High-resolution records of the late Paleocene thermal maximum and circum-Caribbean volcanism: Is there a causal link?: Comment and Reply

COMMENT

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Bralower et al. (1997) highlighted an important issue regarding interpretations of stratigraphy and the global carbon cycle during the late Paleocene thermal maximum (LPTM) ca. 55 Ma. Points of this comment are (1) to stress the significance and problems associated with an interpretation made by Bralower et al. (1997), and (2) to criticize the paper by Bralower et al. (1997), as well as those by other authors (including Dickens et al., 1997), for not rigorously rejecting alternative interpretations.

Bralower et al. (1997) presented two detailed carbon isotope records that span the LPTM in sediment sequences from the Caribbean. Of particular interest is an observed –3‰ excursion in $\delta^{13}C$ across a short (10 cm) depth interval with low (<5%) carbonate content at Site 1001 (Bralower et al., 1997, Fig. 4). Bralower et al. stated, in general agreement with others (Kennett and Stott, 1991; Canudo et al., 1995; Pardo et al., 1997; Schmitz et al., 1997), that this $\delta^{13}C$ excursion occurred within 10 k.y., and that it represents a perturbation of the global carbon cycle.

The significance of a global –3‰ $\delta^{13}C$ excursion within 10 k.y. is that it indicates addition of CO_2 to the ocean and atmosphere at rates approaching those of anthropogenic inputs of fossil fuel (Lu and Keller, 1993; Dickens et al., 1995, 1997; Thomas and Shackleton, 1996). Suddenly, on the basis of a simple interpretation, understanding global change during the LPTM becomes a topic of considerable interest to the broad earth science community.

There is, of course, a major conceptual problem with current interpretations of the negative $\delta^{13}C$ excursion across the LPTM. No mechanism exists in conventional models of the carbon cycle to add massive quantities of CO_2 to the ocean and atmosphere in the Paleocene at rates anywhere close to anthropogenic inputs of fossil fuel (Sundquist, 1986). Either (1) conventional models of the global carbon cycle are incomplete at a basic level, or (2) the interpretation of a rapid and global negative $\delta^{13}C$ excursion during the LPTM is incorrect.

Bralower et al. (1997) acknowledged the dilemma and invoked a largely untested scenario involving thermal dissociation of gas hydrate, and release and oxidation of massive quantities of CH_4 in the ocean and atmosphere (Dickens et al., 1995; 1997). They then speculated that the ultimate cause of this massive CO_2 input was volcanism and a reorganization of ocean circulation.

Assuming that the overall scenario presented by Bralower et al. (1997) is plausible (see for example discussion and caveats by Dickens et al., 1997), the given interpretation for the observed $\delta^{13}C$ excursion should still be criticized because the alternative explanation—incorrect stratigraphy—has not been dismissed. In particular, current evidence for rapid onset of the $\delta^{13}C$ excursion is tenuous. The 10 k.y. time interval at Site 1001 was estimated by dividing the length of the onset of the $\delta^{13}C$ excursion (10 cm) by a linear sedimentation rate (1 cm/k.y.) determined through biostratigraphy. However, linear sedimentation rates were calculated using time intervals and distances significantly longer than the onset of the $\delta^{13}C$ excursion, and the $\delta^{13}C$ excursion spans an interval of intense dissolution where carbonate drops from >70% to <5% (Bralower et al., 1997, Fig. 4). Thus, the sediment column at Site 1001 is condensed over the 10 cm interval that contains the $\delta^{13}C$ excursion, and the inferred rapid onset for the $\delta^{13}C$ excursion using a linear sedimentation rate must be interpreted as a minimum estimate. Similar interpretations of a rapid $\delta^{13}C$ excursion across the LPTM at other locations (Kennett and Stott, 1991; Canudo et al., 1995; Pardo et al., 1997; Schmitz et al., 1997) do not provide confirmation of massive CO_2 input over 10 k.y. because the LPTM identified at these other sites is also characterized by pronounced decreases in carbonate content (presumably caused by dissolution, although see Pardo et al., 1997). Indeed, a relatively slow (>100 k.y.) onset for the $\delta^{13}C$ excursion is plausible with available stratigraphic constraints (Lu et al., 1996).

Massive input of CO_2 enriched in ^{12}C to the ocean or atmosphere over a long time interval, coupled with significant carbonate dissolution (because of CO_2 addition), is an alternative explanation for the LPTM $\delta^{13}C$ excursion that is compatible with conventional models of the carbon cycle (Lu et al., 1996). For example, Rea et al. (1990) and Thomas and Shackleton (1996) suggested that global increases in hydrothermal activity and volcanism could have added massive amounts of CO_2 to the ocean and atmosphere during the late Paleocene and early Eocene. Until Bralower et al. (1997) and other workers (including myself, Dickens et al., 1997) can provide compelling arguments for rapid and massive CO_2 input that do not involve sedimentation rate calculations, especially across dissolution intervals, any interpretation involving abrupt (<10 k.y.) changes in the global carbon cycle during the LPTM is necessarily open to strong criticism.

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REPLY

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Our interpretation of the late Paleocene thermal maximum (LPTM) event in the Caribbean is based on Dickens et al. (1995), who proposed thermal dissociation of methane hydrates to explain the large yet abrupt $\delta^{13}C$ excursion that coincides with this event. The crux of Dickens's current comment is to point out that if a substantial amount of time is condensed at the base of the LPTM interval in deep sea and shelf sections, then conventional mechanisms of carbon cycling may apply, and all interpretations of the LPTM may be in need of revision. As Dickens points out, the factor that makes the LPTM event so relevant to modern global change is its abruptness. But this abruptness in turn renders the LPTM difficult to study. The duration of the LPTM is a fraction of the biochronozones and magnetochronozone in which it occurred, and age estimates can only be obtained by interpolation.

In most deep sea and shelf sections, $CaCO_3$ decreases abruptly at the base of the $\delta^{13}C$ excursion, requiring a unique age model for the LPTM interval (see Bralower et al., 1997). In Caribbean, Tethyan, and most Atlantic sections, the decrease in $CaCO_3$ is particularly severe (Fig. 1) and is associated with intense microfossil dissolution (e.g., Lu et al., 1996; Thomas and Shackleton, 1996; Bralower et al., 1997). Given the stratigraphic limitations, the possibility that we and others have underestimated the amount of time condensed at the base of the LPTM cannot be ruled out. However, existing evidence suggests that the onset of the $\delta^{13}C$ excursion is abrupt, although possibly not as rapid as 10 k.y.

Site 690 on Maud Rise, South Atlantic, has among the most complete deep sea LPTM records (Kennett and Stott, 1991). Scanning electron microscope observations of planktic foraminifers and nannofossils show no detectable evidence for increased dissolution in samples within, compared to horizons below and above, the LPTM. $CaCO_3$ contents decrease from 83% below to 65% at the peak of the LPTM, not nearly as substantially as at other deep sea sites, yet the $\delta^{13}C$ excursion is abrupt (Fig. 1). The onset of the decrease in $CaCO_3$ is 10 cm below the $\delta^{13}C$ excursion, thus these two changes appear to be decoupled. If we assume that upper Paleocene sediments at Site 690 are composed entirely of carbonate and clastic material, and that the flux of clastic material remained constant, then the sedimentation rate at the base of the LPTM (and for much of the event) would be about two times lower than prior to the event. However, the decrease in $CaCO_3$ at site 690 is more likely a result of an increase in clastic input coincident with increased continental weathering (Robert and Kennett, 1994), suggesting little change in sedimentation rate. Given the ~2.5 m.y. duration of Chron 24r, it is implausible (given reasonable sedimentation rates) that the entire LPTM (from the base of the excursion to the point where $\delta^{13}C$ values level out) lasted more than ~200 k.y. Assuming constant sedimentation rates within the LPTM at site 690, the maximum duration of the onset (27 cm in the *Acarinina* record of Kennett and Stott, 1991) is about 20 k.y. However, the extent of this onset may have been increased by bioturbation; recent isotope analyses (Thomas et al., in press) show an abrupt 3 cm onset, equivalent to a duration of ~2 k.y. Lu et al. (1996) argued for a longer "prelude" of 300 k.y., but they appear to be interpreting the well-known long-term decrease in $\delta^{13}C$ that is unrelated to the LPTM.

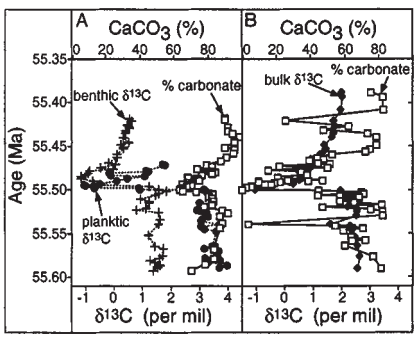

Figure 1. Carbon isotope and carbonate stratigraphy of LPTM interval. A: Site 690 ($\delta^{13}C$ data from Kennett and Stott, 1991, and Thomas and Shackleton, 1996; $CaCO_3$ data from O'Connell, 1990, and D. J. Thomas [unpublished]). B: Site 1001 (Bralower et al., 1997). Sample ages are estimated using age model of Thomas and Shackleton (1996).

The LPTM $\delta^{13}C$ excursion was recorded by soil carbonates in the Bighorn Basin, Wyoming (Koch et al., 1995, Fig. 5), where accumulation rates were nearly two orders of magnitude higher than in the deep sea. Although an interval of 10 m separates pre- and peak-excursion samples, the recovery extends over ~40 m. We cannot rule out the possibility that the base of the land record is condensed; however, the similar shape of $\delta^{13}C$ records from land and marine sections is additional evidence for abrupt LPTM onset.

Ascertaining the rate of the onset of the carbon isotope excursion is important, but we disagree with the implication of Dickens that this knowledge will resolve the cause of the excursion. We have a poor understanding of the dynamics of methane release from the sediment column as a result of thermal dissociation of hydrates. In addition, little is known about the rate of CO_2 release during flood basalt eruptions such as in the North Atlantic Igneous Province. As discussed elsewhere (Thomas and Shackleton, 1996), North Atlantic volcanism is an unlikely explanation for the C-isotope excursion given typical $\delta^{13}C$ values of volcanic CO_2 (–6‰ to –7‰).

Currently, methane hydrate dissociation is the only known mechanism that can explain both the magnitude and abruptness of the LPTM $\delta^{13}C$ excursion (Dickens et al., 1995), but far more information besides the rate of CO_2 input is required before the causes of the remarkable LPTM event are fully understood.

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