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Tectonophysics 245 (1995) 96–99

TECTONOPHYSICS

Time calibration of Triassic/Jurassic microfloral turnover, eastern North America—Reply

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Received 28 February 1994; accepted 21 November 1994

Evidence from sedimentation rates and stratigraphic ranges of palynomorph species indicate that van Veen is incorrect in inferring a condensed section at the Triassic/Jurassic (Tr/J) boundary in the Newark Supergroup. Van Veen bases his argument entirely on the ranges of palynomorph species in western Europe, but correlation of the European sections is equivocal, and the range data employed by van Veen can also be used to argue against a hiatus in the Late Triassic of the Newark Supergroup.

Ranges of Late Triassic species compiled by Brugman (1983) for western Europe (Fig. 1) contradict van Veen's statement that vesicate pollen (e.g. *Vallasporites ignacii* Leschik, 1955, *Enzonalasporites vigens* Leschik, 1955, and *Patinasporites densus* Leschik, 1955) disappear at or below the base of the Rhaetian. *Enzonalasporites vigens* and *Patinasporites densus* are present until the latest Rhaetian, albeit in decreased abundances. In addition, comparison of the European and North American ranges of the Late Triassic index species *Granuloperculatipollis rudis* Venkatachala and Góczán, 1964 and *Ovalipollis pseudoalatus* (Thiergart) Schuurman, 1976 indicate that the Newark basin sections are best placed within the Rhaetian stage.

Regarding the absence of European Rhaetian index species (e.g. *Ricciisporites tuberculatus* and *Limbosporites lundbladii*) in the Newark Supergroup, it is important to recognize that the European sections lay close to sea-level, whereas deposition of the Newark Supergroup occurred in a mountainous rift zone undergoing further uplift in the Late Triassic.

Moreover, central Europe straddled a major floral boundary in the Late Triassic and Early Jurassic (Zeigler et al., 1993). The effects of increasing elevation differences and floral provinciality are likely to be reflected in regional differences in palynofloral composition, a fact which must be considered with great care when undertaking long-distance correlation.

During the Late Triassic, the Norwegian section and the Newark basin were separated by about 25° of latitude (Scotese, 1991) and an intense arid zone (Olsen, 1991), hence minor discrepancies in taxonomic composition and species ranges are unsurprising. While biostratigraphic arguments are certainly a valid method of hypothesizing a hiatus in a stratigraphic section, such arguments are strongest when they are based on a highly corroborated standard reference section. Ideally, such a section would be calibrated in time via a quantitative or semi-quantitative method (e.g. the Shaw method). This is certainly not the case with the Norwegian off-shore section. It could just as well be the case that the

SSDI 0040-1951(94)00256-8

Norwegian section is expanded relative to the Newark section.

The Newark basin was a basin of closed drainage throughout most of its history, including the interval around the Tr/J boundary (Smoot, 1985; Smoot and Olsen, 1988), thus it is difficult to imagine how a hiatus or condensed section could form basin-wide. Data from the Newark basin Continental Coring Project (Olsen and Kent, 1990; Kent and Olsen, 1992; Olsen et al., in press) have shown that the cyclostratigraphic pattern in the uppermost Passaic Formation, which contains the Tr/J boundary, is laterally consistent over very large portions of the Newark basin. This result would not be expected in the event of a local condensed section. Furthermore, there is no sedimentological evidence of erosion or slow deposition in Tr/J boundary sections from the Jacksonwald syncline. On the contrary, synclinal folding in the Late Triassic resulted in relatively high sedimentation rates, rendering the Jacksonwald sections discussed in our paper the most complete Tr/J boundary sections in the Newark basin.

Measurement of Milankovitch-type cycles in and around the Jacksonwald syncline reveals a directional increase in cycle thickness from 4.5 m in the unfolded Newark basin to 20 m (as in our figured section) adjacent to the axis of the syncline and the border fault, where folding is at a maximum (Olsen et al., 1989). These results are indicative of continuous sedimentation in a region of local down-warping. In addition, sedimentary fabrics from cycles below the basalt flow in our measured sections indicate a deepening of the Newark Supergroup lakes, a result contrary to anticlinal uplift and erosion.

Given the lack of sedimentological evidence for a hiatus in the Newark basin sections and the fact that vesicate species do range throughout the Rhaetian in parts of Europe (Fig. 1), there is absolutely no reason to propose that Jacksonwald syncline strata represent condensed sections. Radiometric dates assigned to the Tr/J boundary in recently published time scales range from 200 Ma (Webb, 1981) to 208 Ma (Harland et al., 1989). Hence, we feel that 201 Ma is a reasonable age for the boundary (Dunning and Hodych, 1990) and see no evidence or need for a hiatus of several million years between the advent of *Corollina*-dominated palynofloras that lack Triassic species and subsequent volcanic episodes. Cy-

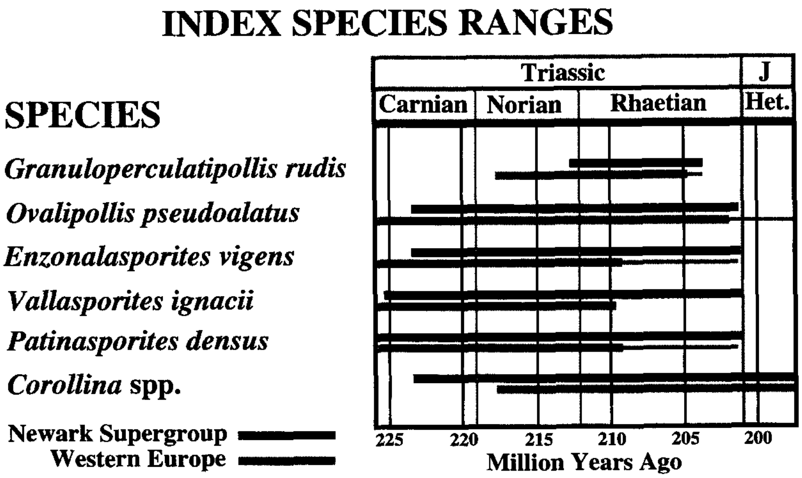

Fig. 1. Ranges of palynomorph species within the Newark Supergroup (solid bars) and western Europe (stippled bars). Vesicate species are shown to persist until the latest Triassic on both sides of the Atlantic, although their abundance in European sections decreases during the Rhaetian. Absolute dates (solid grid) apply only to the Newark Supergroup. Period and stage boundaries (stippled grid) apply to all ranges. European ranges are from Brugman (1983).

clostratigraphy indicates that the 201 Ma basalt flows succeeded the palynofloral turnover by less than 21 ky.

Our paper was intended as a discussion of the method of time-calibration using 21 ky cycles and its implications for Tʀ/J biostratigraphy in the Newark Supergroup. Consequently, we chose not to include lists of palynomorph species from individual sampling horizons. It would perhaps have been to our advantage to point out that the fern-spike assemblages are dominated by two sculptured, trilete species: *Granulatisporites infirmus* (Balme) Cornet and Traverse, 1975 and *Converrucosisporites cameronii* (de Jersey) Playford and Dettman, 1965. The composition of the fern-spike assemblage is thus different in taxonomic composition, spore percentage, and stratigraphic duration from the relatively diverse palynofloras bearing smooth, trilete species of *Deltoidospora* that are abundant throughout the latest Triassic and Early Jurassic of western Europe (Orbell, 1973; Schuurman, 1977).

We agree with van Veen that climate change is one possible cause of the Tʀ/J boundary palynological turnover in the Newark Supergroup. From the Culpeper basin of Virginia to the Fundy basin of Nova Scotia, cycles of latest Triassic and Early Jurassic age display higher proportions of intermediate- to deep-water fabrics than do underlying Late Triassic strata (Olsen et al., 1989). In each case, this evidence of greater lake depth is coincident with the explosion in abundance of the *Corollina* genus, and we have considered the hypothesis that both the fern spike and the sudden disappearances of Late Triassic species are the result of an increase in humidity (Fowell, 1994). However, given that the last appearances of numerous Triassic species, the flourishing of ferns, and the subsequent radiation of *Corollina*-producers are all restricted to a single 21 ky cycle, a mechanism which operates more quickly than sea-level change is required.

We elected to emphasize bolide impact in our recent paper because it effectively explained both the abruptness of the palynofloral turnover and the presence of the fern-spike. We did not, however, mention the Manicouagen impact site in our argument. Our previous paper (Olsen et al., 1990) was published prior to the revised dates of Manicouagen (Hodych and Dunning, 1992), and only there did we relate that impact site to the Tʀ/J boundary palynofloral turnover. Although the new Manicouagen dates preclude its origin as the cause of Tʀ/J boundary extinctions, the hypothesis of an impact origin for the end-Triassic extinction event (Olsen et al., 1987) and the Newark basin fern-spike (Olsen et al., 1990) remains valid. The Chixilub site was not recognized as the origin of the Cretaceous/Tertiary boundary clay until more than ten years after publication of the seminal paper by Alvarez et al. (1980); only in 1992 did we realize we may need to look elsewhere for an appropriate Tʀ/J boundary impact site. Although we do not dispute Hodych and Dunning's (1992) results, the age of Manicouagen may not be settled. Dates of impact melt rocks tend to be biased toward older ages due to inherited radiogenic argon and inherited basement zircons.

In conclusion, we acknowledge that there are discrepancies in the biostratigraphic data between the Norwegian offshore and Newark basin sections. But before an ad hoc explanation of the differences is invoked, a strong independent test which employs a different type of data is needed. A complete magnetic polarity stratigraphy through the Newark basin is now available (Kent and Olsen, 1992). We look forward to a critical comparison when similar data are available from the Norwegian or other European sections.

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