. N-diamonds have been produced under lab conditions and have been identified in meteorites, but they have never been found associated with mantle-derived diamonds.

We have been able to reverse-engineer the process by which the impact-related n-diamonds form. First, various carbon-rich materials (coal, coconut shells, and wood) were charred at about 500°C under low-oxygen conditions. Next, the char was heated to more than 1000°C in a partially sealed vessel, while introducing steam or nitrogen at near-atmospheric pressure. As a result, rounded, nanometer-sized domains of graphite formed in the char, to be then transformed into n-diamonds. To prevent combustion of the n-diamonds, the char was quenched under low-oxygen conditions. As it happens, this procedure is identical to the commercial process for producing activated charcoal, and in fact, samples of commercially available activated carbon manufactured by both Calgon Carbon Corporation and Norit Americas, Inc. were found to be enriched with n-diamonds.

The process of forming n-diamonds requires conditions unlike any that are normal to the surface of the Earth. However, the requirements match the extreme conditions that exist during an ET impact or airburst: (1) transient high temperatures; (2) an oxygen-poor (or steam-rich) atmosphere within the fireball and behind the shock front; and (3) the opportunity for quenching in a low-oxygen environment. Our research confirms that the YD nanodiamonds could not have formed under normal terrestrial conditions, and instead, required conditions consistent with an ET impact. Our research group has filed a provisional patent application for this previously unknown method of producing diamonds.

YDB evidence for impact from magnetic spherules and tektites: Murray Springs, AZ

Fayek, M.