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Technical Comments

Triassic-Jurassic Extinctions

P. E. Olsen *et al.* (*1*) add an important new data point to the emerging pattern of Late Triassic and Early Jurassic extinctions and survivals among terrestrial vertebrates. The principal value of the new Nova Scotian quarries is their rich record of diversity within a tightly defined temporal interval at a point early in the Jurassic. Yet, as the authors note, no new presences or absences of taxa are recorded in this fauna that are not already known from other Early Jurassic localities. What further inferences are warranted?

The authors suggest two extreme hypotheses of the pace of Late Triassic extinction events (catastrophic versus gradual, on the order of "tens of millions" of years). Data already suffice (*2–4*) to place the extinctions of these groups within the Late Norian [5 million years (my) or less]. The new report brings the temporal range of these extinctions to less than 1 my—although only in the Newark Supergroup. This level of temporal and geographic resolution is far too coarse to permit a choice between "catastrophic" and more gradual ecological hypotheses, even if special explanation of the extinction pattern were warranted.

Olsen *et al.* base their hypotheses of rapid extinction in the latest Triassic on evidence stratigraphically below the new Nova Scotian sites. Latest Triassic correlation data come from a remarkable variety of sources, including pollen and spores, radiometric dates, bones and footprints of vertebrates, and remarkably fine microstratigraphic correlations of the Newark lake beds. Olsen *et al.* infer that the pattern of latest Triassic extinctions in the Newark Supergroup is representative of global change; it may be, but do the data show this? Of the 61 families and higher taxa of terrestrial vertebrates shown in their figure 2, only 23 (fewer than 40%) are known in the Newark. Of the 34 taxa that approach or cross the Triassic-Jurassic boundary, only 17 (50%) are present in the Newark. Moreover, all 17, as represented in the Newark, are (i) monotypic—represented by only one genus and species—suggesting the group was already on the wane; (ii) represented by scrappy material that cannot be identified below the high taxonomic level listed—thus providing no real measure of the pace of change of diversity; or both (i) and (ii). Four extinctions (three of which are obviously pseudoextinctions) occur in the next 2-my interval (*3*, figure 25.6, reproduced in Fig. 1).

The Newark's scrappy osteological record, even supplemented by its rich but temporally spotty footprint record, cannot support generalizations about the pace of extinction of latest Triassic taxa. During the last 2-my interval of the Triassic, only two taxa made their last appearances in the Newark (*1*, note 18; *3*, figure 25.6, reproduced in Fig. 1). These were the procolophonids, known only from the endemic genus *Hypsognathus*, and the phytosaurs, known only from indeterminate remains generally referred to the genus *Rutiodon*. The possible phytosaur footprint *Apatopus* and the pseudosuchian footprint *Brachychirotherium* are also last represented during this interval (*3*, figure 25.9). The affected taxa are sparsely represented and already low in diversity by that time; moreover, two taxa do not a mass extinction make. The 12 other taxa that breathed their last sometime during the Norian are not represented in the uppermost part of the Newark.

What seems equally significant is the first appearances of four higher taxa (theropod and sauropodomorph dinosaurs, protosuchian crocodiles, and trithelodontid therapsids) in the earliest Jurassic of the Newark.

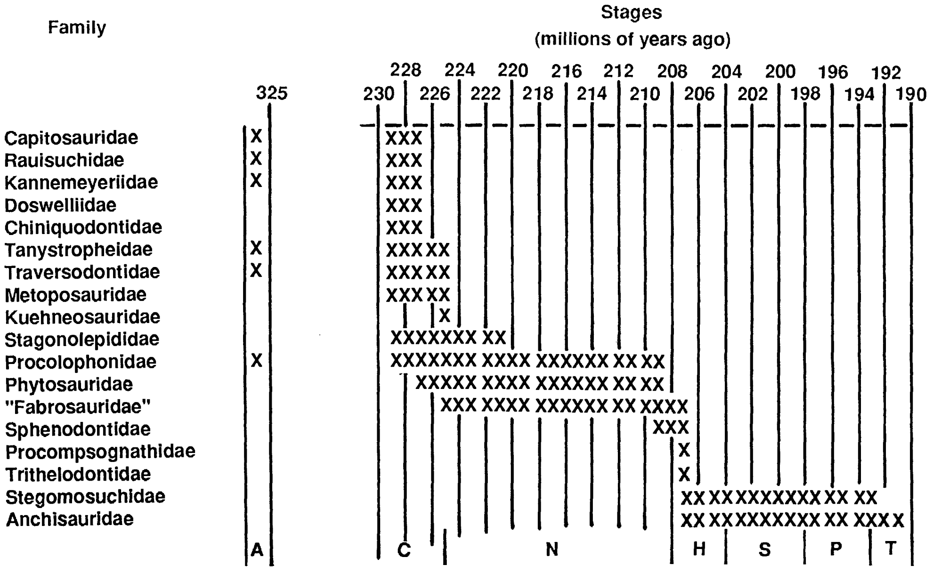

Fig. 1. Distributions of skeletal remains of tetrapods in the Newark Supergroup (from *3*). The patterns shown here by the 2-my scale contrast with those shown by the coarser scale of Triassic-Jurassic stages in figure 2 of Olsen *et al.* (*1*). The Triassic-Jurassic boundary is set at 208 my ago, between the Norian (N) and Hettangian (H) stages. Other abbreviations for stages are as follows: A, Anisian; C, Carnian; S. Sinemurian; P, Pliensbachian; T, Toarcian.

All are already known from latest Triassic horizons elsewhere (*1*, figure 2; *3*, figure 25.2), but not in the Newark. Furthermore, three of these groups—ornithischian ("fabrosaurs") and theropod ("Procompsognathidae") dinosaurs, and sphenodontid rhynchocephalians—have an artificially truncated range in the Newark Jurassic: their lineages persisted well into the Cretaceous or beyond. These patterns further underscore the paucity of latest Triassic vertebrate remains in the Newark Supergroup, in contrast with the richness of the new Early Jurassic fauna from Nova Scotia.

Finally, as with the Cretacous-Tertiary boundary, the patterns of selective (or random) extinction and survival of terrestrial taxa at the Triassic-Jurassic boundary have not received sufficient biological explanation through the mechanism of any extraterrestrial impact (*5, 6*). On the basis of the available data, it is not clear that any such explanation is warranted (*3, 4*). Olsen *et al.* acknowledge that the Manicouagan impact crater in eastern Canada, which has a range of estimated dates of some 19 my, could be synchronous with either the late Carnian or late Norian extinctions. The higher mathematical probability is that neither was the case.

Far more data are needed before the pace of diversity change during the latest Triassic can be assessed with confidence and before any causal connection to an extraterrestrial impact is warranted. Olsen *et al.* should be given the opportunity to provide a richer data base to substantiate their claim that all the latest Triassic extinctions (or at least more than two) occurred within a period of a few hundred thousand years.

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Response: Padian asks, What do the new Nova Scotian vertebrate assemblages tell us about the Triassic-Jurassic extinctions that we did not know already? Before the discovery of the Nova Scotian assemblages there were virtually no osseous terrestrial vertebrate assemblages that could be dated with confidence at the age level (*1*). We have only a tentative Sinemurian-Pliensbachian (although certainly Jurassic) date for the Moenave and Kayenta formation assemblages (*2*), and "Early Jurassic" dates for certain British fissure fillings (*3*), the upper Stormberg Group of southern Africa (*1*), the Kota formation assemblage of India (*4*), and the lower Lufeng beds of China (*5*). Even if one accepts a Sinemurian age for the Kayenta, the extinction of the "typical" Triassic taxa could have happened anywhere from the late Norian through Sinemurian, that is, in an interval of some 10 million years. Therefore, the hypothesis that taxa of Late Triassic aspect were extinct by the close of that period could not be tested by examining earliest Jurassic assemblages, as there were none known. The new Nova Scotian assemblages provide this test: they are early Hettangian in age and occur in a wide range of depositional facies completely overlapping the range of facies in which Triassic terrestrial forms occur; the forms hypothesized to disappear at the end of the Triassic are indeed not present. Further collecting may, of course, prove this hypothesis wrong.

The Nova Scotian assemblages contrain downward the duration over which the extinctions could have occurred, from at least 20 my to less than 5 my. In addition, we further provide data which constrains the extinction of two of the most dominant Late Triassic families (Procolophonidae and Phytosauridae) to within less than 1 my of the boundary. It is irrelevant that we have shown this pattern "only in the Newark Supergroup," as Padian says, because additional discoveries cannot contract their total biostratigraphic ranges; they can only extend them. Therefore, new Triassic age discoveries would contract the duration of the extinction interval, strengthening the case for very rapid change.

We agree with Padian that Late Triassic assemblages are poorly known. Furthermore, the quality of the known record declines as one approaches the Triassic-Jurassic boundary. However, as in the case of the former absence of earliest Jurassic assemblages (*6*), we feel this reflects a lack of collection effort rather than a true representation of the record.

We disagree with Padian's contention that the groups represented in the Newark and which die out during the Triassic "are monotypic . . . suggesting the group was already on the wane" or that "they are represented by only scrappy material indeterminate below the taxonomic level listed." We cannot provide a complete faunal list here, but we provide examples in Table 1. In fact, one family (Procolophonidae) is more diverse at the generic level in the Newark than any other geologic province. In addition, many families are represented by excellent remains, and the only Newark Triassic families represented by truly scrappy material diagnostic only at the family level are the Rauisuchidae. We recognize, however, that much of this material has not been described in detail, and therefore the wealth of well-preserved Newark Supergroup material is not evident from the literature.

Padian notes correctly that there is a large scatter to the available dates from Manicouagan impact melt rocks. If all of the "best" published dates are treated equally, their mean [211 million years ago (ma)] is closer to the Carnian-Norian boundary data (215 ma) than is our preferred date for the Triassic-Jurassic boundary (200 ma). However, there is no greater mathematical probability that the Manicouagan dates represent nei-

Table 1. Partial faunal list of taxa that do not cross the Triassic-Jurassic boundary, from Triassic age rocks of the Newark Supergroup (*10*).

Family Tanystropheidae
- *Tanystropheous* sp. (diagnostic single neck vertebra)
- *Tanytrachelos ahynis* (over 150 articulated skeletons and thousands of isolated bones)

Family Procolophonidae
- *Hypsognathus fenneri* (four articulated skulls and partial postcrania)
- *Leptopleuron* sp. (nearly complete skull)
- *Sclerosaurus* sp. (diagnostic dorsal vertebra)
- *Myocephalus* sp. (diagnostic dentriginous maxilla)
  - New genus 1 (nearly complete skull)
  - New genus 2 (maxilla and partial plate)

Family Rhynchosauridae
- *Hyperodapedon* sp. (several maxillae and other cranial elements)
- *Sphodrosaurus pennsylvanicus* (articulated partial skull and articulated partial skeleton)

Family Traversodontidae
- *Scalenodontodes plymmridon* (diagnostic partial dentaries and isolated teeth)
- *Massetognathus* sp. (diagnostic partial dentriginous dentary)