studied (*1–3*). Detailed descriptions of the sequence around the K-T boundary were given in a recent article by A. A. Ekdale and R. G. Bromley (*2*). The K-T boundary at two of the outcrop sections in eastern Denmark (Stevns Klint and Karlstrup) is marked by a laminated and in part carbonaceous clay layer, referred to as the Fish Clay because it contains skeletal fish remains. At these sections the Fish Clay varies in thickness from 0 to 35 centimeters over lateral distances of a few meters. A few hundred kilometers away in northwestern Denmark, at three other outcrop sections that have been studied in detail (Dania, Kjølby Gaard, and Nye Kløv), there is no Fish Clay, but rather an abrupt change from the underlying Maastrichtian sequence to the overlying Danian sequence. Similarly, in the type locality of the Maastrichtian in eastern Netherlands, more than a thousand kilometers to the south, no clay layer occurs at the K-T boundary (*4*).

The Fish Clay itself has a complex lithology (*2, 3*). Its upper and lower boundaries represent a transitional sequence marked by cyclical sedimentation characterized by finely alternating marl and carbonate seams that have been altered by solution compaction to form a microstylolitic fabric. In between the two transitional boundaries the Fish Clay can be subdivided into four obvious subunits, including, from bottom to top, (i) laminated gray-brown smectite clay containing tiny burrows that participate in the formation of the micronodular fabric in the basal part; (ii) laminated black carbonaceous shale containing common weathered pyrite concretions; (iii) laminated very dark gray smectite clay containing light gray horizontal streaks; and (iv) laminated gray-brown smectite clay grading upward through a burrow-rich, micronodular fabric into the overlying limestone.

The lithology of the Fish Clay clearly indicates that it is a condensed section and that there has been a pulse of calcium carbonate dissolution coincident with the K-T boundary events (*2*). There has been a substantial removal of the calcium carbonate fossiliferous remains that make up the bulk of the underlying Maastrichtian chalk and overlying Danian limestone. The observed iridium anomalies also indicate that the Fish Clay represents a condensed section. For the Dania section, which has no Fish Clay, the peak iridium value is 4 parts per billion compared with peak values of 29 to 87 parts per billion for the Fish Clay of the Stevns Klint section. It is difficult to estimate how great the reduction in sedimentation rate has been for the Fish Clay. If it is assumed that the flux of clay has been essentially the same throughout the K-T transition, a comparison of the clay content of the Fish Clay with that of the underlying and overlying chalk and limestone indicates a reduction in sedimentation rate of 1 to 7 (*2*). Multiplying the concentration anomaly, 3.6 to 1, by the sedimentation rate ratio, 1 to 7, leads to the conclusion that there is no positive anomaly in the flux of elemental carbon across the K-T boundary and perhaps even a negative anomaly.

Contrary to the known lithology of the Fish Clay, Wolbach *et al.* argue that it is the deposition product of a hypothesized asteroid impact and that the deposition time for the clay was 1 year. The Fish Clay is not a worldwide phenomenon and it is not even ubiquitous to all the Danish sections, occurring at two out of five of the outcrop localities. We conclude that the Fish Clay is not the deposition product of an asteroid impact, but rather a shallow-water clay whose complex lithology provides a record of the environmental conditions that prevailed at the time of its deposition.

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Response: Argyle is right in noting that living forests generally do not burn readily, and that a *prompt* global forest fire hence is unlikely. His idea—that the fires started only after the trees had died and "freeze-dried"—seems quite plausible. It had independently been suggested by a referee of our paper and by Paul J. Crutzen. However, soot and iridium appear simultaneously in the lowest 3 millimeters of the nearly undisturbed boundary clay at Woodside Creek, New Zealand (*1*), showing that soot accompanied even the earliest fallout.

We also accept Argyle's statement that an oceanic impact within 1000 kilometers of land has a probability of only 1 in 6. However, that is a virtue rather than a fault. Many taxa that became extinct at the end of the Cretaceous had survived several previous extinctions, and so there must have been something "special" about the Cretaceous extinction—perhaps a fire. As we concede, global fires would be hard to start, even if the impact was on land, as recent evidence suggests (*2*).

We need all the help we can get in finding a source for 10^{17} grams of soot at the Cretaceous-Tertiary (K-T) boundary, and therefore appreciate the suggestion by Cisowski and Fuller that spontaneous combustion of marine sediments may be responsible. However, there are some difficulties with this idea, especially if extended to account for the platinum metals at the K-T boundary.

Siderophile elements at the K-T boundary show a primitive, clearly meteoritic signature. Os, Ir, Au, Pt, Co, Pd, and Ru occur in chondritic proportions to $\pm 20\%$ (*3, 4*); Pt/Ir and Au/Ir ratios agree with meteoritic ratios to within 5% and 7% (*4*); and the Os^{187}/Os^{186} ratios of 1.0 to 1.6 (*5*) match the meteoritic range of 1.0 to 1.4, not the crustal ratio of 35. The Os^{187}/Os^{186} *isotopic* ratio is particularly decisive, as all crustal Os, having evolved in an environment of high Re/Os ratio, is strongly enriched in Os^{187} from the decay of Re^{187}. But even the *elemental* ratios in the crust strongly deviate from meteoritic ratios, and so black shales are not a plausible source of the siderophiles at the K-T boundary. A meteorite is still required.

Relieved of the burden of accounting for the siderophiles, the black shales become interesting potential sources of the K-T soot. As Cisowski and Fuller acknowledge, an enormous amount of shale must be ignited all at once at the precise time of the K-T impact, if the soot is to settle out with the Ir-bearing ejecta layer. It remains to be seen whether this mechanism can account for the large amount of soot, the synchrony of this event with the K-T boundary, and the absence of similar soot layers at other times.

Stripped to its essentials, the question raised by Officer and Ekdale is whether the Ir-rich boundary clay is terrestrial or "meteoritic" (that is, weathered impact glass). If terrestrial, then no one in his or her right mind could make a case for a global fire: 0.021 gram per square centimeter of soot, deposited over $\sim 10^3$ years, is pathetically little. But if meteoritic, then the deposition time must have been less than 1 year, as dust cannot stay aloft any longer (*6*), and 0.021 gram per square centimeter of soot formed all at once requires a fire involving all the world's forests or a comparable amount of fossil carbon.

Let us summarize some of the facts favoring an impact.

1) Ir, Os, and other noble metals are enriched up to 10^3-fold at the K-T boundary, at more than 70 sites worldwide (*7*).

2) There is no adequate terrestrial source.

Os^{187}/Os^{186} ratios rule out the crust, but are consistent with the mantle or meteorites (*5*). Yet Pt/Ir, Au/Ir (*4*) and Nd^{143}/Nd^{144} ratios (*8*) permit only minor amounts of mantle material. Volcanism has been proposed as a source of Ir (*9*), but there is no evidence whatsoever that it also accounts for the observed chondritic proportions of other siderophile elements (*3, 4*). Moreover, the Deccan plateau basalts, often invoked as a potential source of Ir (*10*), contain only 0.005 part per billion of Ir (*11*)—three to four orders of magnitude less than K-T boundary clays.

3) Shocked quartz (*12*) and feldspar (*2*) as well as traces of the high-pressure mineral stishovite (*12*) have been found at several K-T boundary sites, along with spherules resembling microtektites (*13*). No process other than hypervelocity impact is known to produce these features (*14*).

Officer and Ekdale invoke "condensation" of the Danish boundary clay (Fish Clay) to explain the fourfold enrichment in carbon content. This is a sham issue, as the real question is not the fourfold higher carbon content, but the 1000-fold shorter deposition time, which, in turn, hinges on the meteoritic nature of the boundary layer. Moreover, at two New Zealand sites, the soot content rises by factors of at least 40 and 800 (*1*). Nonetheless, we shall briefly respond to their arguments.

1) We agree that there is some evidence for a *small* degree of carbonate dissolution in the Fish Clay (*15*). Possible causes are local formation of sulfuric acid by oxidation of pyrite or a global increase in atmospheric-oceanic CO_2 content after a major fire. However, we find the evidence for a *large* "dissolution pulse" (*15*) quite unconvincing. The arguments at best are permissive but not compelling and at worst are ad hoc, designed to deny the role of meteorite impact. What Maxwellian demon protected the uppermost Cretaceous sediments, only centimeters below, from this "dissolution pulse"?

2) The putative factors by which the boundary layer "condensed" are not self-consistent: 4 for C, 7 for clay, and 2000 for Ir, when one uses the Ir-profile of (*4*) as an example. The Ir value requires that the boundary layer initially was some 600 meters thick and contained 99.95% carbonate!

3) Officer and Ekdale imply that Fish Clay is an artifact produced from a normal boundary section by selective dissolution of carbonate and cite as examples Dania (no Fish Clay, 4 parts per billion of Ir) and Stevns Klint (Fish Clay, 29 to 87 parts per billion of Ir). However, Ekdale in an earlier paper (*15*) acknowledged that the Dania site is "badly disturbed by relatively recent brecciation and apparent tectonic movement," and "thus may not reflect a continuous sedimentary sequence." Absence of evidence is not evidence of absence, especially in a section previously acknowledged to be incomplete.

4) The K-T sequence in Denmark, although well studied, is badly disturbed and hence is not suitable for generalization. However, Smit and Romein (*13*), who have studied 22 K-T sites all over the world, conclude from this much larger data base that a boundary clay layer with Ir and microtektites is the norm rather than the exception. If it is missing at a particular site, this implies a later disturbance, as evidenced by a break in the fossil record (*13*). We refer Officer and Ekdale to Ekdale and Bromley (*15*), who found ample evidence for precisely such disturbance: "The clay layer obviously has served as a zone of weakness and as a lubrication plane for geologically recent movements," and "this carbonaceous, pyritic microfacies *pinches out* laterally up the flanks of the chalk mounds, so that it only occurs in the bottoms of the small troughs between the mounds" (italics ours).

For a different view of K-T stratigraphy in Denmark, we refer the reader to three recent references not quoted by Officer and Ekdale (*4, 13, 16*).

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