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

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ABSTRACT

Palynological data from the Newark basin of the Newark Supergroup reveal a spike in the spore/pollen ratio at the Triassic/Jurassic boundary. This spore spike is coincident with a 60% regional extinction of the palynoflora and approximately synchronous with terrestrial vertebrate extinctions. Orbitally controlled sedimentary cycles allow stratigraphic sections to be calibrated in time, constraining the duration of the microfloral turnover to an interval of 21 ky. The geologically brief palynofloral break is similar to Cretaceous/Tertiary boundary fern spikes. These data support a Triassic/Jurassic boundary impact-extinction scenario.

Introduction

The Late Triassic mass extinction is one of the five most severe extinctions of the Phanerozoic; 23% of marine families and 42% of terrestrial tetrapod families disappeared during the late Norian (Sepkoski, 1984; Olsen et al., 1987). In the oceans, this event eradicated families of ammonites, gastropods, bivalves and articulate brachiopods, decimated the reef-forming calcisponges and corals, and eliminated the last conodonts (Sepkoski, 1982; Stanley, 1988). On the continents, Late Triassic vertebrate faunas dominated by archosauromorph reptiles, labyrinthodont amphibians, and mammal-like reptiles were replaced by Early Jurassic dinosaurs, crocodilomorphs, mammals, and essentially modern amphibians and small reptiles (Olsen et al., 1987).

Suggested causes of the Late Triassic mass extinction range from hypotheses of abrupt, impact-induced extinctions (Olsen et al., 1987; Olsen et al., 1990; Bice et al., 1992) to a relatively gradual decline in diversity brought on by sea-level regression (Hallam, 1981, 1990). Although these theories differ greatly in their predictions for the synchroneity and duration of the extinctions, tests based on the paleontological record remain inconclusive due to the dearth of fossiliferous sections that contain the Triassic/Jurassic (Tr/J) boundary (Hallam, 1981).

Continental strata in the early Mesozoic Newark Supergroup of eastern North America (Fig. 1) provide excellent localities at which to examine fine-scale biotic turnover across the Tr/J boundary. Here, terrestrial tetrapod footprints and osseous remains constrain regional reptile and amphibian extinctions to the last 1–2 my of the Triassic (Olsen et al., 1987; Silvestri, 1990). Lacustrine sediments within this interval contain abundant, well-preserved palynomorph assemblages. The Newark Supergroup is unusual in that orbitally controlled sedimentary cycles allow a high-resolution time scale to be tied to comprehensive stratigraphic sections. In this paper, we use cyclostratigraphy and published radiometric dates to calibrate palyniferous stratigraphic sections in absolute time, thereby demonstrating that Tr/J boundary palynofloral extinc-

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tions are abrupt and synchronous throughout the Newark Supergroup.

Time calibration of the Newark basin section

The Newark Supergroup (Fig. 1) consists of the Triassic and Jurassic rocks that fill a series of rift basins formed during the Pangean breakup. The predominantly lacustrine and fluvial sediments were deposited in tropical environments between 2°S and 9°N (Witte et al., 1991). The younger basins (bold type, Fig. 1) contain a record

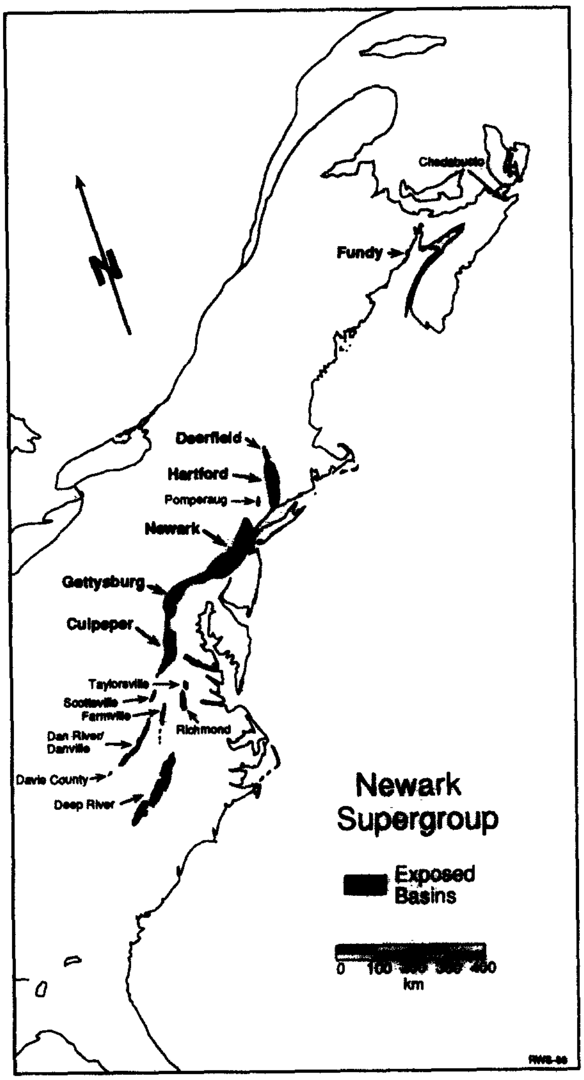


Fig. 1. The early Mesozoic Newark Supergroup of eastern North America, showing distribution of exposed basins. Basins that span the TR/J boundary are shown in boldface. (After Olsen et al., 1989).

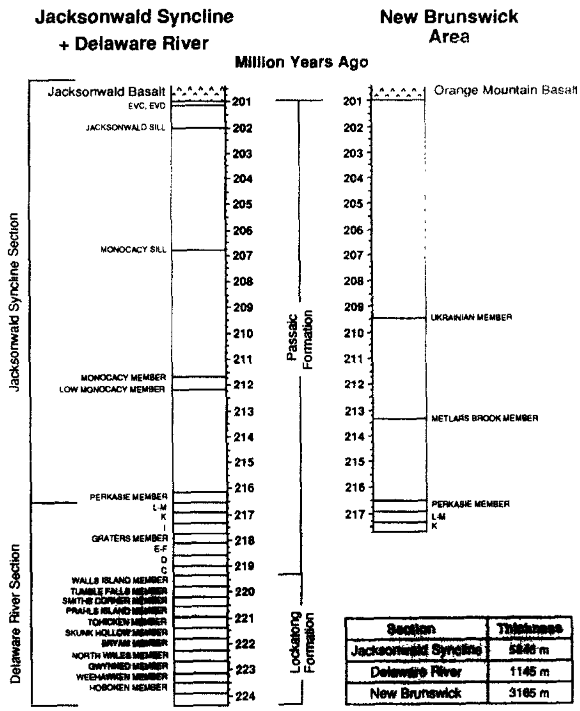


Fig. 2. Carnian to Hettangian sediments of the Newark basin calibrated in time by 21-ky Milankovitch cycles. The Jacksonwald Syncline and Delaware River sections have been spliced together at the base of the Perkasie Member. A date of 201 Ma is accepted for the Jacksonwald and Orange Mountain basalts (Sutter, 1988; Dunning and Hodych, 1990) in order to fix the sections in absolute time. *EVC* and *EVD* are palynologically productive horizons (see Fig. 6).

of essentially continuous deposition from the Late Triassic to the Early Jurassic. The TR/J boundary in these basins is identified by the appearance of palynofloras dominated by the circumpolloid pollen genus *Corollina*. These palynofloras replace diverse, Late Triassic assemblages in which monosaccate and bisaccate morphologies predominate (Cornet, 1977).

Palynologically productive horizons within the Newark Supergroup are largely restricted to the lacustrine facies, in which a hierarchy of transgressive and regressive cycles has been identified on the basis of rock type and fabric (Olsen, 1986; Olsen et al., 1989). The shortest cycles have been calibrated by means of varve counts (Van Houten, 1969) and Fourier analysis and appear to have a duration of ~21 ky (Olsen, 1986). Two longer cycles have periods of 100 and 400 ky (Olsen, 1986; Olsen et al., 1989). Together, these three orders of cycles correspond to periodicities predicted by Milankovitch theory for the Earth's precession and eccentricity cycles (Hays et al., 1976; Berger and Pestiaux, 1984; Short et al., 1991). While eccentricity periods have remained relatively constant throughout Earth history, the progressive increase in the Earth–Moon distance and length of the day have caused a lengthening of the precession cycle. Fundamental precession periods for the Early Jurassic (200 Ma) are calculated to be 18 and 21.5 ky (Berger et al., 1992). The 21-ky cycles of the Newark Supergroup fall within this range and are in close agreement with the longer of the two fundamental Jurassic periods.

Climate models for an idealized geographic representation of Pangea have shown that a large landmass centered on the equator will have hot summers, cold winters, and large-scale summer and winter monsoon circulations (Kutzbach and Gallimore, 1989; Short et al., 1991). The periodic distribution of Newark Supergroup lacustrine cycles indicates that orbitally controlled seasonal and latitudinal variations in solar radiation determined the length and severity of Mesozoic rainy seasons.

Fluctuations of the Newark Supergroup lakes thus appear to have been produced by precipitation cycles of relatively constant period. Consequently, where the local thickness of the 21-ky lacustrine cycle has been documented by means of measured stratigraphic sections and Fourier analysis, rock thickness can be translated into time.

In Figure 2, this method of time calibration is applied to three long stratigraphic sections from the Newark basin (Fig. 3) which together contain the entire Triassic lacustrine record of the basin and continue through the TR/J boundary. The geochemically equivalent Jacksonwald and Orange Mountain basalts (Fig. 2) are correlated with intrusives that have U/Pb and $^{40}Ar/^{39}Ar$ dates of 201 Ma (Ratcliffe, 1988; Sutter, 1988; Dunning and Hodych, 1990). These dates allow the stratigraphic sections to be fixed in absolute time.

The close agreement in the amount of time spanned by the Jacksonwald and New Brunswick statigraphic columns (Fig. 2) is surprising for two reasons: the thickness of the 21-ky cycles varies markedly both within and between these two sections (Olsen et al., 1989); and the strata were

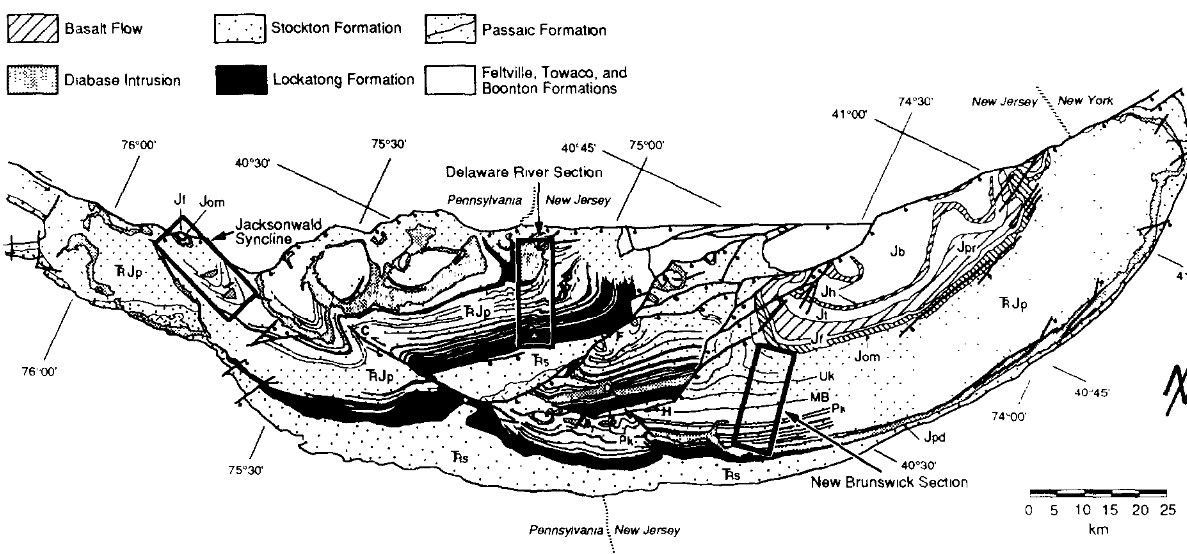
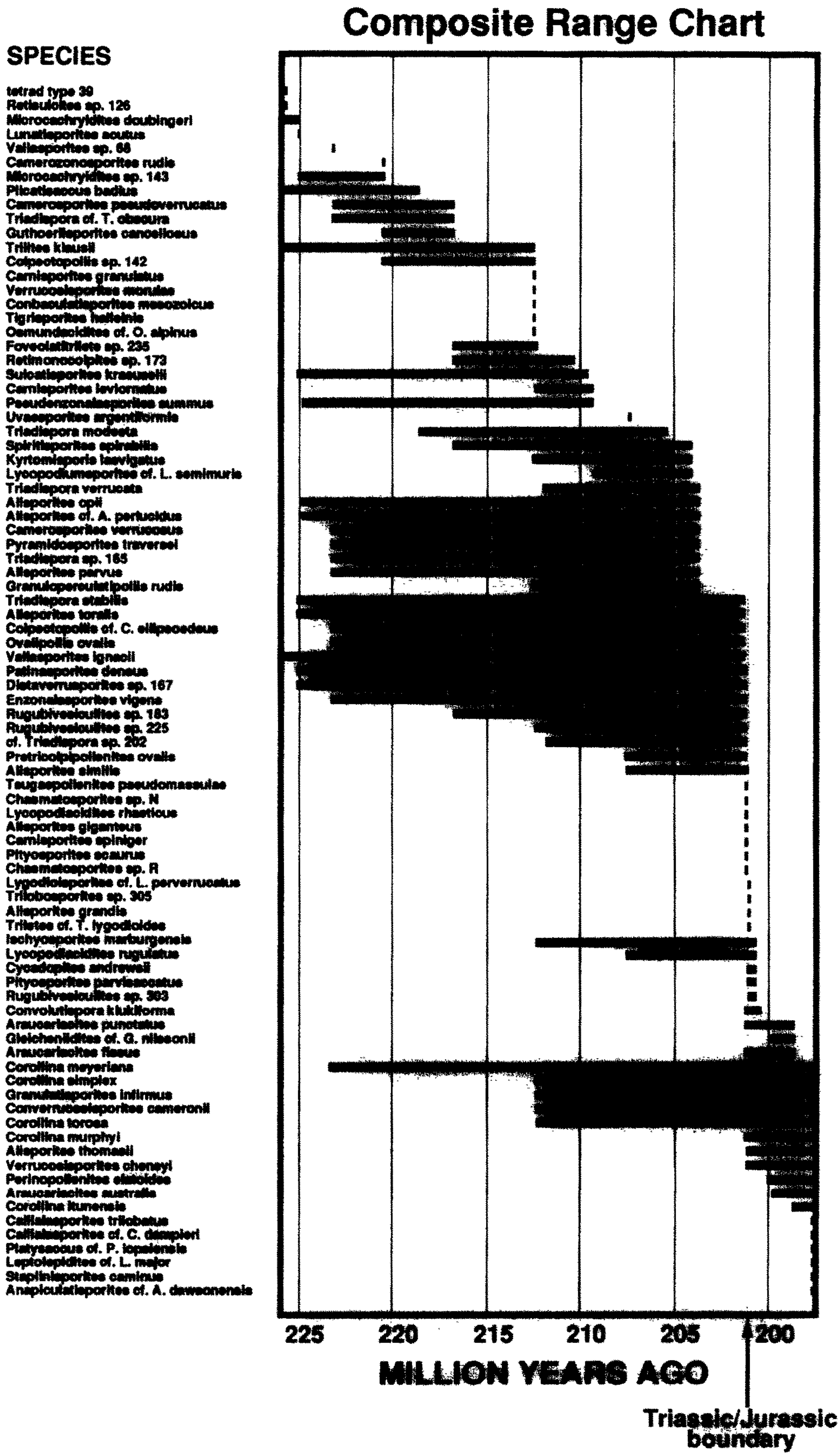


Fig. 3. Geologic map of the Newark basin, showing locations of stratigraphic sections. Abbreviations for stratigraphic units are: *C* = Chalfont fault; *F* = Flemington fault; *H* = Hopewell fault; *Jb* = Boonton Formation; *Jf* = Feltville Formation; *Jh* = Holyoke Basalt; *Jom* = Orange Mountain Basalt; *Jpd* = Palisades diabase; *Jpr* = Preakness Basalt; *Jt* = Towaco Formation; *MB* = Metlars Brook Member; *Pk* = Perkasie Member; *TRJp* = Passaic Formation; *TRs* = Stockton Formation; *Uk* = Ukranian Member. (After Schlische and Olsen, 1988).


Composite Range Chart
SPECIES
tetrad type 39
Retisulcites sp. 126
Microcachryidites doubingeri
Lunatisporites acutus
Vallasporites sp. 68
Camerozonosporites rudis
Microcachryidites sp. 143
Plicatisaccus badius
Camerosporites pseudoverrucatus
Triadispora cf. T. obscura
Guthoerlisporites cancellosus
Triletes klausii
Colpectopollis sp. 142
Carnisporites granulatus
Verrucosisporites morulae
Conbaculatisporites mesozoicus
Tigrisporites halleinis
Osmundacidites cf. O. alpinus
Foveolatitriletes sp. 235
Retimonocolpites sp. 173
Sulcatisporites kraeuselii
Carnisporites leviornatus
Pseudenzonalasporites summus
Uvaesporites argenteaeformis
Triadispora modesta
Spiritisporites spirabilis
Kyrtomisporis laevigatus
Lycopodiumsporites cf. L. semimuris
Triadispora verrucata
Alisporites opii
Alisporites cf. A. perlucidus
Camerosporites verrucosus
Pyramidosporites traversei
Triadispora sp. 165
Alisporites parvus
Granuloperculatipollis rudis
Triadispora stabilis
Alisporites toralis
Colpectopollis cf. C. ellipsoideus
Ovalipollis ovalis
Vallasporites ignacii
Patinasporites densus
Distaverrusporites sp. 167
Enzonalasporites vigens
Rugubivesiculites sp. 183
Rugubivesiculites sp. 225
cf. Triadispora sp. 202
Pretricolpipollenites ovalis
Alisporites similis
Tsugaepollenites pseudomassulae
Chasmatosporites sp. N
Lycopodiacidites rhaeticus
Alisporites giganteus
Carnisporites spiniger
Pityosporites scaurus
Chasmatosporites sp. R
Lygodioisporites cf. L. perverrucatus
Trilobosporites sp. 305
Alisporites grandis
Triletes cf. T. lygodioides
Ischyosporites marburgensis
Lycopodiacidites rugulatus
Cycadopites andrewsii
Pityosporites parvisaccatus
Rugubivesiculites sp. 303
Convolutispora klukiforma
Araucariacites punctatus
Gleicheniidites cf. G. nilssonii
Araucariacites fissus
Corollina meyeriana
Corollina simplex
Granulatisporites infirmus
Converrucosisporites cameronii
Corollina torosa
Corollina murphyi
Alisporites thomasii
Verrucosisporites cheneyi
Perinopollenites elatoides
Araucariacites australis
Corollina itunensis
Callialasporites trilobatus
Callialasporites cf. C. dampieri
Platysaccus cf. P. lopsinensis
Leptolepidites cf. L. major
Stapliniisporites caminus
Anapiculatisporites cf. A. dawsonensis
225
220
215
210
205
200
MILLION YEARS AGO
Triassic/Jurassic boundary

deposited in different tectonic environments. The Jacksonwald Syncline is a tight fold in the southwestern, strike-slip part of the basin, whereas the New Brunswick section was deposited in a monocline in the dip-slip, north-central part of the basin (Fig. 3). The results in Figure 2 indicate that the method of time-stratigraphic calibration is consistent throughout the Newark basin, and as such it is invaluable for studies of biostratigraphy and floral diversity.

Palynology of Triassic / Jurassic boundary sections

A regional range chart (Fig. 4) of palynomorph species has been constructed on the time-calibrated Newark basin section by means of the Shaw method of graphic correlation (Shaw, 1964). As applied here, this method uses continuous correlation lines, fixed by paleontological, palynological and stratigraphic tie points, to allow the first and last appearances of palynomorph species from the Culpeper, Gettysburg, and Hartford basins (Fig. 1) to be extrapolated onto the Newark basin section. Palynomorph-bearing units from the Newark basin can be translated directly into time horizons. The range chart in Figure 4 is thus a compilation of the first and last appearances of palynomorph species from the four basins.

As discussed above, the Tr/J boundary in the Newark Supergroup is characterized by the replacement of diverse palynomorph assemblages of monosaccates and bisaccates by *Corollina*-dominated palynofloras. Figure 4 demonstrates that this boundary falls at ~ 201 Ma; last appearances of 60% of the Late Triassic species (including *Patinasporites densus*, *Vallasporites ignacii*, and *Ovalipollis ovalis*) are localized at this horizon. Rates of extinction and turnover calculated from the data compiled in the range chart (Fig. 5) illustrate the magnitude and severity of this regional extinction.

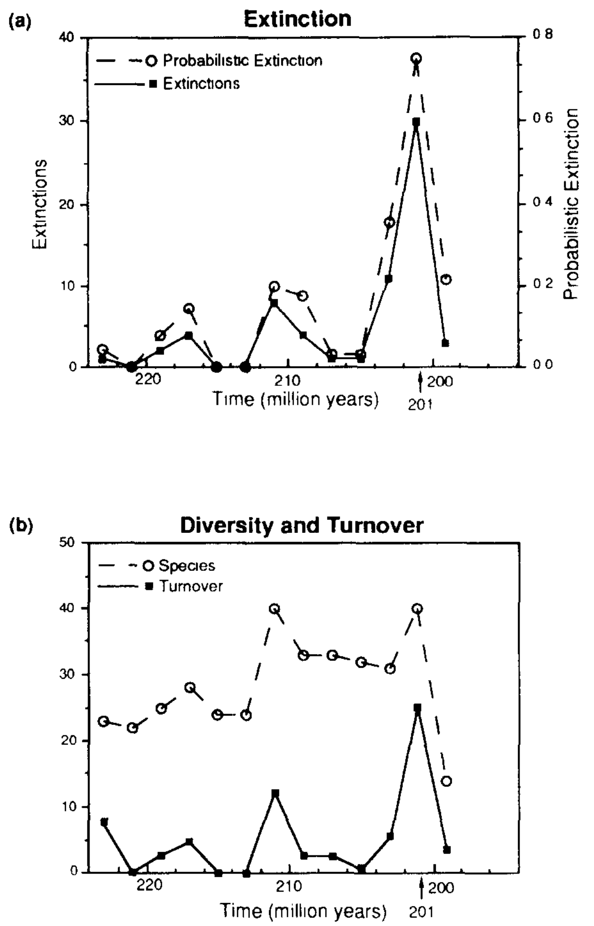


Fig. 5. Extinction, diversity, and turnover during successive 2-my intervals. Arrows denote the age of the Tr/J boundary as determined by Newark Supergroup palynostratigraphy and radiometric dates. (a) Extinction is measured by two different metrics: the total number of extinctions per interval and the probabilistic extinction rate, defined as the number of extinctions divided by the number of taxa present in the interval (Olsen and Sues, 1986). (b) Diversity is defined as the total number of species present in the interval (species richness), and turnover is defined as the total number of originations and extinctions divided by the length of the interval (Olsen and Sues, 1986).

Although the range chart demonstrates that the Tr/J palynofloral turnover was essentially synchronous throughout the Newark Supergroup on a time scale calibrated in millions of years,

Fig. 4. Time-calibrated, composite range chart of palynomorph species from the Newark, Culpeper, Gettysburg, and Hartford basins (palynomorphs collected and identified by Cornet, 1977). The Tr/J boundary is denoted by a 60% regional extinction at ~ 201 Ma.

greater temporal resolution is necessary in order to assess the likely causes of the extinctions. To this end, we intensively sampled the Tr/J boundary in the Jacksonwald Syncline of the Newark basin (Fig. 3) for palynomorph assemblages.

Samples were obtained from two measured stratigraphic sections. Both lie within the lacustrine Passaic Formation and terminate at the overlying Jacksonwald Basalt. The two sections are approximately one mile apart and are stratigraphically correlated on the basis of cyclostratigraphy and the basalt flow. Figure 6 is a composite stratigraphic section showing the relative positions of palynologically productive horizons. Sedimentary units represented in this composite section are present in both stratigraphic sections.

Assemblages GMF-3, -5, -7, -9 and -12, EVC and EVD (Fig. 6) were all obtained from grey siltstones and claystones that represent climatically controlled, deep-water phases of the Newark basin lake (Olsen, 1986). EVC and EVD are located ~ 15 m above the lower five GMF samples, a thickness that corresponds locally to the 21-ky cycle.

The palynoflora obtained from each of the GMF samples is a diverse, Triassic assemblage with abundant monosaccate and bisaccate species. Horizon EVC contains 67% *Corollina* spp. and lacks those species found to undergo a regional extinction at the Tr/J boundary. Thus, EVC represents the first appearance of a Jurassic palynofora in the Jacksonwald Syncline, and the tran-

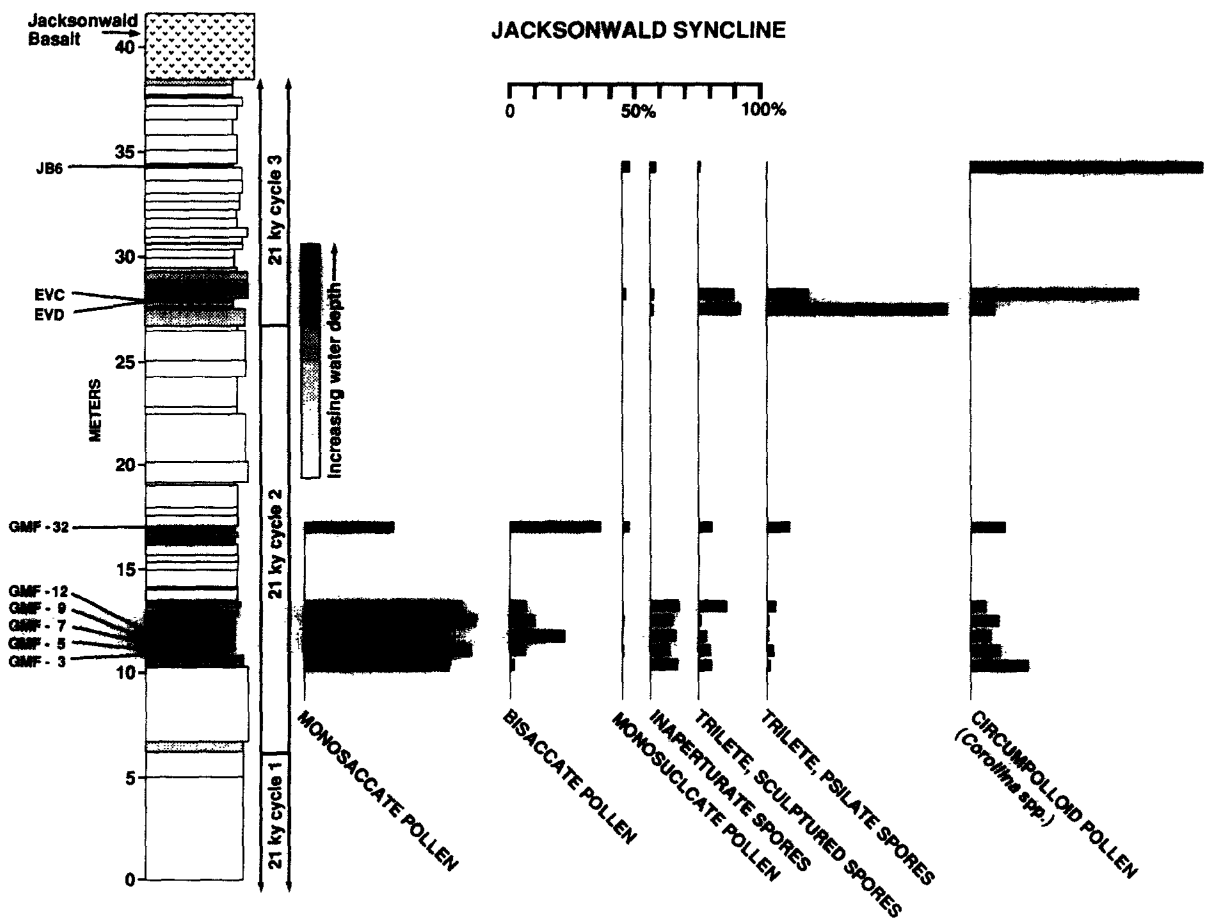


Fig. 6. Composite stratigraphic column of two measured sections from the Jacksonwald Syncline. Sedimentary units depicted here are represented in both sections. Relative abundances of pollen and spore morphotypes are plotted opposite their stratigraphic locations. The lower five *GMF* samples and the *EV* samples were collected from the deep-water phases of successive 21-ky Milankovitch cycles. Sample *EVC* represents the first appearance of a Jurassic palynomorph assemblage; the underlying *EVD* contains 89% trilete spores. Jurassic assemblage *JB6* was collected by Cornet (1977).

sition from Triassic to Jurassic palynomorph assemblages is shown to occur at least 10 m below the first basalt flow and within a single 21-ka interval.

Palynofloras from horizon EVD are strikingly different from both the overlying Jurassic and underlying Triassic assemblages. Samples from EVD contain 89% trilete spore species that belong to the genera *Anapiculatisporites*, *Converrucosisporites*, *Deltoidospora*, *Dictyophyllidites*, *Granulatisporites*, *Kyrtomisporis*, *Porcellispora*, *Reticulatisporites*, *Todisporites*, and *Verrucosisporites* (R. Litwin, pers. commun., 1989; Olsen et al., 1990). This spore-dominated horizon, present in both of the measured sections from the Jacksonwald Syncline, is unique in the Newark basin. Palynomorph assemblages from younger and older rocks of the basin have never yet been found to contain such a high spore/pollen ratio.

Discussion and conclusions

Several causal mechanisms, including volcanism, climate change, and bolide impact, may be hypothesized to explain the abrupt palynofloral turnover at the TR/J boundary in the Newark Supergroup. These mechanisms vary greatly in their ability to explain the palynological and sedimentological data.

A relationship between the Newark Supergroup flood basalts and the transition from Triassic to Jurassic palynofloras appears highly unlikely, as this transition occurs at least 10 m below (and ~ 10 ky before) the first basalt flow. No ash falls have yet been found within the Newark Supergroup, and hence there is no evidence that volcanism could have effected the floristic change.

Climate change is a more plausible hypothesis, yet this mechanism does not adequately account for the magnitude and abruptness of the palynofloral turnover. Furthermore, although cyclicity is evident throughout the Late Triassic of the Newark Supergroup, no unidirectional climate change is recorded in the sediments at the level of the palynological extinctions.

The discovery of a positive iridium anomaly at the Cretaceous/Tertiary (K/T) boundary lead to the hypothesis that a meteorite impact was responsible for the K/T boundary mass extinction (Alvarez et al., 1980, 1984). The sharp increase in trilete spores and concurrent regional extinctions of palynomorph species at the TR/J boundary in the Newark Supergroup invite comparison with palynofloras from K/T boundary sections. Palynological investigations of the K/T boundary in the western United States and Canada find regional extinctions of Late Cretaceous taxa to be coincident with Ir enhancement. Palynomorph assemblages immediately overlying the Ir anomaly record a dramatic increase in the percentage of fern spores (see, for example, Tschudy et al., 1984; Tschudy and Tschudy, 1986; Nichols et al., 1986; Fleming, 1990). These geologically brief fern spikes are interpreted as an initial colonization of ferns following the catastrophic destruction of the Cretaceous flora.

The analogy between the TR/J and K/T boundary sections is imperfect due to the lack of Ir enhancement at the TR/J boundary. However, the presence of excess Ir is dependent on the composition of the bolide. No detectable Ir anomaly is produced by collision with comets (Asaro et al., 1982), though the impact of a comet or meteorite of sufficient size to cause global ecosystem disruption should produce a widespread debris layer of shocked minerals. Such debris layers are known from K/T boundary sites in the western United States (Izett, 1990) and throughout the world (Bohor, 1990).

Three shocked-quartz horizons have recently been reported from latest Triassic sediments of Tuscany, Italy (Bice and McCauley, 1990; Bice et al., 1992). The uppermost of these horizons immediately overlies the last appearance of the Late Triassic *Rhaetavicula* bivalve association (Newton and McRoberts, 1990; Bice et al., 1992). Bice et al., (1992) attribute the multiple shocked-quartz layers to a possible comet shower, although they note that craters of the appropriate size and age have not been found.

To date, no detailed search for shocked minerals has been undertaken in the Newark Supergroup. This test is essential in order to evaluate the validity of the hypothesized relationship between a Late Triassic impact and the TR/J boundary palynofloral turnover. Nevertheless, the presence of a spore spike and a regional palynofloral extinction constrained to an interval of 21 ky is comparable to K/T boundary sections and consistent with theories of bolide impact.

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