Magnitude and duration of a CO_2 super greenhouse at the Triassic-Jurassic boundary

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Stratigraphic transitions from the Triassic to the Jurassic (Tr-J) around 200 Ma record an abrupt extensive global collapse and slow recovery of biodiversity, the cause of which has been tied to a massive abrupt, extrinsically caused climate change (Ward et al., 2001; Hesselbo et al., 2002). The main thrust of the proposed research will be to reconstruct Tr-J paleo-atmospheric CO_2, suggested to have risen dramatically at this time, using stomatal density of the thermophilic dipteraceous fern *Clathropteris meniscoides* and cheirolepidaceous conifers from outcrop and cores of lacustrine deposits from three coeval Early Mesozoic rift valleys preserved in eastern North America. These sections have already been shown to record a mass extinction in fauna and flora and preserve a modest Ir anomaly, a fern spike, and a negative δ^{13}C change of –5‰ at the boundary (Figure 1), in remarkable parallelism to the Cretaceous-Tertiary boundary (Olsen et al., 2002).

The paleomagnetic reversal stratigraphy and cyclostratigraphy of the Newark Supergroup provides a framework for rigorous temporal and geographic control between separate but tectonically similar basins. The results of this proposed research will help differentiate between the possible mechanisms proposed for the origins of the CO_2 anomaly: an extraterrestrial impact (Olsen et al., 2002) and massive continental flood basalt eruptions (Hesselbo et al., 2002). It will also provide greater spatial and temporal resolution of recovery from such perturbations in the face of the current perilous anthropogenic rise in the Earth's atmospheric CO_2 concentration.

Paleoclimatic and paleogeographic context: The Triassic and Early Jurassic—with its one supercontinent, Pangaea, more or less symmetrically disposed about the equator and extending from pole to pole—represents one of the extreme end members of Earth's geography and climate. A "hot house" world, with no evidence of polar ice, it is marked by deposition of coals in polar regions and extremely high pCO_2 (Berner, 1999). Pangean rift basins developed largely in a continental milieu during the Middle to Late Triassic along a broad zone from Greenland through the Gulf of Mexico in the ~40 m.y. preceding the Jurassic opening of the central Atlantic Ocean. Many of these high sedimentation rate rift basins preserve a detailed record of the Tr-J boundary. Robust and well-tested Milankovitch stratigraphy in the Newark provides a high-resolution framework for the transition that makes the Newark uniquely suited to document the rates of environmental change through the boundary and the recovery.

Paleoenvironment, Stomatal densities, and CO_2: The CO_2 content of the atmosphere can be gauged by analysis of leaf stomatal density, and especially, the density values normalized to cuticular epidermal cell density, the stomatal index (Woodward, 1987; Beerling et al., 1998; McElwain, 2001). Continental paleobotanical records offer information on more local phenomena than marine records, and provide a unique opportunity for studying long-lived biogenic precursors to the potentially striking current climatic shifts, linked to local and global CO_2 increases. Based on stomatal data and interpretation of fossil leaf morphology, McElwain et al. (1999) report a fourfold increase in CO_2 and a correlated 3 to 4° C greenhouse warming at the Tr-J boundary in Greenland.

As the work of McElwain et al. (1999) was confined to the last stage of the Triassic (Rhaetian) and first stage of the Jurassic (Hettangian), it provides a narrower CO_2 regime than the proposed study, which, although focused on the Rhaetian/Hettangian, will also include spot samples from the Carnian to the second stage of the Jurassic (Sinemurian). While the species specificity of stomatal density and stomatal index responses to both elevated CO_2 and reduced concentrations has been highlighted (Malone et al., 1993; Ferris and Taylor, 1994). McElwain et al. (1999) measured stomatal density, index and ratio from four genera across the boundary, none of which occur on both sides of the boundary. Although three genera (*Clathropteris*, *Todites*, and *Equisetities*), cross the boundary, they calculated CO_2 from only ginkogalean and cycadalean forms because they belong to extant groups or are morphological (or ecological) equivalents of living taxa. Furthermore, the Greenland section offers few additional sources of paleoecological or paleoclimatic data, and most importantly, it lacks a time scale for calibrating rates of climatic change.

In the proposed work, the dipteraceous fern *Clathropteris meniscoides* and cheirolepidaceous conifers (*Brachyphyllum and Pagiophyllum*), common to both Upper Triassic and Lower Jurassic floral zones across a 6° paleolatitude permeated by Milankovitch cyclicity, provide the material basis for exploring the climatic and biotic consequences of the Tr-J boundary event.

The stratigraphic range of *C. meniscoides* stretches from the Late Triassic to the Middle Jurassic (Harris, 1931; Vakhrameev, 1991) with well-preserved samples in the Newark (Cornet, 1977), Hartford (Hitchcock, 1855), and Deerfield basin correlative strata. In the Newark basin, *C. meniscoides* occurs as the single pre-boundary macrofossil in the Perkasie member of the uppermost Passaic Formation (215 Ma). It is also abundant in older strata, particularly in the Richmond basin at ~230 Ma. It is characteristic of the Rhaeto-Liassic in Greenland, Northern Europe, China and parts of Southeast Asia. While there is evidence for a Rhaeto-Liassic maximum, there is insufficient data for a global *C. meniscoides* increase specifically at the boundary. Spores of *Clathropteris* (*Granulatisporites infirmus* and *Converrucosisporites cameronii*) are the dominant palynomorphs in the fern spike at the Tr-J boundary (Figure 1) shown to contain a modest Ir anomaly (Olsen et al., 2002), as well as in a candidate Tr-J section in the northern Hartford basin (Whiteside and Olsen, 2003).

Conifers are by far the most common floral remains in the Newark Supergroup, particularly around the Tr-J boundary and succeeding strata. There is already apparent strong physiognomic change in the form of thickened cuticles at and above the fern spike (Cornet, 1977). Conifer remains are present in nearly every gray shale bed, and these same beds form the basis of the Milankovitch cyclostratigraphy comprising the time scale for this proposed study.

Proposed Research: The objective of the proposed research is to document the timing and rates of the CO_2 super greenhouse and the biotic recovery across the Tr-J boundary from the Newark, Hartford, and Deerfield basins through: (1) the collection of *C. meniscoides* and conifer megafossils for stomatal-assays and leaf physiognomy as well as bulk sediment samples for both microfossil and stable carbon isotope analysis on tracheids, cuticles (methodology after Visscher, 1994), and taxon-specific pollen (methodology after Beerling and Jolley, 1998), and (2) composition of a detailed microsedimentological study of the Tr-J plant-bearing beds.

I anticipate that the pCO_2 data generated from this proposed study will allow me to constrain the models for the major ecological insult. For example, if an impact was the driving mechanism for CO_2-forced global warming, the anomaly should fade away quickly (~10 ky). If ocean-atmosphere CO_2 buffering from volcanic outgassing is responsible, the excursion should be long-lived (~600 ky, the duration of the flood basalts). These durations are based on Milankovitch cyclostratigraphy of the same strata containing the phytological samples.

Preliminary sampling indicates that there is sufficient fossil material through the boundary and succeeding strata to accomplish the goals of this proposal. In addition I have been able to show that there is a recoverable δ^{13}C record for the strata, and it has already been documented by others that there is a stomatal density change across the Tr-J boundary (McElwain et al., 1999), albeit without the necessary time control.

Budget

$3,500 Mass spectrometry expenses —~350 samples (bulk rock, pollen, cuticles) @ $10 sample
$ 500 Supplies (chemicals, sieves, etc.) for cuticular maceration and pollen techniques
$ 600 SEMs to obtain clear images of stomata and epidermal cells, tracheids and cuticles
$ 900 Travel (Field work expenses)

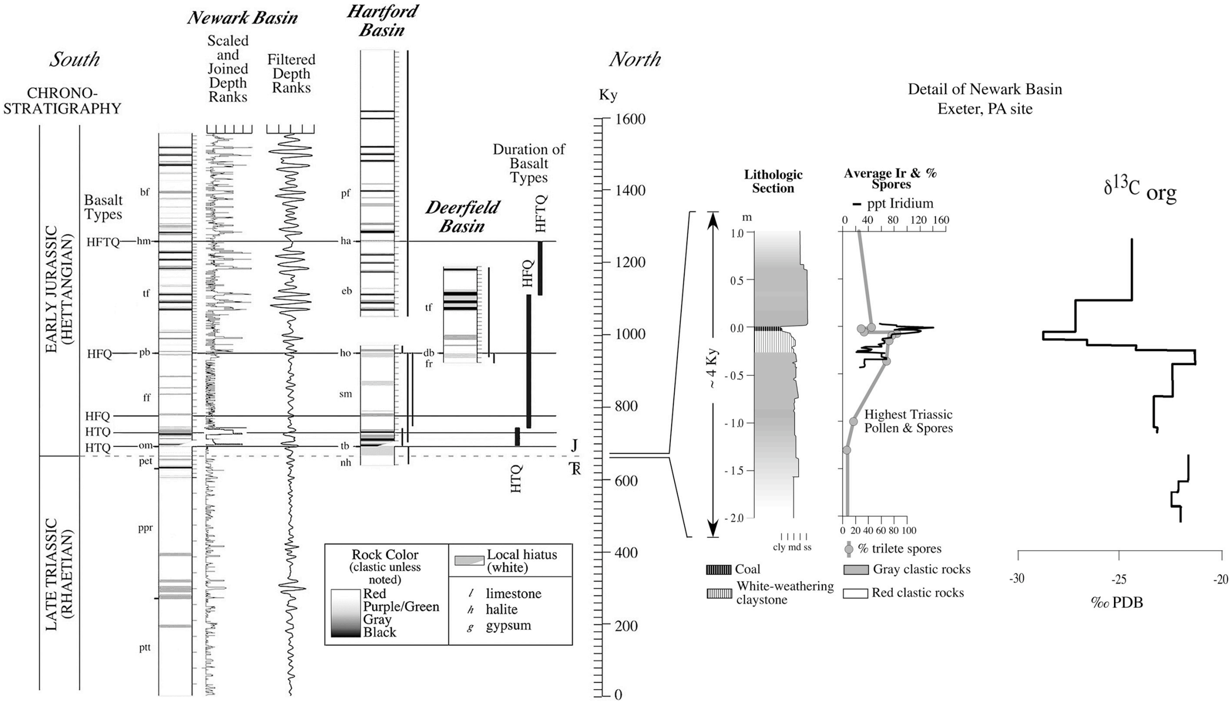

Figure 1. Cyclostratigraphic calibration for 1.6 m.y. around the Triassic-Jurassic boundary in the three proposed study basins in eastern North America: Newark, Hartford, and Deerfield. Basin sections are arranged in paleogeographic position, with measured sections showing basic lithologies and cyclostratigraphies of individual basins. Insert is fine-scale correlation between the Ir anomaly, fern spike, and $\delta^{13}C_{org}$ from Exeter, PA (Newark Basin). Cyclostratigraphic, Ir, and pollen and spore data from Olsen et al. (2002, 2003).

REFERENCES CITED

Berner, R.A. 1991. A model for atmospheric CO_2 over Phanerozoic time. *American Journal of Science*, v. 291, p. 339-376,

Beerling, D.J., and Jolley, D.W. 1998. Fossil plants record an atmospheric $^{12}CO_2$ and temperature spike across the Palaeocene-Eocene transition in NW Europe. *Journal of the Geological Society, London*, v. 155, p. 591-594.

Beerling, D.J., McElwain, J.C., and Osborne, C.P. 1998. Stomatal responses of the "living fossil" *Gikgo biloba* L. to changes in atmospheric CO_2 concentrations. *Journal of Experimental Botany*, v. 49, p. 1603-1607.

Cornet, B. and Traverse, A., 1975. Palynological contributions to the chronology and stratigraphy of the Hartford basin in Connecticut and Massachusetts. *Geoscience and Man*, v. 11, p. 1-33.

Cornet, B. 1977. The palynostratigaphy and age of the Newark Supergroup. Ph.D. Thesis, Department of Geology, The Pennsylvania State University, State College, PA, p. 165-172, p. 192-222.

Ferris, R. and Taylor, G. 1994. Stomatal characteristics of four native herbs following exposures to elevated CO_2. *Annals of Botany*, v. 73, p. 447-453.

Fowell, SJ. 1994. Palynology of Triassic-Jurassic boundary sections from the Newark Supergroup of Eastern North America: Implications for catastrophic extinction scenarios. Ph.D thesis, Columbia University NY, 154 p.

Harris, T.M., 1931. The fossil flora of Scoresby Sound East Greenland. *Meddelelser om Grønlad*, v. 112, 114 p. *In* Cornet, B. *Clathropteris meniscoides* (Brongniart) Brongniart, Associated spores and *Equisetites* from the Newark Supergroup of Massachusetts, USA. Unpublished ms. 33 p.

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.

Hitchcock, E., Jr. 1855. Description of a new species of *Clathropteris* discovered in the Connecticut Valley Sandstone. *American Journal of Science*, v. 20, p. 22-25.

Malone, S.R., Mayeux, H.S., Johnson, H.B., and Polley, H.W. 1993. Stomatal density and aperture length in four plant species grown across a subambient gradient. *American Journal of Botany*, v. 80, p. 1413-1418.

McElwain, J.C., Mitchell, F.J.G., and Jones, M.B. 1995. Relationship of stomatal density and index of *Salix cinerea* to atmospheric carbon dioxide concentration in the Holocene. *Holocene*, v. 5, p. 216-220.

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.

Olsen, P.E., Kent, D.V., Sues, H.D., Koeberl, C., Huber, H., Montanari, A., Rainforth, E.C., Fowell, S.J., Szajna, M.J., Hartline, B.W. 2002. Ascent of dinosaurs linked to Ir anomaly at Triassic-Jurassic boundary. *Science*, v. 296, p. 1305-1307.

Vakhrameev, V.A. 1991. *Jurassic and Cretaceous floras and climates of the Earth*. Cambridge University Press, 318 p.

Visscher, H. 1994. Links with the past in the plant world: cuticles as recorders of diversity, kerogen formation and palaeoatmospheric CO_2 level. *Palaeobotanist*, v. 42, p. 86-92.

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

Whiteside, J.H., and Olsen, P.E. 2003. Possible Triassic-Jurassic boundary sections, Hartford basin, Eastern North America. *In* Geological Society of America, Abstracts with Programs, v. 35, p. 84.

Woodward, F.I. 1987. Stomatal numbers are sensitive to increases in CO_2 from preindustrial levels. *Nature*, v. 327, p. 617-618.