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Geologically rapid Late Triassic extinctions: Palynological evidence from the Newark Supergroup

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ABSTRACT

Orbitally controlled, sedimentary cycles of the Newark Supergroup permit palyniferous Late Triassic sections to be calibrated in time. Carnian palynofloras from the Richmond basin exhibit 2-m.y. fluctuations in the spore/pollen ratio, but taxonomic composition remains stable. Diversity of Norian and Rhaetian palynofloras increases prior to a 60% reduction at the Triassic/Jurassic boundary. The extinction of Late Triassic palynomorph species is coincident with a spike in the spore/pollen ratio and approximately synchronous with the last appearances of tetrapod taxa and ichnofossil genera. This geologically brief episode of biotic turnover is consistent with bolide impact hypotheses.

INTRODUCTION

The composition and diversity of Triassic faunas and floras are of particular interest with respect to the late Norian (=Rhaetian) mass extinction, an event that culminated in a 42% decrease in the number of terrestrial tetrapod families (Olsen et al., 1987) and a 23% reduction in diversity of marine invertebrate families (Sepkoski, 1984). Although the Norian event is recognized as one of the most severe Phanerozoic mass extinction episodes, substantial disagreement remains as to the duration and synchroneity of the Late Triassic terrestrial and marine extinctions.

Multiple extinction events throughout the Carnian and Norian have been proposed for both terrestrial tetrapods (Benton, 1986) and marine invertebrates (Benton, 1986; Johnson and Simms, 1989). Hallam (1981) argued that the extinctions were concentrated in the latter part of the Norian (=Rhaetian), but he maintained that the tetrapod turnover preceded extinction of the marine invertebrates by several million years. Olsen et al. (1987) provided evidence that Triassic vertebrate faunas persisted until the latest Triassic.

Although these hypotheses make different predictions about the Late Triassic fossil record, the dearth of Triassic/Jurassic boundary sections (Hallam, 1981), the difficulty of correlating marine and terrestrial strata, and the proliferation of Late Triassic time scales (see Kerp, 1991) render them difficult to test.

These problems can be partially surmounted in the Newark Supergroup of eastern North America (Fig. 1). Sedimentation in these rift basins was continuous from the Carnian through the Hettangian, and the Triassic/Jurassic boundary is accessible in five separate basins. The presence of dated basalt horizons, in conjunction with periodic sedimentary cycles, permits construction of a Late Triassic time scale calibrated in absolute time (Fig. 2) (Fowell and Olsen, 1993). No marine strata are present, but the variety of fossilized materials, including osseous tetrapod remains, palynomorphs, and vertebrate ichnofossils, permits comparison of a suite of organisms preserved under diverse conditions. In this chapter, we deal primarily with the palynological record. However, it is hoped that the numerous tetrapod fossils and palynomorph-bearing horizons will ultimately enable more rigorous correlations with global terrestrial and marine strata.

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CYCLICITY

The Newark Supergroup is composed predominantly of fluvial and lacustrine strata that fill a series of rift basins formed by the Pangean breakup. During the Late Triassic and Early Jurassic, this chain of elongate half grabens stretched from 4°S to 15°N (Witte et al., 1991). Climate models for idealized geographic representations of Pangea have shown that a large landmass centered on the equator will exhibit summer and winter monsoon circulation patterns (Kutzbach and Gallimore, 1989; Short et al., 1991). These models are consistent with the thick lacustrine deposits of the Newark Supergroup, where long-term fluctuations of annual precipitation are indicated by the presence of hierarchical transgressive and regressive lacustrine cycles (Olsen, 1986; Olsen et al, 1989).

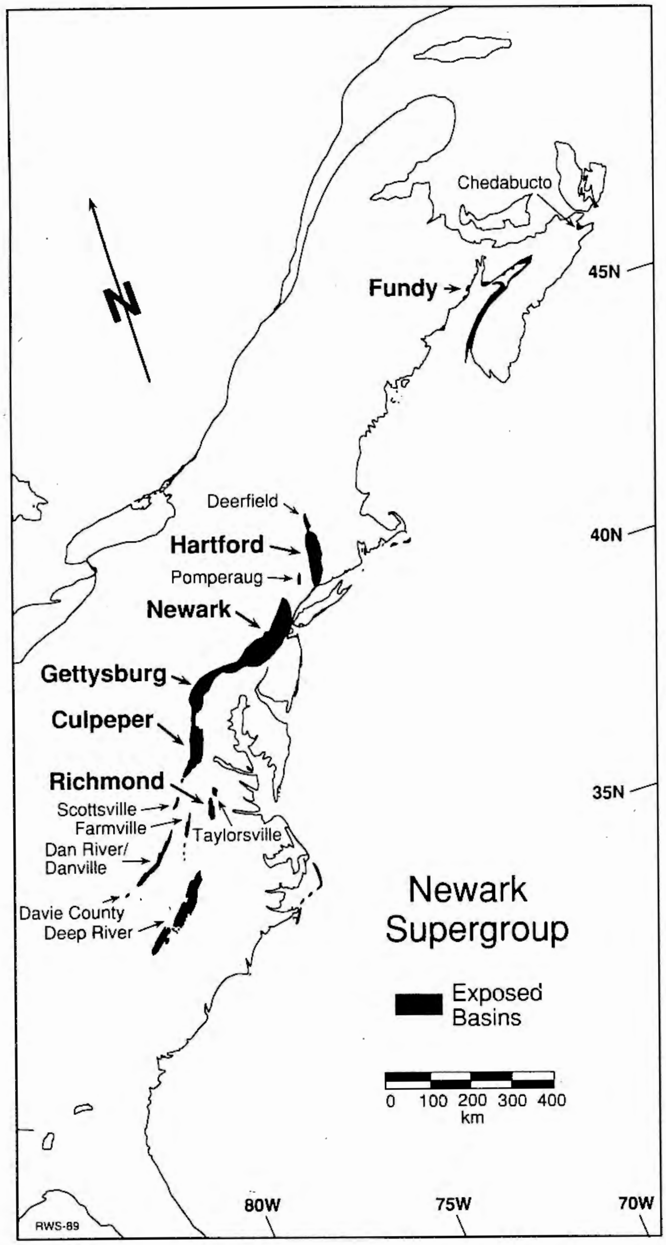

Figure 1. The early Mesozoic Newark Supergroup, showing distribution of exposed basins (from Olsen et al., 1989). Palynomorph assemblages discussed in this chapter were collected from basins shown in boldface type.

The shortest of these cycles are shallowing-upward packages between 1.5 and 35 m thick, identified in outcrop on the basis of rock type and fabric (Olsen, 1986; Olsen et al., 1989; Olsen, 1991). Using the rationale outlined by Olsen (1986), cycles have been calibrated via biostratigraphic age estimates and published radiometric dates. Biostratigraphic calibration and Fourier analysis of these cycles both yield an average periodicity of approximately 21 k.y. (Olsen, 1986). This value falls between the 18-k.y. and 21.5-k.y. precession periods calculated for the Early Jurassic (Berger et al., 1992).

Fourier analysis of long stratigraphic columns and cores of the entire Triassic Newark basin section reveals higher-order cycles with periodicities of 100 k.y., 400 k.y., and 2 m.y. (Olsen, 1986). The 100-k.y. and 400-k.y. cycles correspond to periodicities predicted by Milankovitch theory for the Earth's eccentricity cycles (Hays et al., 1976; Short et al., 1991), which have remained relatively constant throughout Earth history (Berger and Pestiaux, 1984). A 2-m.y. eccentricity cycle can also be shown to exist from the orbital dynamics, but unlike the other cycles its effect on climate has not been modeled.

The regularity and duration of the Newark Supergroup lacustrine cycles are compatible with the hypothesis that orbitally controlled seasonal and latitudinal variations in solar radiation determined the length and intensity of Mesozoic rainy seasons. A latitudinal climatic gradient is also apparent; differences in the type and abundance of sedimentary structures and facies indicate that southern Newark Supergroup basins were far more humid than the northern basins (Hubert and Mertz, 1980; Olsen, 1991; Olsen et al., 1989). This drier-to-the-north trend resulted in three primary types of lacustrine cycles distinguishable by the ratio of wet/dry fabrics: the humid Richmond type, the dry Fundy type, and the intermediate Newark type (Olsen, 1991). Palynologically productive horizons are generally restricted to the deeper-water lacustrine facies. Consequently, the completeness of the palynological record in stratigraphic sections from the Newark Supergroup increases with the average lake depth.

Dry lacustrine cycles occur in the Fundy basin of Nova Scotia (Fig. 1), where sedimentation rates were so low that 21-k.y. cycles cannot be identified. Higher-order cycles are manifested in the form of sand-patch cycles (Smoot and Olsen, 1985, 1988). These cycles are approximately 1 to 2 m thick and consist of sedimentary fabrics that record alterations between shallow, perennial lakes and playas with salt crusts (Olsen, 1991). Deep-water lacustrine facies are extremely rare, and preserved palynofloras are similarly sparse.

Intermediate Newark-type cycles are present in the Dan River/Danville, Culpeper, Gettysburg, Newark, Pomperaug,

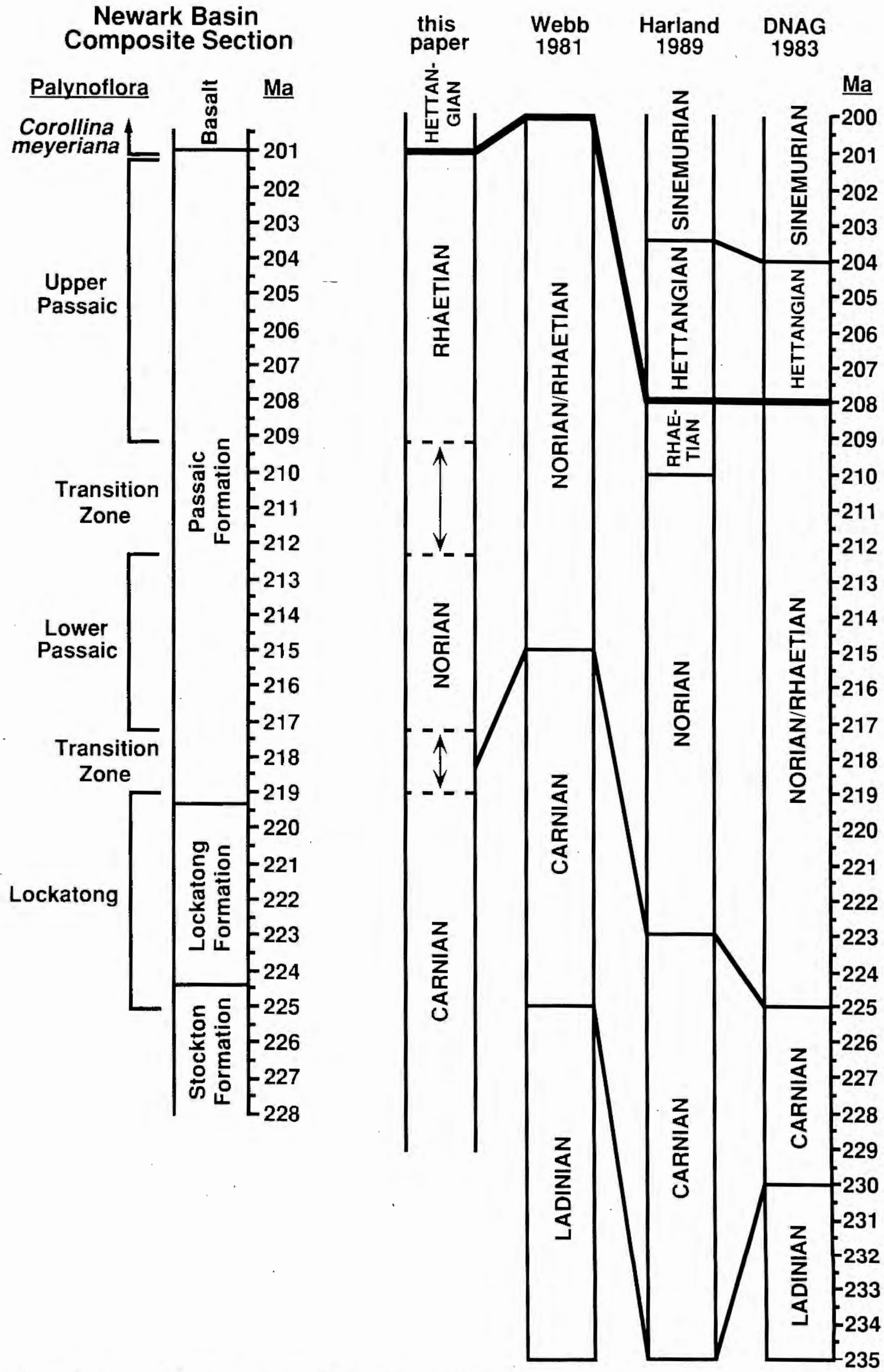

Figure 2. Newark basin section calibrated in absolute time by 21-k.y.-cycle thicknesses and radiometric dates (see text). Palynostratigraphy outlined by Cornet (1977) permits construction of a preliminary Late Triassic time scale for the Newark Supergroup. Time scales by Webb (1981), Harland et al. (1989), and Palmer (1983) (DNAG) are shown for comparison.

Hartford, and Deerfield basins (Fig. 1). These 21-k.y. cycles display a range of sedimentary fabrics, from deep-water microlaminae to subaerial desiccation cracks. Many of the cycles contain deep-water facies, but shallow-water and desiccated fabrics are more common (Olsen, 1991). Palynomorph preservation is restricted to the deep-water facies and is discontinuous within individual 21-k.y. cycles.

Humid Richmond-type cycles are present in the Richmond and Taylorsville basins of the southern Newark Supergroup (Fig. 1). Desiccated, mudcracked fabrics are rare, and 21-k.y. cycles consist primarily of microlaminated claystones, coals, and shallow-water siltstones (Olsen, 1991). The nearly continuous palynological record of the Richmond basin is ideal for studies of early Late Triassic microfloral diversity.

PALYNOFLORAL ASSEMBLAGES AND SEDIMENTARY CYCLICITY OF THE CARNIAN RICHMOND BASIN

Outcrops are rare in the Richmond basin, but a nearly complete palynological record has been obtained from the ~2,000-m-deep Horner #1 well (Fig. 3). Well cuttings of the entire middle Carnian Richmond basin section, from the Otterdale Formation to the base of the Tuckahoe Formation, were collected at 9.1-m (30-ft) intervals and processed for palynomorphs.

In contrast to Early Jurassic palynomorph assemblages, which are dominated by a single pollen genus *(Corollina),* the morphological and generic diversity of the Richmond basin palynofloras is characteristic of Triassic assemblages throughout the Newark Supergroup. Dominance of either bisaccate or monosaccate (circumsaccate) pollen morphotypes is also typical. Spores, however, are far more abundant in the Carnian Richmond basin assemblages than in Norian palynofloras from northern basins. The Horner #1 well cuttings exhibit large fluctuations in the relative abundance of pollen and spores (Fig. 3) that appear to reflect the 2-m.y. climate cycle.

Well logs from Horner #1 indicate that the thickness of the 21-k.y. cycle increases from 7 to 10 m downsection. Adjacent to the Horner #1 well, a 150-m outcrop of the Turkey Branch Formation also exhibits an extremely regular, 7-m cycle thickness. Cores of underlying formations confirm the presence of thicker, 10-m cycles. The average 21-k.y. cycle thickness is estimated to be 8.5 m for the palynologically productive portions of the Horner well. Application of this estimate to the data in Figure 3 demonstrates that the Horner #1 well spans approximately 4 m.y. Peaks of the pollen/spore ratio, emphasized by smoothing of the data in Figure 3, occur at ~2-m.y. intervals. The spores were produced by lower vascular plants that favored high precipitation and/or humidity, whereas pollen-producing seed plants dominated during intervals of relatively arid climate.

Despite periodic fluctuations in palynomorph abundances, the taxonomic composition of the assemblages remains relatively stable throughout the entire Carnian record of the Richmond basin. This indicates that the climatic variations produced gradual floral changes and were not of sufficient magnitude to cause regional extinctions.

LATE TRIASSIC AND EARLY JURASSIC PALYNOFLORAS

The youngest sediments in the Richmond basin are of Carnian age, but the palynological record is continued through Norian, Rhaetian, and Hettangian strata in basins to the north. The Triassic/Jurassic boundary in these basins has been identified by the appearance of palynofloras dominated by the circumpolloid pollen genus *Corollina.* This Early Jurassic *Corollina meyeriana* palynoflora (Fig. 2) rapidly replaces the diverse, monosaccate- and bisaccate-dominated assemblages characteristic of the Carnian, Norian, and Rhaetian (Cornet, 1977; Cornet and Olsen, 1985).

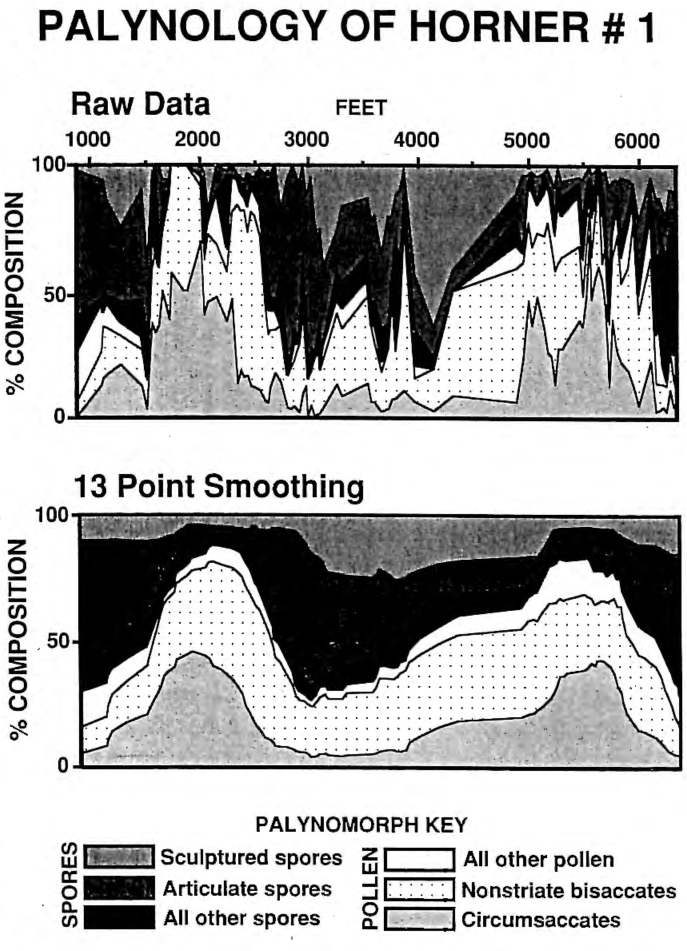

Figure 3. Composition of palynomorph assemblages from the Richmond basin Horner #1 well. Smoothing of the data via a 130-ft moving window emphasizes cyclical variations of the pollen/spore ratio. The entire palynological record (900 ft to 6,400 ft) spans an estimated 4 m.y., based on 21-k.y. cycle thicknesses from well log, core, and outcrop data.

The abrupt transition from Late Triassic to Early Jurassic palynofloras is evident in Figure 4, a composite range chart of palynomorph species from deep-water, lacustrine facies of the Culpeper, Gettysburg, Hartford, and Newark basins (see Table 1 for species names with citations). Temporal resolution of these ranges is derived from Newark basin cyclostratigraphy. Fowell and Olsen (1993) use measured cycle thicknesses from the Late Triassic and earliest Jurassic lacustrine record of the Newark basin to calibrate the stratigraphic section in relative time (Fig. 2). This section is fixed in absolute time by 202.2 ± 1.3 Ma $^{40}Ar/^{39}Ar$ dates (Sutter, 1988) and 201 ± 1 Ma U/Pb dates (Dunning and Hodych, 1990) of the Palisades sill, which fed the Orange Mountain basalt and the correlative Jacksonwald basalt (Ratcliffe, 1988).

The composite range chart in Figure 4 was constructed on the time-calibrated Newark basin section using the graphic correlation method outlined by Shaw (1964). As discontinuous preservation precluded calculation of continuous correlation lines from the palynological data alone, correlation lines were fixed by paleontological, stratigraphic, and palynological tie points (Fowell and Olsen, 1993).

Species' ranges for the late Carnian, Norian, and Rhaetian (Fig. 4; Table 1) indicate that palynofloral diversity increased throughout the last 24 m.y. of the Triassic (see Fig. 5 of Fowell and Olsen, 1993). The transition from diverse Triassic assemblages to *Corollina*-dominated Jurassic palynofloras occurs at approximately 201 Ma and is coincident with a loss of 13 of the 20 most common Late Triassic species. In total, 24 of the 40 species recorded from the latest Triassic palynofloras are absent from Early Jurassic assemblages. This represents a 60% regional extinction across the Triassic/Jurassic boundary.

TRIASSIC/JURASSIC BOUNDARY SECTIONS

Palynomorph assemblages from exposures in the Jacksonwald Syncline of the Newark basin further limit the Triassic/Jurassic boundary palynofloral turnover to an 11-m interval that is barren of palynomorphs. A local cycle thickness of ~20 m allows the duration of this transition to be constrained to less than 21 k.y. (Fig. 5) (Fowell and Olsen, 1993).

Palynomorph assemblages characterized by unusually high percentages (>50%) of trilete spores have been recovered from the Triassic/Jurassic boundary in three Jacksonwald syncline sections (Fig. 5a, b, and c). All three sections lie within the Passaic Formation, and two extend to the base of the ~201 Ma Jacksonwald basalt. Stratigraphic correlations are facilitated by the cyclostratigraphy of the sections and the presence in each of a black, organic-rich clay layer overlain by an unusual, blue-gray, plant-bearing sandstone. Spore-dominated assemblages Cl, EVD, 6-4, and 6-5 are composed of 50 to 89% trilete spore species of the genera *Anapiculatisporites, Converrucosisporites, Deltoidospora, Dictyophyllidites, Granulatisporites, Kyrtomisporis, Porcellispora, Reticulatisporites, Todisporites,* and *Verrucosisporites* (R. Litwin, personal communication, 1989; Olsen et al., 1990). These palynofloras occur between the highest Triassic assemblage (A4, Fig. 5a) and the lowest Jurassic *Corollina meyeriana* palynoflora (EVC, Fig. 5b).

Palynofloras from section 6 (Fig. 5c) and the Exeter Village section (Fig. 5b) serve to bracket the stratigraphic duration of the spore-dominated assemblages. The percentage of trilete spores increases markedly between samples 6-2 and 6-4 of section 6 and decreases again from 6-5 to 6-6. The abundance of trilete spores also drops off dramatically above sample EVD of the Exeter Village section.

In Figure 6, spore percentages from all productive localities in the Jacksonwald Syncline are plotted against thickness above and below the base of the blue-gray sandstone. The spore-dominated palynofloras have a limited stratigraphic distribution (less than 0.5 m), apparently originating and terminating abruptly.

In the Grist Mills (Fig. 5a) and Exeter Village (Fig. 5b) sections, this spore spike occurs above typical Late Triassic assemblages of monosaccates and bisaccates and below *Corollina*-rich Jurassic palynofloras. This relationship is not apparent in section 6 (Fig. 5c). Samples 6-1 and 6-2, which underline the spore spike, contain the high percentages of *Corollina* typical of Jurassic assemblages. Yet these assemblages retain low abundances of the monosaccate Triassic index species *Vallasporites ignacii* and *Patinasporites densus.* The only comparable palynofloras in the Newark Supergroup are from the Fundy basin, where samples with abundant *Corollina* and rare (but clearly not reworked) *Patinasporites densus* are present 32 cm below the North Mountain basalt. This basalt has been assigned a U/Pb date of 202 ± 1 Ma (Hodych and Dunning, 1992) and is correlative with the Jacksonwald basalt. Given the low sedimentation rates in the Fundy basin (Olsen et al., 1989; Olsen, 1991), the Fundy assemblages may be time-equivalent with samples 6-1 and 6-2. We consider these palynofloras indicative of uppermost Triassic strata due to the presence of diagnostic Triassic species, which are absent from overlying assemblages in both the Newark and Fundy basins.

DISCUSSION AND CONCLUSIONS

Evidence for a geologically rapid, terminal-Triassic biotic turnover in the Newark Supergroup is not confined to the palynological record. Footprint assemblages from the Jacksonwald Syncline show that the last appearances of the Late Triassic ichnofossil genera *Gwyneddichnium, Apatopus, Brachychirotherium,* and two new genera are coincident with the palynologically defined Triassic/Jurassic boundary (Silvestri, 1991; Silvestri and Szajna, 1993). Absence of these five footprint taxa from Early Jurassic assemblages corresponds to the disappearance of previously abundant tetrapod trackmakers and constitutes a decrease of approximately 50% in the diversity of Newark basin ichnofossil genera (Silvestri, 1991; Silvestri and Szajna, 1993).

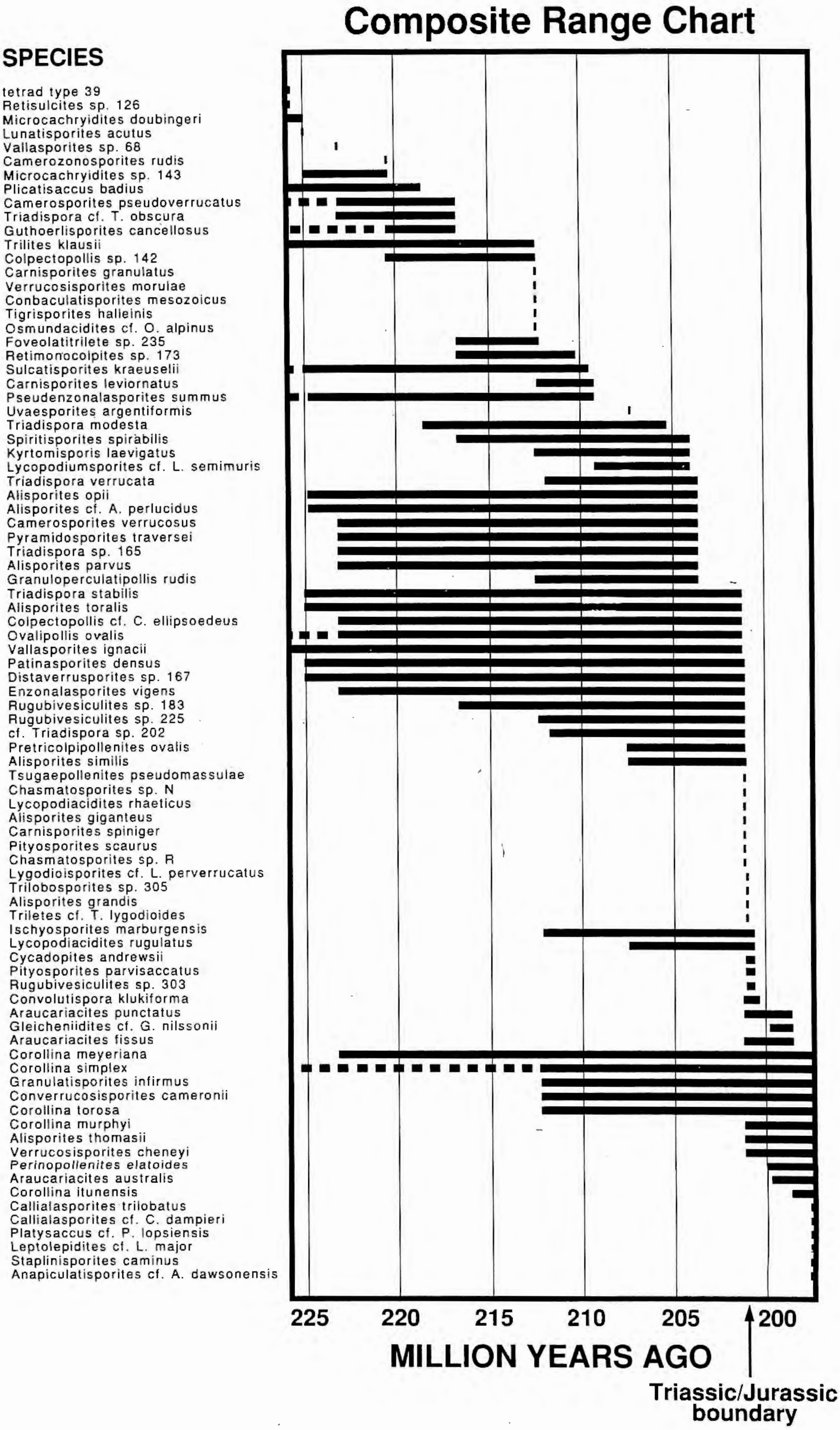
Composite Range Chart
SPECIES
tetrad type 39
Retisulcites sp. 126
Microcachryidites doubingeri
Lunatisporites acutus
Vallasporites sp. 68
Camerozonosporites rudis
Microcachryidites sp. 143
Plicatisaccus badius
Camerosporites pseudoverrucatus
Triadispora cf. T. obscura
Guthoerlisporites cancellosus
Trilites klausii
Colpectopollis sp. 142
Carnisporites granulatus
Verrucosisporites morulae
Conbaculatisporites mesozoicus
Tigrisporites halleinis
Osmundacidites cf. O. alpinus
Foveolatitrilete sp. 235
Retimonocolpites sp. 173
Sulcatisporites kraeuselii
Carnisporites leviornatus
Pseudenzonalasporites summus
Uvaesporites argentiformis
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. ellipsoedeus
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. lopsiensis
Leptolepidites cf. L. major
Staplinisporites caminus
Anapiculatisporites cf. A. dawsonensis
225
220
215
210
205
200
MILLION YEARS AGO
Triassic/Jurassic boundary

Figure 4. Time-calibrated range chart of palynomorph species collected by Cornet (1977) from the Newark, Culpeper, Gettysburg, and Hartford basins. Solid lines denote composite ranges within the four basins. Dashed lines extend the ranges of species present in older strata of the Richmond basin. The Triassic/Jurassic boundary coincides with a 60% regional extinction of common Triassic species at approximately 201 Ma.

Terrestrial tetrapod fossils of Late Triassic age are preserved throughout the Newark Supergroup. However, no characteristic Triassic taxa are found among abundant osseous remains from the earliest Jurassic strata of the Fundy basin. Calibration of the ranges of the Late Triassic vertebrate families by lacustrine cycles indicates that the last appearances of dominant Triassic taxa occurred within an interval of 850 k.y. that brackets the Triassic/Jurassic boundary (Olsen et al., 1987).

The abruptness and apparent synchroneity of the tetrapod, ichnofossil, and palynofloral extinctions in the Newark Supergroup are consistent with catastrophic extinction scenarios involving volcanism or bolide impacts. Fowell and Olsen (1993) previously rejected volcanism as a catalyst for Late Triassic palynological turnover in the Newark Supergroup on the grounds that the first basalt flows lie 7 to 10 m above the transition from Triassic to Jurassic palynomorph assemblages and ash-fall horizons have not been observed.

Bice et al. (1992) report the discovery of multiple shocked quartz horizons from the Triassic/Jurassic boundary in Tuscany, Italy; the uppermost horizon coincides with the

TABLE 1. ALPHABETICAL LIST OF PALYNOMORPH SPECIES IN FIGURE 4

Alisporites giganteus (Danzé-Corsin and Laveine) Cornet 1977
Alisporites grandis (Cookson) Dettman 1963
Alisporites opii Daugherty 1941
Alisporites parvus de Jersey 1963
Alisporites cf. *A. perlucidus* (Pautsch) Pautsch 1973
Alisporites similis (Balme) Dettman 1963
Alisporites thomasii (Couper) Nilsson 1958
Alisporites toralis (Leschik) Clarke 1965
Anapiculatisporites cf. *A. dawsonensis* Reiser and Williams 1969
Araucariacites australis Cookson 1947
Araucariacites fissus Reiser and Williams 1969
Araucariacites punctatus (Nilsson) Cornet and Traverse 1975
Callialasporites cf. *C. dampieri* (Balme) Sukh Dev 1961
Callialasporites trilobatus (Balme) Sukh Dev 1961
Camerosporites pseudoverrucatus Scheuring 1970
Camerosporites verrucosus Mädler 1964
Camerozonosporites rudis (Leschik) Klaus 1960
Camisporites granulatus Schulz 1967
Carnisporites leviornatus (Levet-Carette) Morbey 1975
Carnisporites spiniger (Leschik) Morbey 1975
Chasmatosporites sp. N Cornet 1977
Chasmatosporites sp. R Cornet 1977
Colpectopollis cf. *C. ellipsoideus* Visscher 1966
Colpectopollis sp. 142 Cornet 1977
Conbaculatisporites mesozoicus Klaus 1960
Converrucosisporites cameronii (de Jersey) Playford and Dettman 1965
Convolutispora klukiforma (Nilsson) Schutz 1967
Corollina itunensis (Pocock) Cornet and Traverse 1975
Corollina meyeriana (Klaus) Venkatachala and Góczán 1964
Corollina murphyae Cornet and Traverse 1975
Corollina simplex (Danzé-Corsin and Laveine) Cornet and Traverse 1975
Corollina torosa (Reissinger) Klaus 1960
Cycadopites andrewsii Cornet and Traverse 1975
Distaverrusporites sp. 167 Cornet 1977
Enzonalasporites vigens Leschik 1955
Foveolatitriletes sp. 235 Cornet 1977
Gleicheniidites cf. *G. nilssonii* Pocock 1977
Granulatisporites infirmus (Balme) Cornet and Traverse 1975
Granuloperculatipollis rudis Venkatachaia and Góczán 1964
Guthoerlisporites cancellous Playford and Dettmann 1965
Ischyosporites marburgensis de Jersey 1963
Kyrtomisporis laevigatus Mädler 1964
Leptolepidites cf. *L. major* Couper 1958
Lunatisporites acutus Leschik 1955
Lycopodiacidites rhaeticus Schulz 1967
Lycopodiacidites rugulatus (Couper) Schulz 1967
Lycopodiumsporites cf. *L. semimuris* Danzé-Corsin and Laveine 1963
Lygodioisporites cf. *L. perverrucatus* Couper 1958
Microcachryidites doubingeri Klaus 1964
Microcachryidites sp. 143 Cornet 1977
Osmundacidites cf. *O. alpinus* Klaus 1960
Ovalipollis ovalis Krutzsch 1955
Patinasporites densus Leschik 1955
Perinopollenites elatoides Couper 1958
Pityosporites parvisaccatus de Jersey 1959
Pityosporites scaurus (Nilsson) Schulz 1967
Platysaccus cf. *P. lopsiensis* (Malyavkina) Pocock 1970
Plicatisaccus badius Pautsch 1971
Pretricolpipollenites ovalis Danzé-Corsin and Laveine 1963
Pseudenzonalasporites summus Scheuring 1970
Pyramidosporites traversei Dunay and Fisher 1979
Retimonocolpites sp. 173 Cornet 1977
Retisulcites sp. 126 Cornet 1977
Rugubivesiculites sp. 183 Cornet 1977
Rugubivesiculites sp. 225 Cornet 1977
Rugubivesiculites sp. 303 Cornet 1977
Spiritisporites spirabilis Scheuring 1970
Staplinisporites caminus (Balme) Pocock 1962
Sulcatisporites kraeuselii Mädler 1964
tetrad type 39 Cornet 1977
Tigrisporites halleinis Klaus 1960
Triadispora cf. *T. obscura* Scheuring 1970
Triadispora modesta Scheuring 1970
Triadispora stabilis Scheuring 1970
Triadispora verrucata (Schulz) Scheuring 1970
Triadispora sp. 165 Cornet 1977
cf. *Triadispora* sp. 202 Cornet 1977
Triletes cf. *T. lygodioides* Mai 1967
Triletes klausii Bharadwaj and Singh 1964
Trilobosporites sp. 305 Cornet 1977
Tsugaepollenites pseudomassulae (Mädler) Morbey 1975
Uvaesporites argentiformis (Bolchovitina) Schultz 1967
Vallasporites ignacii Leschik 1955
Vallasporites sp. 68 Cornet 1977
Verrucosisporites cheneyi Cornet and Traverse 1975
Verrucosisporites morulae Klaus 1960

JACKSONWALD SYNCLINE SECTIONS

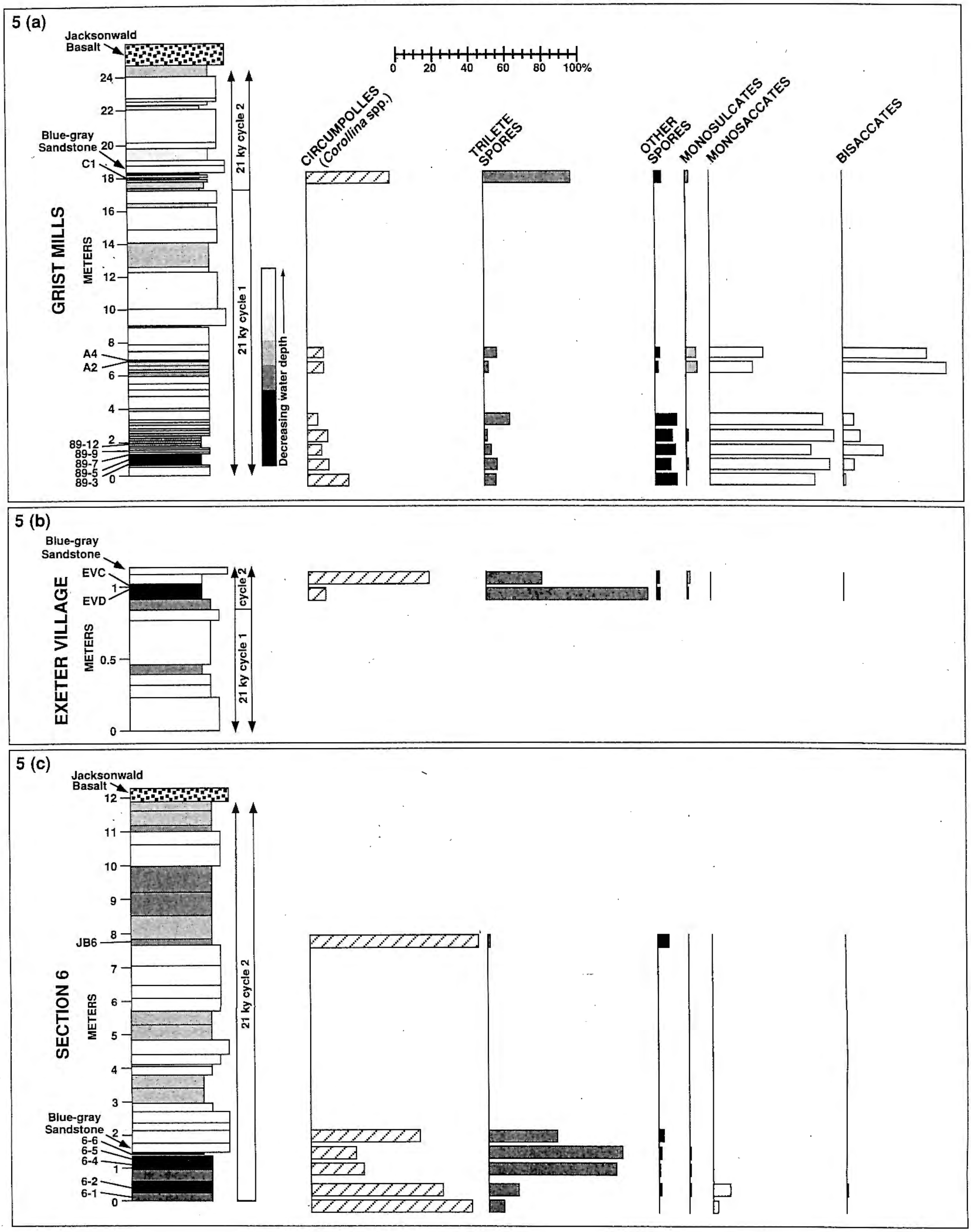

Figure 5. Triassic/Jurassic boundary sections from the Jacksonwald Syncline of the Newark basin. A blue-gray, plant-bearing sandstone present in all three sections serves as a basis for correlations. Relative abundances of pollen and spore morphotypes are plotted opposite their stratigraphic positions. 21-k.y. Milankovitch cycles constrain the duration of the palynological turnover. (a) Grist Mills section: Sample C1 contains 50% spores and is underlain by diverse assemblages typical of the Late Triassic. (b) Exeter Village section: Spore-dominated floras are replaced by Jurassic assemblages between samples EVD and EVC. EVD consists of 89% trilete spores; EVC contains 67% *Corollina* and lacks characteristic Late Triassic species. (c) Section 6: Spore-dominated floras first appear between samples 6-2 and 6-4. Sample JB6 is a typical Jurassic assemblage containing 95% *Corollina.* Samples 6-1 and 6-2 contain 89% and 73% *Corollina,* respectively, but unlike JB6 these samples retain monosaccate and bisaccate species characteristic of the Late Triassic.

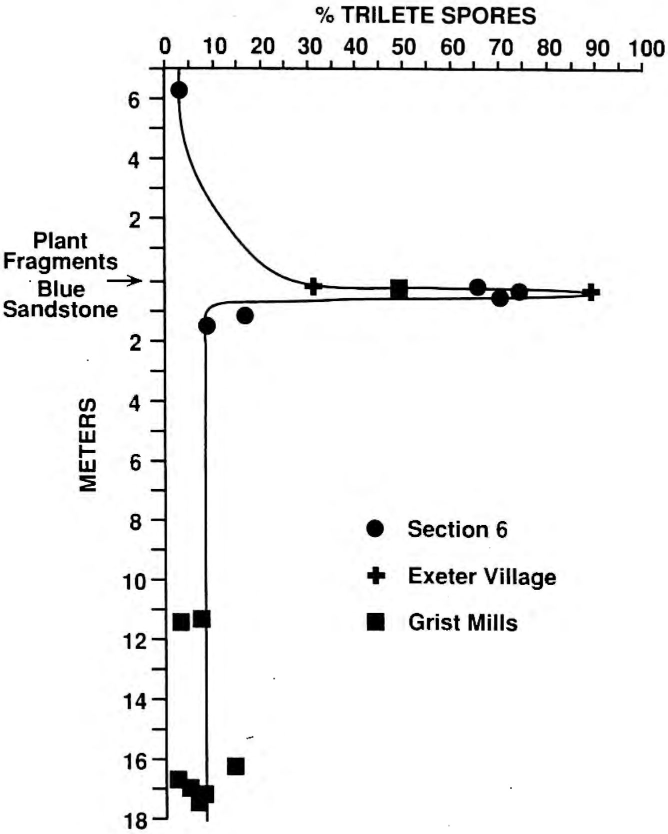

Figure 6. Percentage of trilete spores from all productive localities in Figure 5. Measured sections are correlated to the base of a distinctive blue-gray sandstone. Spore-dominated palynofloras occupy a narrow stratigraphic range less than 0.5 m thick.

abrupt disappearances of Rhaetian bivalves and Late Triassic foraminifera. Bice et al. (1992) suggest that the presence of three shocked quartz layers fits the comet shower model proposed by Hut et al. (1987).

Aspects of the Newark Supergroup palynofloral record are consistent with a multiple-impact scenario. The presence of a geologically brief spore-spike above the last appearances of Late Triassic palynomorph species is analogous to Cretaceous/Tertiary boundary fern spikes (Tschudy et al., 1984; Tschudy and Tschudy, 1986; Nichols et al., 1986; Fleming, 1990) hypothesized to represent a recolonization of ferns following catastrophic destruction of the Cretaceous flora.

The presence of short-lived "transitional" assemblages, in which *Corollina* is dominant but rare Late Triassic species persist (samples 6-1 and 6-2, Fig. 5c), indicates possible disruption of the flora prior to the Triassic/Jurassic boundary turnover. It is tempting to suggest a relationship between these palynofloras and one of the lower shocked quartz horizons of Bice et al. (1992) and to correlate the spore-spike with the uppermost shocked quartz layer and the extinctions of Triassic bivalves and foraminifera. Such correlations are premature, however, and require better estimates of sedimentation rates in the Tuscany section and evidence for shocked quartz in the Newark basin sections. To date, a comprehensive search for shocked quartz in the Newark Supergroup has not been completed, but we are currently conducting this crucial test of the validity of the impact hypothesis.

Enhanced temporal resolution and accurate stratigraphic correlations are also essential to future comparisons of Triassic/Jurassic boundary sections. Periodic sedimentary cycles and good palynofloral preservation within the Newark basin allow temporal calibration of Late Triassic palynofloral zones. Preliminary results are shown in Figure 2 and compared to published chronostratigraphic time scales. Recently acquired cores of the entire Triassic Newark basin section will permit refinement of the temporal data and better resolution of the boundaries between palynofloral zones. It is hoped that the combination of palynological and tetrapod data from the Newark Supergroup will eventually enable correlation between our continuously calibrated Late Triassic time scale and global sections with ammonite control.

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