

## Fireball passes and nothing burns—The role of thermal radiation in the Cretaceous-Tertiary event: Evidence from the charcoal record of North America: Comment and Reply

### COMMENT

#### Douglas S. Robertson

*Cooperative Institute for Research in Environmental Sciences (CIRES), Campus Box 216, University of Colorado, Boulder, Colorado 80309, USA*

#### Malcolm C. McKenna

*1000 Jasmine Circle, Boulder, Colorado 80304, USA*

#### Owen B. Toon

*Atmospheric/Space Physics Laboratory, 392 UCB, University of Colorado, Boulder, Colorado 80309, USA*

#### Sylvia Hope

*Department of Ornithology and Mammalogy, California Academy of Sciences, Golden Gate Park, San Francisco, California 94118-4599, USA*

#### Jason A. Lillegraven

*Department of Geology and Geophysics, P.O. Box 3006, University of Wyoming, Laramie, Wyoming 82071-3006, USA*

Belcher et al. (2003) reported that at six locations across North America quantities of charcoal in the Cretaceous-Tertiary (K-T) boundary clay are about an order of magnitude below background levels. They interpreted this absence of charcoal as evidence for the absence of a global conflagration at the K-T boundary. The case for their argument would be much stronger had they found no change in charcoal levels at the boundary layer rather than a marked decrease from background levels. The general background levels of charcoal presumably were generated by ordinary wildfires ignited largely by lightning. Therefore, in order to explain the absence of background charcoal levels in terms of an absence of unusual fire at the K-T boundary, Belcher et al. must also assume either an absence of ordinary lightning-induced fires (which does not seem likely) or the existence of a mechanism other than fire that would destroy the background charcoal only at the K-T boundary.

We think, instead, that fire is the only mechanism that is likely to have destroyed charcoal so thoroughly at the K-T boundary. Obviously, fire can destroy charcoal as well as create it. Low intensity fires will create charcoal, but high-intensity (i.e., high-temperature) fires will tend to destroy it. The observed unusual absence of charcoal therefore constitutes strong *prima facie* evidence for a fire of unusually high intensity at the K-T boundary.

There is good reason to think that the conflagration at the end of the Cretaceous attained unusual intensity. Any fire is essentially in thermodynamic balance between heat production (by combustion) and heat loss (largely through convection and radiation). A large fire will generally have a lower surface-to-volume ratio and will therefore have lower heat losses and higher temperatures than a smaller fire. Fires at the K-T boundary, which were ignited essentially simultaneously across entire continents by the infrared radiation from reentrant ejecta, were therefore likely to have been of unprecedented intensity. Also, heat from this infrared radiation continued to be added to the fires for several hours even as they burned. The resulting extraordinarily high temperatures very plausibly destroyed vegetative fuel to a level much lower than that required to explain normal preservation of charcoal at background levels. No other simple explanation easily accounts for an order-of-magnitude decrease in preserved charcoal at the K-T boundary. Certainly the idea of an absence of unusual fire fails to do so.

Today we have no first-hand experience with the intensity of continental-scale wildfires. Perhaps the only similar phenomena in recent history are the firestorms that were caused by incendiary bombing in World War II. In July 1943, for example, the firestorm in Hamburg, Germany, burned approximately ten square kilometers in a few hours; it attained

temperatures of perhaps 800 °C in the streets and wind speeds of hurricane force (Middlebrook, 1980), clearly intense enough to destroy charcoal. The fires that were ignited simultaneously across millions of square kilometers at the K-T boundary can hardly have been any less intense than these much smaller-scale firestorms.

Belcher et al. (2003, p. 1063) stated that their conclusion implies that Melosh et al. (1990) “overestimated the mass of the high-velocity ejecta by at least two orders of magnitude.” Because the Melosh et al. mass estimate is based on direct observation of the spherules in the boundary clay (remnants of the reentrant ejecta), we find the suggestion of a two-order-of-magnitude error to be, at best, implausible. It would imply that the spherule layer has an average accumulated thickness of less than a tenth of a millimeter. Smit (1999) estimated the ejecta layer to have had an accumulated thickness of 2–3 mm at points more than 7000 km from the impact site.

Belcher et al. noted that significant quantities of uncharred organic remains are present in the K-T boundary layers. They claimed, incorrectly, that presence of such material is inconsistent with the idea of an intense continental firestorm. However, a substantial amount of organic matter would be expected to be present in the soil at any given time prior to a conflagration, and a few centimeters of soil would provide sufficient insulation to prevent charring from even the most intense fires. Perhaps still more important, many plants would have started to regenerate from buried roots, seeds, and spores on time scales of days after a global conflagration. The roots of these new-grown plants might well have proliferated in a nutrient-rich ash layer, thereby providing the observed record of uncharred plant fossils.

Therefore, precisely opposite to the interpretation by Belcher et al., the important new evidence that they report is consistent with the occurrence of continental-scale firestorms at the end of the Mesozoic era. For a more complete discussion of the biological effects of this thermal stress following the Chicxulub impact see Robertson et al. (2004).

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### REPLY

#### Claire M. Belcher

#### Margaret E. Collinson

*Department of Geology, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK*

#### Arthur R. Sweet

*Geological Survey of Canada, 3303 33rd Street NW, Calgary, Alberta T2L 2A7, Canada*

## Alan R. Hildebrand

Department of Geology and Geophysics, University of Calgary, Alberta T2N 1N4, Canada

## Andrew C. Scott

Department of Geology, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK

The suggestion that globally extensive wildfires were ignited as part of the Cretaceous-Tertiary (K-T) boundary events (e.g., Robertson et al., 2004; Melosh et al., 1990; Kring and Durda, 2002) ignores the following: (1) absence of above background levels of charcoal, (2) absence of charred peats, (3) absence of geomorphological and sedimentological evidence, and (4) presence of significant quantities of noncharred material.

Belcher et al. (2003) and Scott et al. (2000) have shown that the K-T sedimentary rocks contain below-average background levels of charcoal (but not lower than the minimum background level recorded) when compared to the charcoal record of the Late Cretaceous. Robertson et al. claim high temperatures would destroy charcoal produced in a K-T firestorm. They favor the model of Melosh et al. (1990), which predicted atmospheric temperatures of ~827 °C following the K-T impact. Such temperatures do not explain the lack of charcoal, as high temperature does not destroy charcoal. We have produced charcoals in ovens at temperatures over 900 °C for one week. Furthermore, the K-T charcoal does not show very high reflectance. Scott (2000) demonstrated that charcoal reflectance increases with temperature. High temperatures would have generated very highly reflecting charcoals. The key in charcoal destruction is not temperature but oxygen availability. Robertson et al. (2004) suggest local oxygen deficiencies occurred under the K-T fires, as in firestorms over burning cities during World War II. Plant material may be totally consumed by hot flames fed with oxygen (Scott, 2000), whereas charcoal formation occurs where there is heat and a lack of oxygen. Therefore, the suggestion of Robertson et al. (2004) would provide the ideal situation for creating beautifully preserved, highly reflecting charcoal particles.

A long standing problem with K-T ejecta reentry models (e.g., Melosh et al., 1990; Toon et al., 1997; Kring and Durda, 2002) is the assumption that the upper K-T layer consists of ballistically distributed ejecta. This may be true for the lower claystone (found only across the United States) that decreases in thickness with distance from Chicxulub following a power law relation with exponent of -3 (Hildebrand and Stansberry, 1992), a characteristic of ballistically distributed ejecta, but this is not the dispersal mechanism for the upper layer, which is uniform in thickness (~3 mm) across the world. Its presence was a puzzle finally explained by dispersal of impact fireballs seen from remote observations of the SL9 impacts on Jupiter. These showed that impact fireballs collapse hydrodynamically (e.g., Hammel et al., 1995), indicating the assumption that the upper layer is ballistically distributed is invalid. Therefore, ballistic dispersal does not produce a layer of uniform thickness across the globe; hydrodynamic collapse of an impact fireball would globally disperse impact products and release an order of magnitude less energy, which would be insufficient to ignite vegetation.

There are several reports of the K-T boundary in coal (peat deposits) (Sweet et al., 1999; Scott et al., 2000; Belcher et al., 2003). Peat is an excellent fuel for wildfires, especially if the temperatures and duration envisioned by Robertson et al. had been achieved. Charred peats occur elsewhere in the fossil record (Petersen, 1998) but we see no evidence of such material in our K-T peat sequences.

Robertson et al. argue a few centimeters of soil would provide sufficient insulation to prevent charring. While thermal penetration of soil is not high, it has been shown that at 2.5 cm depth fires of 700 °C (Rundel, 1981) increase the temperature to 200 °C. For the temperatures and

durations indicated by Robertson et al., much of the litter layers would have produced charcoal (beginning at >300 °C). By suggesting that unburned organic matter in the soil could be the source of noncharred material in the K-T layers, Robertson et al. ignore stratigraphy. The K-T stratigraphy consists of two distinctive layers: a lower cream-colored claystone overlain by a thinner brown to orange claystone. What soil there was before the impact is below the K-T layers and has no part in the noncharred material story. Moreover, the pollen and spores immediately under/in/above the K-T layers are impeccably preserved (i.e., no evidence of heating during deposition). Palynomorphs in the K-T layers are not derived from the latest Cretaceous sediments or from the overlying coals as leakage, as the assemblages are so different (see Sweet et al., 1999). The noncharred plant fragments (which are not root material) cannot be sourced from soil.

If Robertson et al. argue for complete removal of organic material then we ought to see major erosion and deposition events (as is common following wildfires; e.g., Meyer et al., 1992). If there was a major global fire we would see evidence in the sedimentological record. We see no evidence of this in the areas we studied, confirming our view that extensive fires did not occur as part of the K-T events.

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