

## Carbon isotopic evidence for biomass burning at the K-T boundary: Comment and Reply

### COMMENT

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Breakdown of the  $\delta^{13}\text{C}$  surface-to-deep gradient above the Cretaceous-Tertiary (K-T) boundary and its temporary shift to more negative planktic  $\delta^{13}\text{C}$  values relative to benthic values has generally been interpreted as reflecting a major reduction in primary productivity possibly associated with increased riverine influx (Shackleton and Hall, 1984; Zachos et al., 1989; Stott and Kennett, 1989; Kump, 1991). Ivany and Salawitch (1993) argued that near cessation of primary productivity is insufficient to create the observed negative  $\delta^{13}\text{C}$  values while dismissing riverine influx as being too little over too long a time. Instead, they invoke massive (25%) global biomass burning at K-T boundary time as causal agent. Their argument rests on the assumption that the negative planktic  $\delta^{13}\text{C}$  shift occurred on a time scale of less than that of ocean mixing (<1000 yr). Thus, they also assumed that a geologically instantaneous event triggered the planktic  $\delta^{13}\text{C}$  event.

This assumption is erroneous. Biostratigraphic data show that of the eight deep-sea sections used by Ivany and Salawitch to justify their argument all have hiatuses at the K-T boundary with the basal Danian and possibly part of the uppermost Cretaceous missing, as illustrated in Figure 1 (MacLeod and Keller, 1991a, 1991b; for Site 690 see Keller, 1993). Several of these cores also do not exhibit Ir anomalies, though by itself one Ir anomaly cannot unambiguously identify the K-T boundary (multiple Ir anomalies characterize some boundary sequences; see Donovan et al., 1988). In all eight sections, these data indicate that at least 50 to 100 ka of the basal Tertiary is missing. Moreover, the  $\delta^{13}\text{C}$  signal at Site 577 may be compromised by homogenized sediments due to bioturbation. The apparent instantaneous nature of the  $\delta^{13}\text{C}$  shift in these deep-sea sections is thus an artifact of a K-T boundary hiatus and not a sudden environmental event. In more complete low-latitude K-T boundary transitions, such as El Kef and Brazos, the  $\delta^{13}\text{C}$  shift occurred gradually over 30 to 50 ka (Keller and Lindinger, 1989; Barrera and Keller, 1990). Moreover, recent data from high-latitude sections (Nye Klov and Ocean Drilling Program Site 738; Keller, 1993; Keller et al., 1993; Barrera and Keller, 1994) indicate that neither a mass extinction nor a  $\delta^{13}\text{C}$  change in surface to deep gradient occurred in high latitudes.

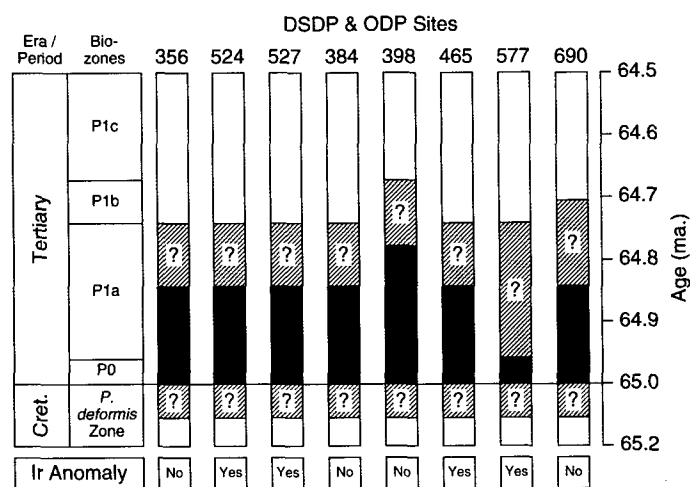


Figure 1. Diagram of biostratigraphic-temporal completeness for eight cores analyzed by Ivany and Salawitch (1993). Completeness determinations based on biostratigraphic data published in primary literature and compared to global sequence of trans-K-T biostratigraphic datums (see MacLeod and Keller, 1991b). Black = intervals of time missing due to hiatus or severe stratigraphic condensation (e.g., below sampling resolution). Question marks = intervals of time that may be partially represented by positive net sediment accumulation. Age estimate for K-T boundary from Cande and Kent (1992) and for duration of lower Danian biozones from Herbert and D'Hondt (1990) and MacLeod and Keller (1991a, 1991b) for P0 and P1a, and from Boersma (1984) for P1b. Biozonation from Keller (1993).

The current data base thus indicates that the  $\delta^{13}\text{C}$  surface-to-deep gradient reversal was restricted to low latitudes and occurred over several tens of thousands of years. This long-time scale and these latitudinal restrictions fail to support global biomass burning as a major causal event. Earlier proposed hypotheses of long-term increased weathering rates and decreased primary productivity (MacDougall, 1988; Zachos et al., 1989; Kump, 1991) still appear to be the most conservative interpretation of the observed  $\delta^{13}\text{C}$  changes.

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- maximum possible ranges for all taxa involved. MacLeod and Keller (1991a, 1991b) used graphic correlation to show that of 28 boundary sections examined, 22 are missing the lowermost Danian and possibly the very uppermost Cretaceous. No deep-sea sites were found to be complete.
- Our first concern is that construction of the composite section is sensitive to sources of error that falsely extend ranges. Although precautions were taken, reworking of specimens may be a significant problem for MacLeod and Keller. Olsson and Liu (1993) concluded that all but three of the 26 K-T boundary survivors cited by MacLeod and Keller can be dismissed as having been reworked upward.
- The second problem with applying graphic correlation to K-T boundary problems is that this method is most reliable only when complete ranges of taxa are employed. The combination of a substantial number of taxa for which both first and last appearances are known stabilizes the resulting composite. The data base used by MacLeod and Keller contains 89 taxa, only six of which have both first and last occurrence data recorded. All last occurrences are Cretaceous taxa, and all first occurrences are Paleocene taxa. This breaks the data into two sets, one below the boundary that will tend to be extended upward in the composite, and one above the boundary that will tend to be extended downward. Combined with the possibility of reworked specimens further extending ranges across the boundary, the composite may become greatly (and unduly) expanded about the K-T boundary. An individual section, when plotted against the composite, may give the false appearance of a hiatus because most range events, while presumably clustered near the boundary in the individual sections, have been "stretched out" in the composite.
- Deep-sea sites are especially vulnerable to false identification of a hiatus because sedimentation rates are slow and vary considerably across the K-T boundary. Olsson and Liu (1993) pointed out that slow deposition, combined with the short duration of Zone P0, likely resulted in a layer so thin that bioturbation or drilling disturbance could have mixed it into adjacent zones and effectively obscured it in deep-sea sites. They emphasized that mixing is not equivalent to a hiatus, but graphic correlation would be unable to discriminate between them.
- Keller and MacLeod claim that the shift in  $\delta^{13}\text{C}$  "occurred gradually over an interval of 30 to 50 ka" in the more complete sections of Brazos and El Kef. However, the bulk of the shift in  $\delta^{13}\text{C}$  of planktonic carbonate for both Brazos and El Kef occurred between two closely spaced, adjacent sample horizons, suggesting that the onset of the isotopic anomaly was quite rapid, less than 3 ka (e.g., Fig. 3 of Barrera and Keller, 1990). The shift in  $\delta^{13}\text{C}$  of benthic carbonate for each core was more gradual, as would be expected for a nearshore section. Furthermore, the surface-to-deep gradient for Brazos became negative by about 1‰ (Barrera and Keller, 1990).
- It is unlikely that resolution on the order of hundreds of years, necessary to prove beyond a doubt that the  $\delta^{13}\text{C}$  shift was enhanced by input of terrestrial biomass, will ever be obtained from the geologic record. However, we reiterate that a global, negative surface-to-deep gradient in  $\delta^{13}\text{C}$  can only be maintained for one ocean mixing cycle.
- Latitudinal variation in expression or severity of boundary events remains an interesting and as yet unresolved issue. The absence of a shift in  $\delta^{13}\text{C}$  at some high-latitude sites (Keller and MacLeod, Comment above, and references therein) may be attributable to localized oceanographic effects such as upwelling in nearshore settings or mixing in less thermally stratified deep water. Other high-latitude sites show a shift, particularly in bulk carbonate, that is admittedly difficult to interpret (Stott and Kennett, 1989). Latitudinal

## REPLY

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Keller and MacLeod criticize our suggestion that the negative surface-to-deep gradient observed in  $\delta^{13}\text{C}$  at several deep-sea Cretaceous-Tertiary boundary sites was short lived and associated with boundary events (Ivany and Salawitch, 1993) on the basis that the sections used in our study have hiatuses at the K-T boundary. They maintain that more complete shelf and slope sections show a gradual decline in the  $\delta^{13}\text{C}$  gradient and that the apparently rapid shift in  $\delta^{13}\text{C}$  of deep-sea cores is simply an artifact of an extremely condensed or incomplete record. Additionally, they claim that recent data from high-latitude sites suggest no change in either faunal diversity or the  $\delta^{13}\text{C}$  gradient at the boundary. We address their concerns with several of our own.

Graphic correlation (Shaw, 1964) provides an estimate of true taxonomic ranges by combining information from many different sections into a composite standard reference section containing the

nal gradients in bivalve extinction patterns were found to be an artifact of one particularly diverse tropical group (Raup and Jablonski, 1993). It is possible that a similar bias exists in microfossil data. Keller (1993) claimed that there is no boundary extinction in Antarctic Site 738, yet 2 to 4 cm below her boundary, all dominant Cretaceous taxa disappear, the single remaining taxon is dwarfed and becomes exceedingly abundant, and iridium abundance peaks.

Graphic correlation is a valuable technique for establishing chronologies and correlating sections when long periods of time, spanning many complete range zones, are considered. We believe that the conclusions of Keller and MacLeod are compromised by the inherent limitations of this method when applied to exceedingly short-term K-T events. We believe that the dramatic changes in biological, sedimentological, and geochemical parameters documented at numerous sites worldwide are correlative and indicative of a single catastrophic event. To ascribe them individually to varying local conditions at slightly different times seems not to be the most "conservative" interpretation of the data.

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