Lucas, S.G. and Spielmann, J.A., eds., 2007, The Global Triassic. New Mexico Museum of Natural History and Science Bulletin 41.

INTERPRETING THE UPPER TRIASSIC CARBON ISOTOPE RECORD

LAWRENCE H. TANNER

Dept. Biological Sciences, Le Moyne College, Syracuse, NY 13214 USA, email: tannerlh@lemoyne.edu

Carbon isotope analyses of Upper Triassic marine strata from multiple locations generally record an extended period of stability of the isotopic composition of the ocean atmosphere system during the Late Triassic. Although a minor positive shift may occur at the Carnian-Norian boundary (Muttoni et al., 2004), and a potential positive excursion has been reported from the Norian-Rhaetian boundary (Sephton et al., 2002; Ward et al., 2004), no excursions of significant magnitude or duration are noted in Upper Triassic strata older that latest Rhaetian. Significant negative excursions in the carbon isotope composition of organic matter have been identified in close proximity to the system boundary in a number of marine sections. For example, the sections at St. Audrie's Bay, southwest England (Hesselbo et al., 2002, 2004), Csövár, Hungary (Pálfy et al., 2001), and Tiefengraben, Austria (Kuerschner et al., 2007) display negative $\delta^{13}C$ excursions of approximately 2.0 to 3.0$^{o}/_{oo}$. Consistently, these excursions begin below the highest occurrence (HO) of conodonts, supporting their correlatability. At the Kennecott Point section in the Queen Charlotte Islands, Canada, a negative $\delta^{13}C$ excursion (of approximately 1.5-2.0 $^{o}/_{oo}$) spans the TJB, beginning immediately below the HO of Triassic ammonites and radiolarians, and continuing above the lowest occurrence (LO) of Jurassic radiolarians (Ward et al., 2001, 2004; Williford et al., 2007). In the New York Canyon section of Nevada, USA, a negative $\delta^{13}C$ excursion of similar magnitude (about 2.0 $^{o}/_{oo}$) also begins just below the HO of conodonts, Triassic ammonites (*Choristoceras crickmayi* and *Arcestes* spp.) and Triassic bivalves (Guex et al., 2004). Additionally, a similar trend has been claimed for several other sections based on the carbon-isotope composition of carbonate deposited in more proximal environments (e.g., Galli et al., 2005, 2007).

A negative $\delta^{13}C$ excursion for organic carbon in terrestrial environments also has been claimed for nonmarine strata encompassing the Triassic-Jurassic boundary (TJB), but these data are problematic (McElwain et al., 1999; Hesselbo et al., 2002). The presumption is that the marine excursion resulted from a drastic alteration of the $\delta^{13}C$ of the global CO_2 reservoir that similarly was recorded by vascular plants. However, published isotope analyses of plant macrofossils for TJB sections in Scania fail to exhibit this excursion in any fashion (McElwain et al., 1999). Data from Greenland display an apparent trend that appears to correlate with the marine data, although there is significant intersample $\delta^{13}C$ variability and therefore a lack of the consistency that is displayed in the marine record (McElwain et al., 1999; Hesselbo et al., 2002). Notably, terrestrial organic matter displays significant interspecific variations in isotopic composition due to variations in the organic composition. Furthermore, variations in the isotopic composition of plants may result from environmental factors other than the $\delta^{13}C$ of the atmosphere.

The widespread nature of the negative isotope excursion draws comparisons to other major paleontologic boundaries in which negative carbon isotope excursions are prominent features, such as the end-Permian (Holser and Magaritz, 1992; Magaritz et al., 1992), the end-Cretaceous (Kump, 1991) and the late Paleocene (Koch et al., 1992; Norris and Röhl, 1999), although these various isotopic events vary in their magnitude and duration. The significance and causes of most of these isotopic events are not yet fully understood, however, although diverse mechanisms have been proposed and various attempts have been made to explain them through mass-balance modeling (Kump and Arthur, 1999; Beerling and Berner, 2002; Berner, 2002; Dickens, 2003). Major changes in the carbon isotope composition of both organic matter and carbonate suggest a disruption of the carbon cycle of global extent; such a disruption may result from a variety of causes. Diagenesis can be ruled out where $\delta^{13}C$ displays parallel trends for both carbonate and organic matter because diagenesis has little effect on the isotopic composition of organic matter (Kump and Arthur, 1999). The introduction of large volumes of isotopically light carbon into the global carbon reservoir will produce this parallel trend, but there are multiple sources of light carbon. Sudden decreases in primary productivity may result in a rapid buildup of light carbon in the carbon reservoir, and this mechanism has been offered to explain the shifts at the K-T boundary (Kump, 1991) and the end-Permian (Holser and Magaritz, 1992; Magaritz et al., 1992). However, Beerling and Berner (2002) and Berner (2002) have pointed out that the loss of primary productivity alone can account for no more than one-half of the observed isotopic shift. The rapid release of dissolved CO_2 derived from organic decomposition during ocean overturn may also introduce substantial volumes of light carbon; this process has been suggested to explain the end-Permian isotopic excursion (Knoll et al., 1996). Such an overturn should be recorded by deposition of anoxic ocean sediments, but widespread anoxia is not recognized at the TJB (Pálfy et al., 2001).

The dissociation of methane hydrates in ocean-floor sediments is now regarded widely as a likely source for the rapid introduction of large volumes of very light carbon ($\delta^{13}C$ = –60 to -65 $^{o}/_{oo}$) to the ocean-atmosphere system (Dickens et al., 1995, 1997). In theory, once the release of sea-floor methane is triggered, ocean warming and dropping of the thermocline may result in continued dissociation and a "runaway greenhouse" effect (Dickens et al., 1995). The isotopic shifts at the end-Paleocene clearly coincide with a warming event of 5-7^{o}C, the late Paleocene thermal maximum (LPTM). This event is now explained as the result of methane release, possibly triggered by a change in oceanic thermohaline circulation (Dickens et al., 1995). Additionally, methane release has been proposed to explain other isotopic excursions in the stratigraphic record, particularly, the end-Permian (Krull and Retallack, 2000; Wignall, 2001; Berner, 2002). Pálfy et al. (2001) proposed that CAMP eruptive activity in some way triggered methane release that led to biotic extinction at the system boundary. However, mass balance calculation of the volume of methane required to effect a significant isotopic shift in the ocean carbon reservoir raises questions regarding the potential to store sufficient quantities of methane in the warm ocean of the Late Triassic.

The eruption of large igneous provinces is, perhaps, not coincidentally, associated with the isotopic excursion events associated with some paleontologic boundaries, including the end-Permian (the Siberian traps eruption), the end-Triassic (CAMP), the end-Cretaceous (Deccan Traps), and the LPTM (the North Atlantic Igneous Province; Wignall, 2001). Although McElwain et al. (1999) initially suggested a major role of CAMP degassing of isotopically light CO_2 in driving the isotopic shift, subsequent authors have discounted this hypothesis on the basis that unreasonably large volumes of mantle-derived CO_2 with $\delta^{13}C$ = -5 to -6 $^{o}/_{oo}$ are required to effect the observed shift. Notably, these calculations assume a deep mantle origin for CAMP magmas, an assumption not clearly supported by petrologic constraints. Wignall (2001) pointed out that much lighter CO_2 ($\delta^{13}C$ = -20 $^{o}/_{oo}$) may be derived from the carbon in recycled lithosphere at subduction boundaries. Current understanding of the source of the CAMP magmas does not dictate against such recycling. Consequently, I propose an alternative to the currently popular *deus ex machina* of methane release; the consequences of the voluminous CAMP eruptions included the release of well over 1000 Gt of isotopically depleted C as CO_2. Moreover, the environmental consequences of the eruptions, including atmospheric opacity and acid fallout, forced a significant decline in primary productivity. Together, these effects produced the observed change in the isotopic composition of carbon in the ocean-atmosphere system and forced the biotic turnover that marks the system boundary.

REFERENCES

Beerling, D.J., and Berner, R.A., 2002, Biogeochemical constraints on the Triassic-Jurassic boundary carbon cycle event: Global Biogeochemical Cycles, v. 16, 10.1029/2001GB001637.

Berner, R.A., 2002, Examination of hypotheses for the Permo-Triassic boundary extinction by carbon cycle modeling: Proceedings of the National Academy of Sciences, v. 99, p. 4172-4177.

Dickens, G.R., 2003, Rethinking the global carbon cycle with a large, dynamic and microbially mediated gas hydrate capacitor: Earth and Planetary Science Letters, v. 213, p. 169-183.

Dickens, G.R., Castillo, M.M., and Walker, J.C.G., 1997, A blast of gas in the latest Paleocene: simulating first-order effects of massive dissociation of oceanic methane hydrate: Geology, v. 25, p. 259-262.

Dickens, G.R., O'Neil, J.R., Rea, D.K., Owen, R.M., 1995, Dissociation of oceanic methane hydrate as a cause of the carbon isotope excursion at the end of the Paleocene: Paleoceanography, v. 10, p. 965-971.

Galli, M. T., Jadoul, F., Bernasconi, S. M., Cirilli, S., and Weissert, H., 2007, Stratigraphy and palaeoenvironmental analysis of the Triassic–Jurassic transition in the western Southern Alps (Northern Italy): Palaeogeography, Palaeoclimatology, Palaeoecology, v. 244, p. 52-70.

Galli, M. T., Jadoul, F., Bernasconi, S. M., Weissert, H., 2005, Anomalies in global carbon cycling and extinction at the Triassic/Jurassic boundary: Evidence from a marine C-isotope record: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 16, p. 203-214.

Guex, J., Bartolini, A., Atudorei, V., and Taylor, D., 2004, High-resolution ammonite and carbon isotope stratigraphy across the Triassic-Jurassic boundary at New York Canyon (Nevada): Earth and Planetary Science Letters, v. 225, p. 29-41.

Hesselbo, S.P., Robinson, S.A., Surlyk, F., and Piasecki, S., 2002, Terrestrial and marine extinction at the Triassic-Jurassic boundary synchronized with major carbon-cycle perturbation: a link to initiation of massive volcanism?: Geology, v. 30, p. 251-254.

Hesselbo, S.P., Robinson, S.A., and Surlyk, F., 2004, Sea-level change and facies development across potential Triassic-Jurassic boundary horizons, SW Britain: Journal Geological Society of London, v. 161, p. 365-379.

Holser, W.T., and Magaritz, M., 1992, Cretaceous/Tertiary and Permian/Triassic boundary events compared: Geochimica et Cosmochimica Acta, v. 56, p. 3297-3309.

Knoll, A.H., Bambach, R.K., Canfield, D.E., and Grotzinger, J.P., 1996, Comparative Earth history and Late Permian mass extinction: Science, v. 272, p. 452-457.

Koch, P.L., Zachos, J.C., and Gingerich, P.D., 1992, Correlation between isotope records near the Paleocene/Eocene boundary: Nature, v. 358, p. 319–322.

Krull, E.S., and Retallack, G.J., 2000, $\delta^{13}C$ depth profiles from paleosols across the Permian-Triassic boundary: evidence for methane release: Geological Society of America Bulletin, v. 112, p. 1459-1472.

Kuerschner, W. M., Bonis, N. R., Krystyn, L., 2007. Carbon-isotope stratigraphy and palynolostratigraphy of the Triassic-Jurassic transition in the Tiefengraben section—Northern calcareous Alps (Austria). Palaeogeography, Palaeoclimatology, Palaeoecology, v. 244, p. 257-280.

Kump, L.R., 1991, Interpreting carbon-isotope excursions: strangelove oceans: Geology, v. 19, p. 299-302.

Kump, L.R., and Arthur, M.A., 1999, Interpreting carbon-isotope excursions: carbonates and organic matter: Chemical Geology, v. 161, p. 181-198.

Magaritz, M., Krishnamurthy, R.V., and Holser, W.T., 1992, Parallel trends in organic and inorganic carbon isotopes across the Permian/Triassic boundary: American Journal of Science, v. 292, p. 727-739.

McElwain, J.C., Beerling, D.J., and Woodward, F.I., 1999, Fossil plants and global warming at the Triassic-Jurassic boundary: Science, v. 285, p. 1386-1390.

Muttoni, G., Kent, D.V., Olsen, P., di Stefano, P., Lowrie, W., Bernasconi, S., Martin and Hernandez, F., 2004, Tethyan magnetostratigraphy from Pizzo Mondello (Sicily) and correlation to the Late Triassic astrochronological polarity time scale: Geological Society of America Bulletin, v. 116, p. 1043-1058.

Norris, R.D., and Röhl, U., 1999, Carbon cycling and chronology of climate warming during the Palaeocene/Eocene transition: Nature, v. 401, p. 775-778.

Pálfy, J., Demeny, A., Haas, J., Htenyi, M., Orchard, M.J., and Veto, I., 2001, Carbon isotope anomaly at the Triassic-Jurassic boundary from a marine section in Hungary: Geology, v. 29, p. 1047-1050.

Sephton, M.A., Amor, K., Franchi, I.A., Wignall, P.B., Newton, R., and Zonneveld, J.-P., 2002, Carbon and nitrogen isotope disturbances and an end-Norian (Late Triassic) extinction event: Geology, 30, p. 1119-1122.

Ward, P. D., Haggart, J. W., Carter, E. S., Wilbur, D., tipper, H. W., and Evans, T., 2001, Sudden productivity collapse associated with the T-J boundary mass extinction: Science, v. 292, p. 1148-1151.

Ward, P.D., Garrison, G.H., Haggart, J.W., Kring, D.A., Beattie, M.J., 2004, Isotopic evidence bearing on Late Triassic extinction events, Queen Charlotte Islands, British Columbia, and implications for the duration and cause of the Triassic-Jurassic mass extinction: Earth and Plan. Science Letters v. 224, p. 589-600.

Wignall, P.B., 2001, Large igneous provinces and mass extinctions: Earth Science Reviews, v. 53, p. 1-33.

Williford, K. H., Ward, P. D., Garrison, G. H., and Buick, R., 2007, An extended organic carbon-isotope record across the Triassic-Jurassic boundary in the Queen Charlotte Islands, British Columbia, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 244, p. 290-296.