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A SUMMARY OF THE BIOSTRATIGRAPHY OF THE NEWARK SUPERGROUP OF EASTERN NORTH AMERICA
WITH COMMENTS ON EARLY MESOZOIC PROVINCIALITY

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ABSTRACT

The Newark Supergroup of Eastern North America consists of rocks judged to range in age from early Middle Triassic through late Early Jurassic. Dating is principally based on the recognition of seven palynological zones correlated with the European standard stages and on correlation of vertebrates and megafossil plants. The basic floristic trends are a decrease in diversity into the Early Jurassic and the rise to strong dominance of the cheirolepidaceous conifers. Based on published radiometric scales, the Newark depositional episode lasted roughly 45 million years and was antecedent to the actual separation of the North American and African Plates. Correlation of other Early Mesozoic continental areas with the Newark allows the conclusions that there was a shift from Late Triassic floral and faunal provinciality to Early Jurassic homogeneity, and that this shift was synchronous with a widening of the equatorial arid zone.

RESUMEN

El Supergrupo Newark, del Oriente de América del Norte, consiste en rocas que a juicio de los autores tienen un margen de edad entre el Triásico Medio temprano y el Jurásico Temprano tardío. La asignación de edad se basa principalmente en el reconocimiento de siete zonas palinológicas que se correlacionan con los pisos estandar europeos y en la correlación mediante vertebrados y megafósiles vegetales. Las tendencias florísticas básicas son un decremento de la diversidad hacia el Jurásico Temprano y el surgimiento a una dominancia fuerte de las coníferas del tipo Cheirolepidiaceae. De acuerdo con escalas radiométricas publicadas, el episodio de depósito Newark duró unos 45 millones de años y precedió la separación de las placas de América del Norte y de Africa. La correlación de otras áreas continentales del Mesozoico temprano con el Newark permite las conclusiones de que en este lapso sucedió un cambio que a partir de la provincialidad de flora y fauna del Triásico Tardío llevó a la homogeneidad del Jurásico Temprano, y que este cambio fue contemporáneo con el ensanchamiento de la zona árida ecuatorial.

INTRODUCTION AND GEOLOGICAL CONTEXT

The Newark Supergroup (Figure 1) consists of a series of Early Mesozoic deposits of principally red non-marine clastics and minor thoeliitic igneous rocks exposed in a long series of discrete basins from Nova Scotia, Canada to South Carolina, U.S.A. (OLSEN, 1978; VAN HOUTEN, 1977; FROELICH and OLSEN, 1984). The long axes of these basins parallel the fabric of the Appalachian Orogene and in most cases the basin sequences are preserved as internally faulted and tilted halfgrabens. A long series of closely related basins occur beneath the Atlantic Coastal Plain and on the Continental Shelf (OLSEN, 1978).

Most Newark Supergroup rocks were apparently deposited in asymmetrically subsiding troughs formed along major Paleozoic thrust faults, which were reactivated in the Early Mesozoic as listric normal or normal-oblique faults (LINDHOLM, 1978; PETERSON, et al., 1984). There were at least several kilometers of dip-slip movement during the history of the basins. Whether these basins formed in a simple extensional system acting perpendicular to the axis of the basins or in a wrench system acting oblique to the fabric of the orogene is a matter of ongoing debate (MANSPEIZER and OLSEN, 1981; MANSPEIZER, 1982); however, it is certain that these basins formed just before the onset of actual separation of the North American and African plates and the oldest formation of Atlantic oceanic crust in the Middle Jurassic (SUTTER and SMITH, 1979).

As much as 10 km of principally fluvial and lacustrine sediments filled these basins. Most sequences show a bulls-eye facies pat-

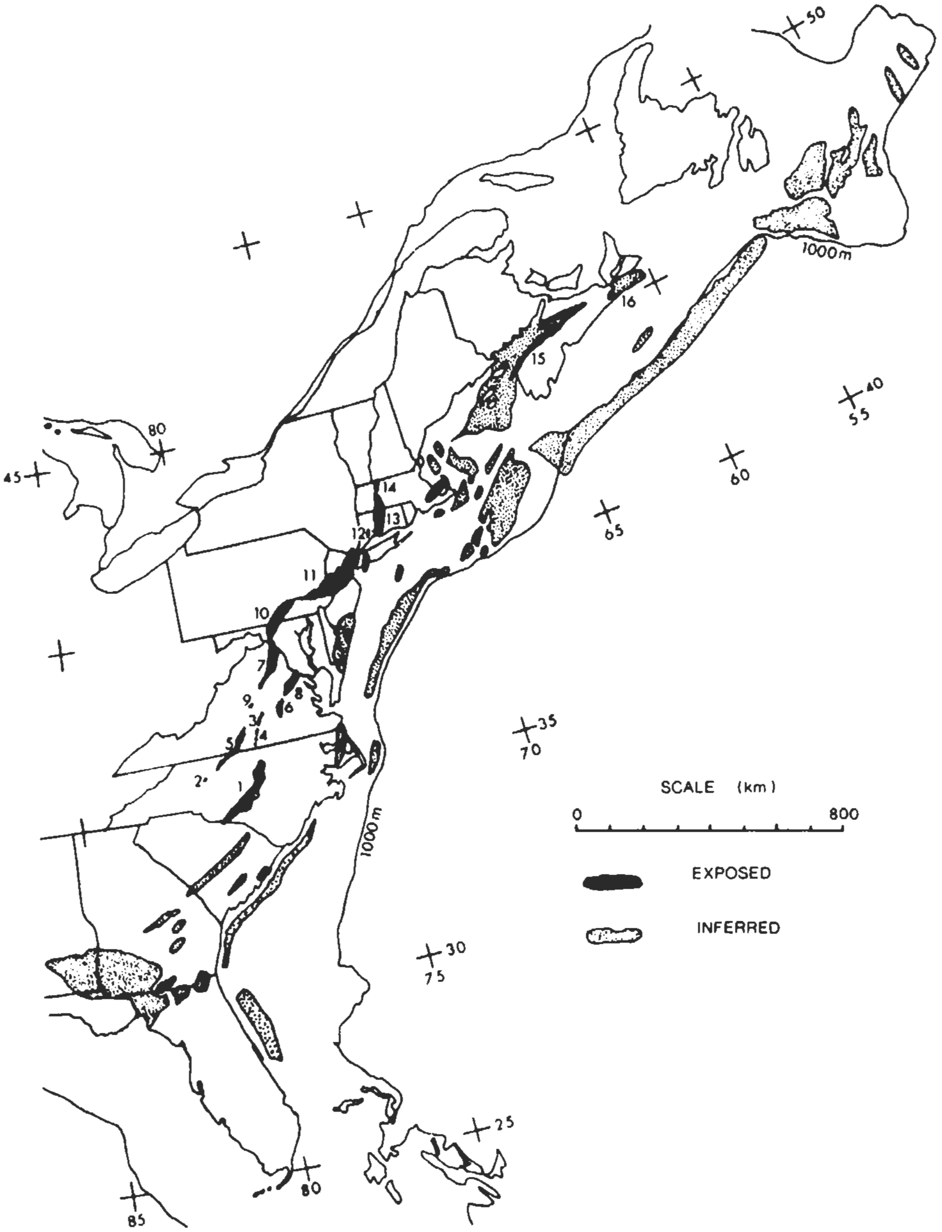


Figure 1: The Newark Supergroup of Eastern North America. Modified from OLSEN (1978). The inferred areas probably overlap the Newark in age but some may not be lithologically similar to the Newark. Key to Figure in Table 1.

tern of coarse fluvial sediments along the basin edges and finer sediments in the middle. Evidently most basins had internal drainages and perched outlets and therefore contained lakes as long as there was sufficient precipitation. Some of these lakes covered more than 7,000 km^2 and may have been deeper than 100 m. In addition to fluvio-lacustrine sediments, several Newark Supergroup basins also contain extrusive basalt sequences high in the sections, and in one basin (the Fundy Basin in Nova Scotia, Canada) there are a number of intervals of eolian sandstone (HUBERT and MERTZ, 1980; OLSEN, 1981).

No marine fossils are known from the Newark Supergroup and this has greatly hindered correlation of these continental beds with the standard European section. Fortunately most intervals contain at least some beds with well preserved pollen and spore assemblages, megafossil plants, and terrestrial and aquatic vertebrates. These allow an internal correlation of the Newark as well

Key to Figure	Rock-stratigraphic term	Basin name	Age range
1	Chatham Group	Deep River Basin	Carnian-?Norian (Late Triassic)
2	undifferentiated	Davie County Basin	?Late Triassic
3	undifferentiated	Farmville Basin	?Carnian (Late Triassic)
4	undifferentiated	4 small basins south of Farmville Basin	?Carnian (Late Triassic)
5	Dan River Group	Dan River and Danville Basins	Carnian-?Norian (Late Triassic)
6	Tuckahoe and Chesterfield Groups	Richmond Basin and subsidiary basins	Carnian (Late Triassic)
7	Culpeper Group	Culpeper Basin	Norian-?Sinemurian (Late Triassic-Early Jurassic)
8	none	Taylorsville Basin	Carnian (Late Triassic)
9	undifferentiated	Scottsville Basin and 2 subsidiary basins	?Late Triassic-Early Jurassic
10	none	Gettysburg Basin	Carnian-Hettangian (Late Triassic-Early Jurassic)
11	none	Newark Basin	Carnian Sinemurian (Late Triassic-Early Jurassic)
12	none	Pomperaug Basin	?Late Triassic-Early Jurassic
13	none	Hartford Basin and subsidiary Cherry Brook Basin	Norian-?Bajocian (Late Triassic-?Middle Jurassic)
14	none	Deerfield Basin	?Norian-?Toarcian (Late Triassic-Early Jurassic)
15	Fundy Group	Fundy Basin	?Middle Triassic-Early Jurassic
16	Chedabucto Formation (=Eurydice Formation?)	Chedabucto Basin (=Orpheus Basin?)	?Late Triassic-Early Jurassic

Table 1: Divisions of the Newark Supergroup and key to Figure 1. Note that "none" under the rock-stratigraphic term category indicates that, although the rocks of the basin may have been divided into formations, no inclusive name for all the formations of that basin have been proposed. Modified from OLSEN (1978).

as correlation with the European standard stages and other Early Mesozoic sections.

We address 4 main goals in this paper: 1) to summarize the age-correlative data from the Newark, concentrating on the pollen and spore and vertebrate assemblages; 2) to relate this local chronostratigraphic framework to other continental Early Mesozoic areas and the European standard stages; 3) to attempt to calibrate the biostratigraphy of the Newark by correlation with published radiometric scales; and 4) to use information from these correlations to briefly examine floral and faunal provinciality during the Early Mesozoic.

PALYNOLOGICAL CORRELATIONS

Plants, especially pollen and spores, are of paramount importance to the biostratigraphy of the Newark. CORNET (1977a) proposed seven pollen and spore zones, which are summarized below and in Figures 2 and 3. The oldest zone, the Chatham-Richmond-Taylorsville palynoflora, is recognized in the Chatham Group of the Deep River Basin and in the Richmond and Taylorsville basins, and contains about 155 pollen and spore species. This assemblage can be divided into two subzones.

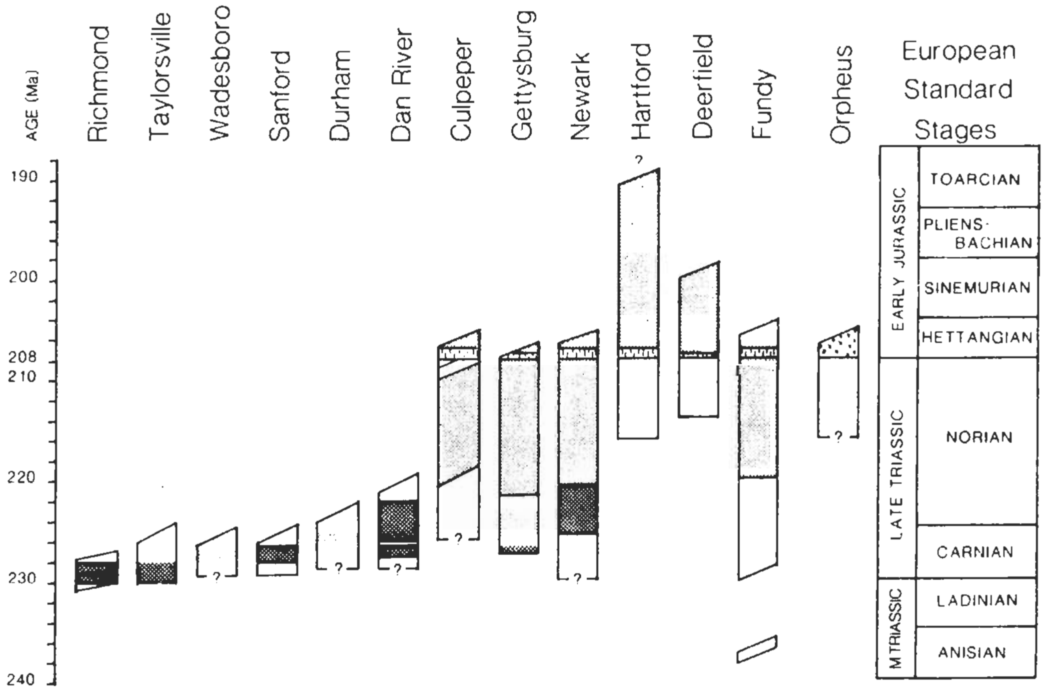


Figure 2: Internal correlation of the Newark, based on faunal and floral data (correlations based on data presented in CORNET (1977a, 1977 b), OLSEN and GALTON (1977, in press), OLSEN, McCUNE and THOMSON (1982) and OLSEN (1983a, 1983b).

Within each column representing a single basin, the dark gray zones represent principally lacustrine rocks which are dominantly gray or black; the lighter gray zones represent lacustrine rocks which are dominantly red but which may have significant gray beds; the white zones are dominantly fluvial or unknown; the vertically ruled zones represent extrusive basalt formations which often have interbedded sedimentary formations with lacustrine rocks; and the zone marked with "x"s represent salt deposits in the offshore Orpheus Graben. Horizontal lines within the columns are formation boundaries.

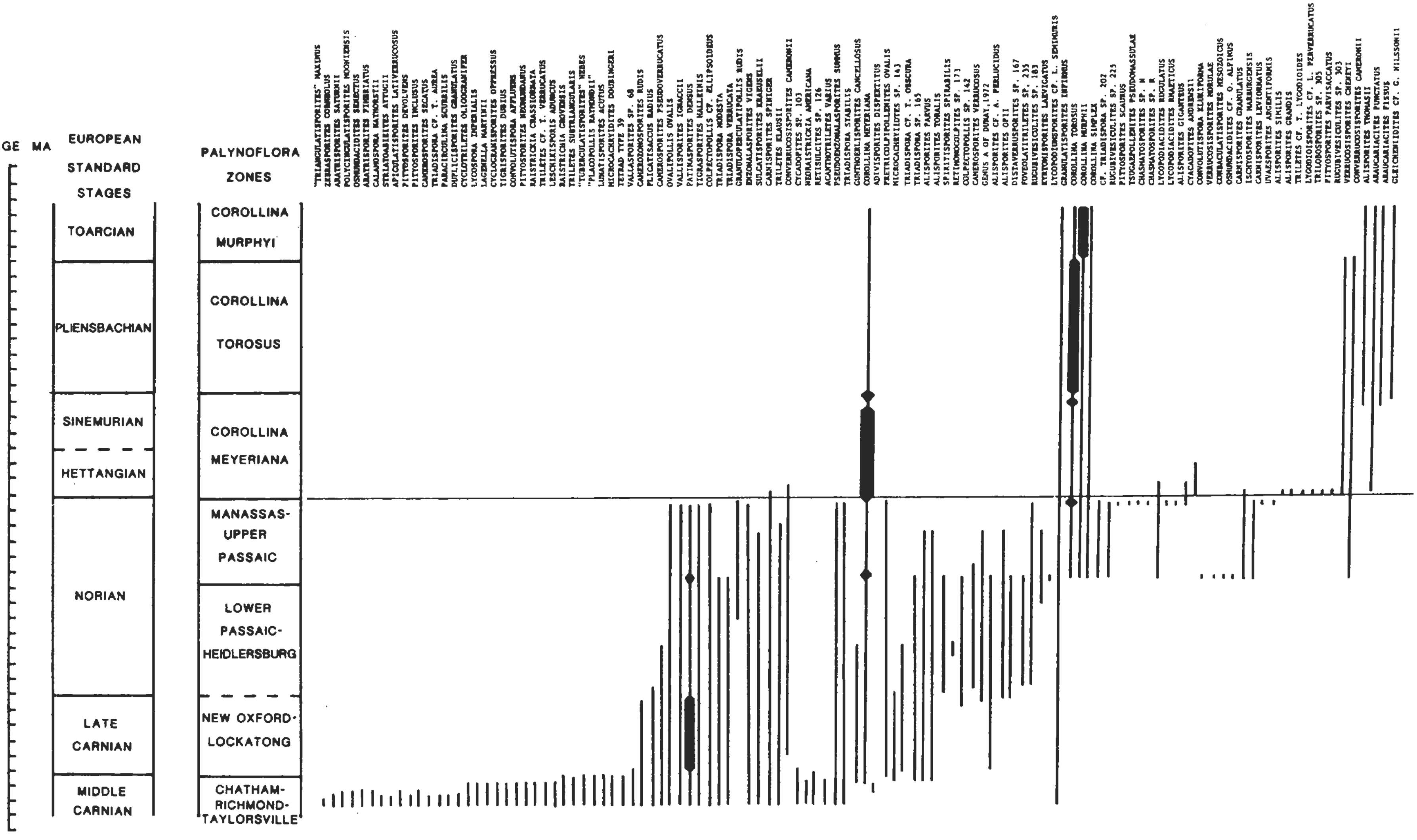


Figure 3: The distribution of age-diagnostic palynomorph taxa within the Newark Supergroup (data adapted from CORNET, 1977a).

A lower subzone is dominated either by cryptogam spores and gynmospermous monosulcate pollen, or by a diversified gymnospermous assemblage of non-striate bisaccate and circumsaccate pollen with minor percentages of monosulcate pollen, circumpolles, tetradopolles, and striate bisaccate pollen. This subzone occurs in the Richmond and Taylorsville basins. A similar pollen-dominated assemblage occurs in the basal Pekin Subbasin of the Chatham Group. *Aratrisporites scabratus*, *A. fimbriatus*, *Calamospora nathorstii*, and *Laricoidites* spp. make up the dominant cryptogram elements of the oldest spore and monosulcate-dominated assemblage, while *Osmundacidites* spp., *Baculatisporites* spp., and *Granulatisporites* spp. compete with articulate spores (e.g. *Laricoidites* sp. and *Pilasporites* sp.) for dominance in younger spore-dominated assemblages.

These contrasting cryptogamous and gymnospermous palynofloras alternate with one another through the Richmond-Taylorsville basin sequences as the lithologic facies alternate from deltaic-lacustrine to fluvio-deltaic. Based on recent well data from the Richmond Basin, at least two upwards-coarsening lacustrine to fluvial sequences, and the "head and tail" portions of two additional sequences record the cyclic waxing and waning of a large rift valley lake.

The upper subzone contains a less diversified spore assemblage and has more abundant *Patinasporites densus*, a circumsaccate morphotype that ranges down to the oldest Richmond Basin strata. The upper subzone also lacks *Aratrisporites* spp. and contains only rare striate bisaccate pollen, which decrease in abundance and diversity upwards through the lower subzone. This upper sub-assemblage occurs in the upper Pekin Formation and Cumnock Formations of the Chatham Group, the lower New Oxford Formation of the Gettysburg Basin, and perhaps the lower Wolfville Formation of the Fundy Group (TRAVERSE, 1983).

Age-diagnostic species of the oldest zone include the overlapping ranges of *Patinasporites densus*, *Striatoabieites aytugii*, *Triadispora verrucata*, *Protodiploxypinus doubingeri*, *Plicatisaccus badius*, *Triadispora* cf. *T. aurea*, and *Lagenella martinii*, indicating a probable late Middle Carnian age. However, palynoflorules older than Middle Carnian are only now becoming well known in Europe and it is possible that the beds of the Richmond and Taylorsville basin may be substantially older than this assessment - perhaps even as old as Middle Triassic.

The upper sub-assemblage of the Chatham-Richmond-Taylorsville palynoflora is replaced upwards in the Gettysburg Basin by the New Oxford-Lockatong palynoflora, which has also been recognized in the Newark (CORNET, 1977a) and Dan River basins (ROBBINS, 1982). This assemblage is dominated by *Patinasporites densus*, *Vallisporites ignacii*, *Alisporites parvus*, and *Triadispora* spp. It still contains *Camerosporites secatus* and *C. pseudoverrucatus*, but lacks the Middle Carnian age-diagnostic taxa of the Chatham-Richmond-Taylorsville palynoflora, all of which indicate that it is of Late Carnian Age.

The New Oxford-Lockatong palynoflora is gradually replaced upwards in the Newark Basin by the Lower Passaic-Heidlersburg palynoflora found thus far in the Culpeper, Gettysburg, Newark, and Hartford basins. This assemblage is distinguished by the presence of *Camerosporites verrucosus*, an abundance of large and varied bisaccate species, including the giant *Alisporites opii*, and the continued dominance of *Patinasporites densus*, *Vallasporites ignacii*, and *Triadispora* spp. This assemblage appears to be of Norian age. The upper portion of this zone, in the Newark Basin, contains the first rare occurrences of *Corollina meyeriana*.

The Lower Passaic-Heidlersburg palynoflora slowly changes upwards into the Manassas-Upper Passaic palynoflora in the Culpeper and Newark basins. This zone is distinguished by the first occurrence of *Corollina torosus* and *Granuloperculatipollis rudis* and the continuation of taxa common in the previous zone. This zone correlates with what palynostratigraphers have been calling the Rhaetian in Europe. The Rhaetian was first defined in marine rocks in the Austrian Alps, but these rocks have been recently shown to be partly equivalent to marine Late Norian strata elsewhere in Europe (PEARSON, 1970; TOZER, 1979). A number of authors do no longer consider the Rhaetian to represent an independent stage. What its loss does to the palynologically defined Rhaetian is unclear. However, Rhaetian palynofloras probably should be regarded as Late Norian, while "typical" Norian assemblages are probably best regarded as Early and Middle Norian. The Manassas-Upper Passaic palynoflora is thus Late Norian in age and is recognized in the Culpeper, Newark, and possibly Fundy basins (The name Manassas was originally chosen for palynological localities near Manassas, Virginia, and does not refer to the Manassas Formation of the Culpeper Basin, which is older).

This latter zone ends upwards with a rapid transition to the *Corollina meyeriana* palynoflora, which is characterized by a switch from a high diversity assemblage dominated by bisaccate pollen, *Patinasporites*, *Corollina meyeriana*, *C. torosus*, and *Granuloperculatipollis rudis* to a low diversity assemblage very strongly dominated (+90%) by the circumpolles *Corollina meyeriana*. This transition takes place over an 80 m thick "barren" interval below the Orange Mountain Basalt in the Newark Basin (Jacksonwald Syncline). By the top of this interval, all taxa characteristic of the Late Triassic are absent. The high diversity assemblage below this interval is peculiar in having a suite of pollen grains showing all the characters typical of angiosperms, although they are not assignable to any known angiosperm group. According to DOYLE (1978), "...these grains are perhaps the best candidates yet for pre-Cretaceous angiosperms...". An assemblage of somewhat similar grains occurs in the Chatham-Richmond-Taylorsville palynoflora.

The *Corollina meyeriana* palynoflora is characterized by the first common appearance of *Convolutispora klukiforma*; this zone is the lowest of the Jurassic pollen and spore zones in the Newark. The Triassic-Jurassic boundary is best placed just below the Orange Mountain Basalt and the oldest extrusives in other basins (CORNET, 1977a, 1977b) rather than within the zone of extrusives as suggested by CORNET, et al. (1973) and CORNET and TRAVERSE (1975). The *Corollina meyeriana* palynoflora continues through the entire zone of extrusives and into the overlying sediments in all of the Newark Supergroup Basins. Pollen and spore assemblages do not allow a finer subdivision within this zone or a correlation of individual sedimentary formations between extrusives in different basins. This zone seems to cover all of the Hettangian and Sinemurian of the Early Jurassic.

The *Corollina torosus* palynoflora succeeds the *C. meyeriana* palynoflora upwards with a strong switch in the dominant taxon from *Corollina meyeriana* to *C. torosus*. This switch occurs in the beds some distance above the uppermost extrusives in the Culpeper and Hartford basins. The age of this assemblage appears to be Pliensbachian.

In the Portland Formation of the Hartford Basin there is one zone younger than the *Corollina torosus* palynoflora. The *Corollina murphyi* palynoflora occurs in the highest sampled horizons in the Portland and, hence, in the Newark Supergroup. It is characterized by a dominance of *Corollina murphyi* over *C. torosus* (52% vs. 39% . The age of this assemblage appears to be Toarcian.

RELATIONSHIP OF PALYNOMORPH ZONES TO MEGAFOSSIL ZONES

Although the megafossil plants of the Newark were a major focus of research, particularly with regard to age, in the late 19th and early 20th centuries, much less attention has been paid to them since the 1920's. Recently, ASH (1980) has reviewed North American Early Mesozoic plant assemblages and divided them into three zones all of which are represented in the Newark Supergroup (Figure 3).

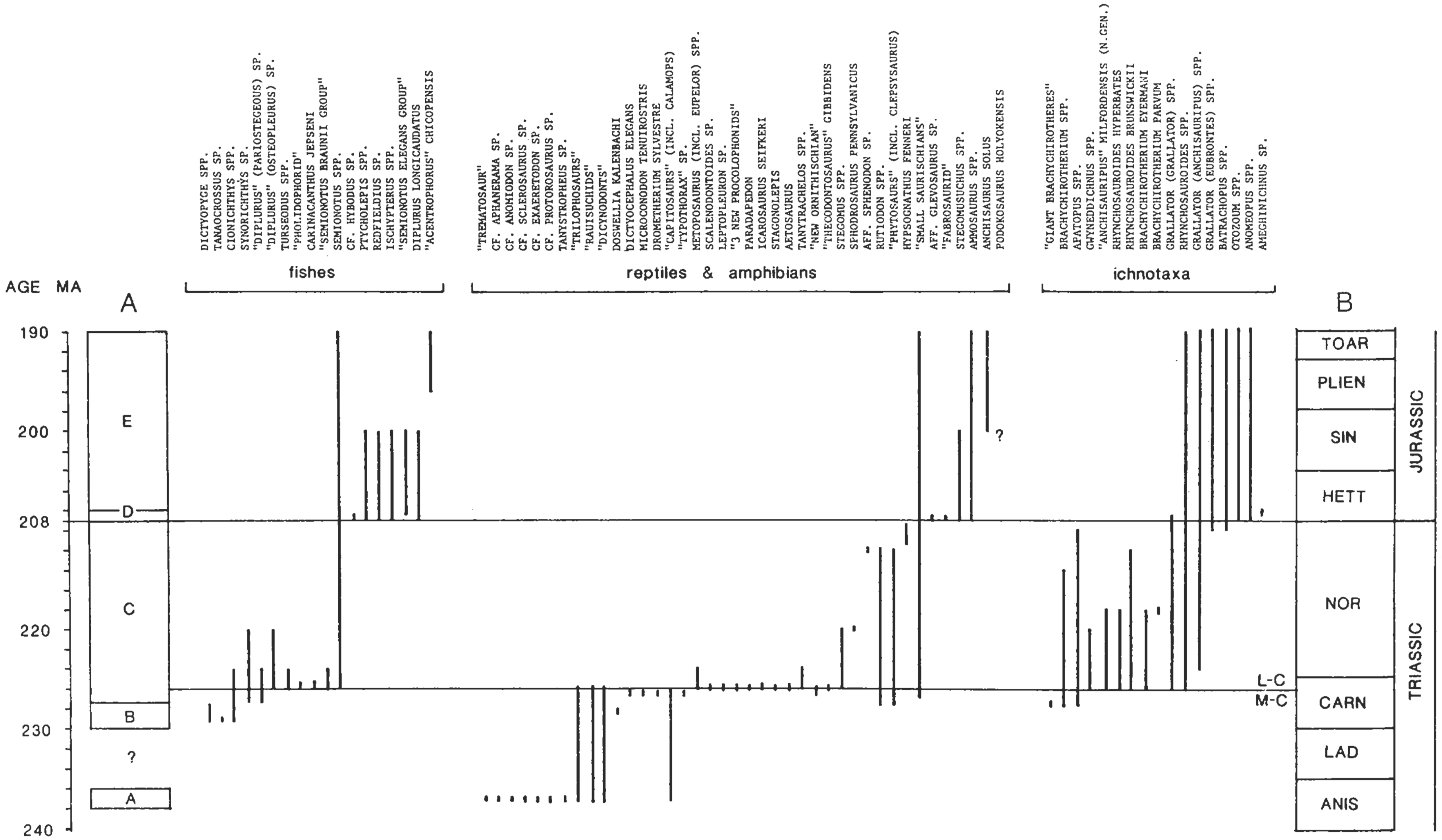
The oldest is called by ASH the Zone of *Eoginkgoites*, a bennettitalean gymnosperm. The zone of which it is typical has been identified in the Newark in the Richmond Basin, the Pekin, and the Cumnock Formations of the Deep River Basin, and the Stockton Formation of the Newark Basin (ASH, 1980). Florules of this zone are the most diverse in the Newark Supergroup, with very common ferns and bennettitaleans. Florules in this zone include those described by FONTAINE (1883), HOPE and PATTERSON (1970), DELEVORYAS and HOPE (1971, 1975, 1976), EMMONS (1856, 1857), WILLARD et al. (1959), BROWN (1911), and BOCK (1952, 1969, in part).

Above the Zone of *Eoginkgoites* is ASH's Zone of *Dinophyton*, a conifer-like gymnosperm. This zone has been recognized in the upper member of the Cow Branch Formation of the Dan River Basin (OLSEN *et al.*, 1978), and in the middle New Oxford Formation of the Gettysburg Basin (ASH, 1980; WARD, 1900; CORNET, 1977b). Newark assemblages from this zone are sometimes dominated by conifers, but are generally still diverse with an abundance of bennettitaleans. These florules are still poorly known.

The youngest zone recognized by ASH is called simply the Upper Zone. This zone is strongly dominated by cheirolepidaceous conifers, especially *Brachyphyllum*, *Pagiophyllum*, and *Hirmerella*. The cycadeoid *Otozamites* and the fern *Clathropteris* are often common. Compared to the older two zones, the florules of this zone are of very low diversity. This zone is represented in the syn- and post-extrusive sediments of the Culpeper, Gettysburg, Newark, Pomperaug, Hartford, and Deerfield basins. Scattered descriptions of elements of these florules were described by EMMONS (1857), BOCK (1969), and especially NEWBERRY (1888), and CORNET (1977a), but these are diverse assemblages which definitely can be further subdivided.

The Zone of *Eoginkgoites* corresponds broadly to CORNET's (1977a) Chatham-Richmond-Taylorsville palynoflora and it is thus Middle Carnian (or older) in age. The Zone of *Dinophyton* corresponds to the New Oxford-Lockatong palynoflora and is Late Carnian in age. The Upper Zone corresponds to the Jurassic pollen and spore zones of CORNET (1977a). It should also be noted that this last assemblage clearly resembles what is called the *Hirmerella* (*Cheirolepis*) assemblage, typical of the Early Jurassic of Great Britain (CORNET , 1977a) and it probably corresponds to Harris's Zone of *Thaumatopteris* (ASH, 1980) of Hettangian age. ASH based his zones mostly on deposits in the Western United States. There is as yet no definitive evidence for sediments intermediate in age between the Late Carnian and the Early Jurassic in that area. Therefore, ASH did not recognize megafossil plant zones that might correspond to the Lower Passaic-Heidlersburg palynoflora or the Manassas-Upper Passaic palynoflora in the Newark. NEWBERRY (1888), BOCK (1969, in part) and CORNET (1977a) have described some florules corresponding to these palynomorph zones, notably that of Milford, New Jersey from beds of the Lower Passaic-Heidlersburg palynoflora. In any case, the megafossil assemblages from these latter two zones of the Newark are the least well known of the supergroup.

In very broad terms, the most obvious floral trend visible through the entire Newark section is decreasing floral diversity. The oldest beds of the Newark, typified by the Richmond Basin section, have both the largest number of described megafossil species and the largest number of pollen and spore morphotypes. As important as the number of taxa is, no single taxon is consistently dominant from locality to locality within the Richmond Basin and at some localities the


AGE MA
190
200
208
220
230
240
A
E
D
C
B
?
A
fishes
DICTYOPYGE SPP.
TANAOCROSSUS SP.
CIONICHTHYS SPP.
SYNORICHTHYS SP.
"DIPLURUS" (PARIOSTEGEOUS) SP.
"DIPLURUS" (OSTEOPLEURUS) SP.
TURSEODUS SPP.
"PHOLIDOPHORID"
CARINACANTHUS JEPSENI
"SEMIONOTUS BRAUNII GROUP"
SEMIONOTUS SPP.
CF. HYBODUS SP.
PTYCHOLEPIS SPP.
REDFIELDIUS SP.
ISCHYPTERUS SPP.
"SEMIONOTUS ELEGANS GROUP"
DIPLURUS LONGICAUDATUS
"ACENTROPHORUS" CHICOPENSIS
reptiles & amphibians
"TREMATOSAUR"
CF. APHANERAMA SP.
CF. ANOMIODON SP.
CF. SCLEROSAURUS SP.
CF. EXAERETODON SP.
CF. PROTOROSAURUS SP.
TANYSTROPHEUS SP.
"TRILOPHOSAURS"
"RAUISUCHIDS"
"DICYNODONTS"
DOSWELLIA KALENBACHI
DICTYOCEPHALUS ELEGANS
MICROCONODON TENUIROSTRIS
DROMETHERIUM SYLVESTRE
"CAPITOSAURS" (INCL. CALAMOPS)
"TYPOTHORAX" SP.
METOPOSAURUS (INCL. EUPELOR) SPP.
SCALENODONTOIDES SP.
LEPTOPLEURON SP.
"3 NEW PROCOLOPHONIDS"
PARADAPEDON
ICAROSAURUS SEIFKERI
STAGONOLEPIS
AETOSAURUS
TANYTRACHELOS SPP.
"NEW ORNITHISCHIAN"
"THECODONTOSAURUS" GIBBIDENS
STEGOMUS SPP.
SPHODROSAURUS PENNSYLVANICUS
AFF. SPHENODON SP.
RUTIODON SPP.
"PHYTOSAURS" (INCL. CLEPSYSAURUS)
HYPSOGNATHUS FENNERI
"SMALL SAURISCHIANS"
AFF. CLEVOSAURUS SP.
"FABROSAURID"
STEGOMUSUCHUS SPP.
AMMOSAURUS SPP.
ANCHISAURUS SOLUS
PODOKOSAURUS HOLYOKENSIS
?
ichnotaxa
"GIANT BRACHYCHIROTHERES"
BRACHYCHIROTHERIUM SPP.
APATOPUS SPP.
GWYNEDDICHNUS SPP.
"ANCHISAURIPUS" MILFORDENSIS (N.GEN.)
RHYNCHOSAUROIDES HYPERBATES
RHYNCHOSAUROIDES BRUNSWICKII
BRACHYCHIROTHERIUM EYERMANI
BRACHYCHIROTHERIUM PARVUM
GRALLATOR (GRALLATOR) SPP.
RHYNCHOSAUROIDES SPP.
GRALLATOR (ANCHISAURIPUS) SPP.
GRALLATOR (EUBRONTES) SPP.
BATRACHOPUS SPP.
OTOZOUM SPP.
ANOMOEPUS SPP.
AMEGHINICHNUS SP.
L-C
M-C
B
TOAR
PLIEN
SIN
HETT
NOR
CARN
LAD
ANIS
JURASSIC
TRIASSIC

relative abundances of taxa are surprisingly evenly distributed. By the Late Carnian, however, conifers often dominate the macroflora, and conifer pollen is dominant in the microflora. The dominance of one taxon in the microflora rarely exceeds 50%. In the Early Jurassic Newark, however, conifers are very strongly dominant in both macro and microfloras and often comprise more than 90% of the assemblages.

VERTEBRATE ZONES

Vertebrate fossils are relatively common in most parts of the Newark Supergroup, especially fishes and reptile footprints. OLSEN, McCUNE, and THOMSON (1982) and OLSEN and GALTON (1977; 1984) have reviewed much of the biostratigraphically useful vertebrate data and recognized a number of informal biostratigraphic zones. Recent discoveries have shown that the useful biostratigraphic zones are fewer in number and less complex than originally thought (OLSEN, 1983a, 1983b). The distribution of vertebrates in the Newark and the zones they define are shown in Figure 4. Note the correspondence between the upper limit of the *Apatopus* zone and the base of the *Corollina meyeriana* palynoflora and the apparent lack of correspondence of the boundaries of the other vertebrate zones with the palynoflora zones.

The oldest Newark vertebrate assemblage occurs in a small isolated deposit within the Fundy Basin (A of Figure 4). Vertebrates from this deposit differ from all others in the Newark and indicate an early Middle Triassic (Anisian) age for the deposit. These are the oldest beds in the Newark. No floral data are available from these beds, unfortunately.

The next oldest assemblage occurs in the Richmond, Taylorsville, and Scottsville basins (B of Figure 4) and is characterized by vertebrates found nowhere else. Typical is the unique refieldiid fish *Dictyopyge*. This assemblage characterizes the lower part of the Chatham-Richmond-Taylorsville palynoflora zone and appears to be of Middle Carnian age, but it might be older.

The abundance of phytosaur reptiles makes up the next assemblage (C of Figure 4), which is characteristic of Late Triassic vertebrate assemblages from other parts of the world such as the German Middle and Late Keuper. The upper Chatham-Richmond-Taylorsville through the Lower Passaic-Heidlersburg palynofloras contain this phytosaur-dominated assemblage, which makes up the bulk of the Newark.

The youngest Newark vertebrate assemblage is characterized by a dominance of the remains of dinosaurs and crocodiles and has no counterpart in the European Late Triassic (OLSEN and GALTON, 1977, In Press) (D and E of Figure 4). Correspondingly the associated palynofloras are the *Corollina meyeriana* through the *Corollina murphii* palynofloras, themselves correlated with the Early Jurassic. This assemblage has its oldest representatives in the sediments above the oldest extrusives in the Newark.

CALIBRATION OF THE NEWARK

Five current and somewhat different radiometric scales are available for the Early Mesozoic on a stage by stage level (Figure 5). All five scales use partially independent data and have rather different age assignments for the boundaries between stages and periods (Figure 5). The lengths of the intervals between stages are, however, closely comparable. These scales can be tied to the Newark using the palynologically defined age-boundaries, discussed above. Within the Newark the best defined boundaries are the Middle Carnian - Late Carnian boundary, the Norian - Hettangian boundary and the Pliensbachian - Toarcian boundary. To apply the radiometric scales to the Newark we have had to assume that the Late Carnian was 1/3 the duration of the Carnian and, of course, assume that the correlation of the radiometric scales with the European standard stages are correct.

The duration of intervals within most of the Newark calibrated by the available radiometric scales are in very good agreement with independent calibration by lacustrine sedimentary cycles ascribed to climate control by the 21,000 year precession cycle (VAN HOUTEN, 1969, 1980; OLSEN, 1984a, 1984b). However, the thicknesses of the palynologically defined Middle Carnian of the Newark is out of proportion with the 1.5 - 3.5 million years alloted to the Middle Carnian in the published scales. If the sedimentation rates ascribed to the palynologically defined post-Middle Carnian of the Newark were similar to those of the Newark Middle Carnian, the duration of the pre-Late Carnian of the Newark would be on the order of 10 million years. This suggests either a major problem with assessments of the duration of the Carnian, problems with correlation of the palynoflorules of the Newark with the European section, or the possibility that the sedimentation rates for the older beds were significantly higher. The last possibility is in line with sedimentological data from the Richmond Basin.

CORRELATION WITH OTHER AREAS OF CONTINENTAL SEDIMENTATION

Important areas of early Mesozoic continental sedimentation outside the Newark include the European Keuper and Infralias, the Newark Supergroup-like basins of Morocco, the Chinle Formation, Dockum Group, and Glen Canyon Group of the southwestern United States, the Stormberg Group of southern Africa, the Ischigualasto and Los Colorados of Argentina, and finally the Lower Lufeng of China. Correlation between some of these areas and the European standard stages is hampered by a lack of some classes of age-

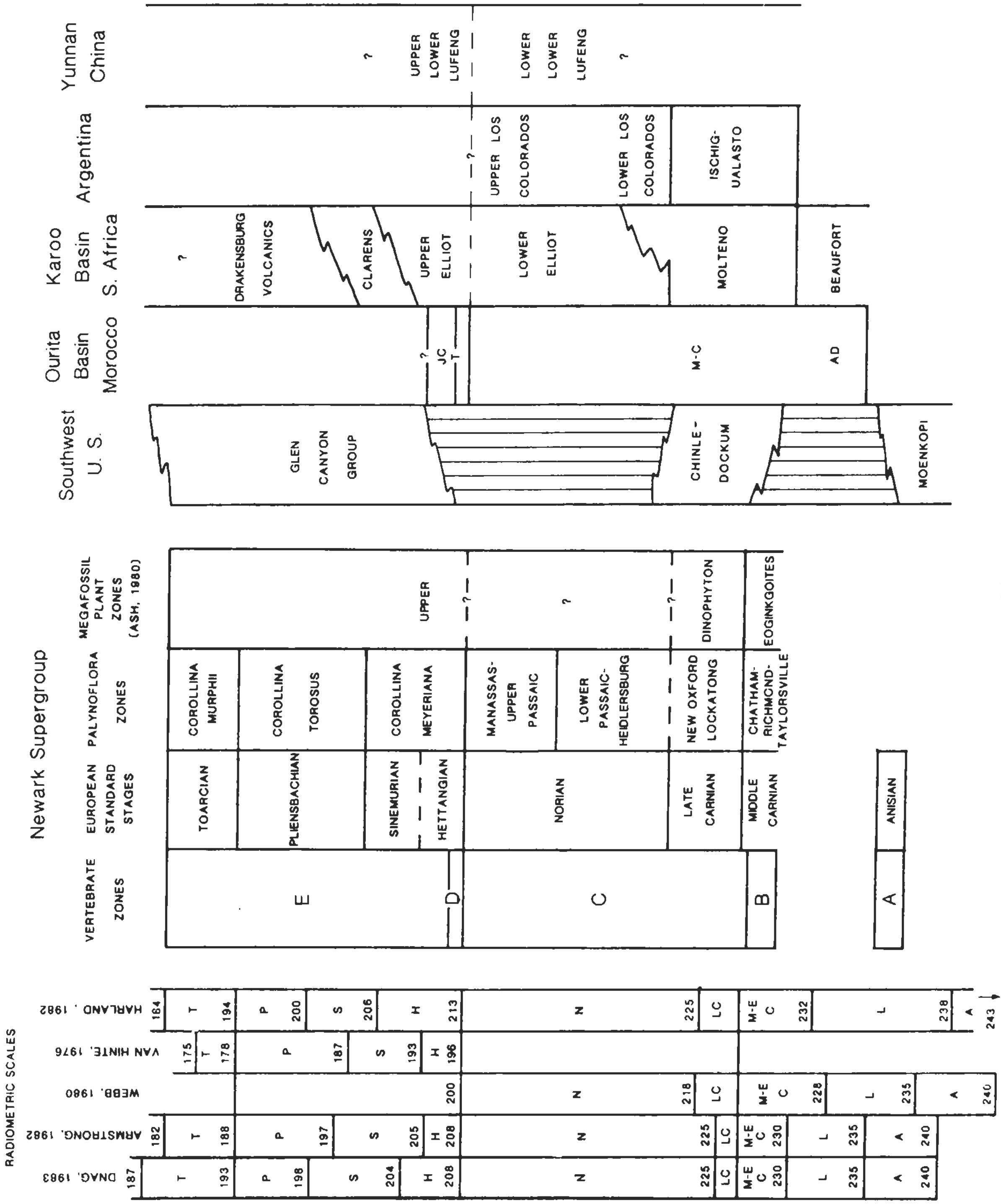

RADIOMETRIC SCALES
DNAG, 1983
187 T 193 P 198 S 204 H 208 N 225 LC M-E C 230 L 235 A 240
ARMSTRONG, 1982
182 T 188 P 197 S 205 H 208 N 225 LC M-E C 230 L 235 A 240
WEBB, 1980
200 N 218 LC M-E C 228 L 235 A 240
VAN HINTE, 1976
175 T 178 P 187 S 193 H 196
HARLAND, 1982
184 T 194 P 200 S 206 H 213 N 225 LC M-E C 232 L 238 A 243
Newark Supergroup
VERTEBRATE ZONES
E
D
C
B
A
EUROPEAN STANDARD STAGES
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
NORIAN
LATE CARNIAN
MIDDLE CARNIAN
ANISIAN
PALYNOFLORA ZONES
COROLLINA MURPHII
COROLLINA TOROSUS
COROLLINA MEYERIANA
MANASSAS-UPPER PASSAIC
LOWER PASSAIC-HEIDLERSBURG
NEW OXFORD LOCKATONG
CHATHAM-RICHMOND-TAYLORSVILLE
MEGAFOSSIL PLANT ZONES (ASH, 1980)
UPPER
?
?
?
DINOPHYTON
EOGINKGOITES
Southwest U. S.
GLEN CANYON GROUP
CHINLE-DOCKUM
MOENKOPI
Ourita Basin Morocco
?
JC
T
M-C
AD
Karoo Basin S. Africa
?
DRAKENSBURG VOLCANICS
CLARENS
UPPER ELLIOT
LOWER ELLIOT
MOLTENO
BEAUFORT
Argentina
?
UPPER LOS COLORADOS
LOWER LOS COLORADOS
ISCHIG-UALASTO
Yunnan China
?
UPPER LOWER LUFENG
LOWER LOWER LUFENG
?

Figure 5

correlative data, such as palynomorphs or marine invertebrates, but correlation by vertebrates through the Newark provides the necessary and crucial link. Figure 5 shows an attempted correlation of the above areas with the Newark and the European standard stages.

Of particular interest are the assignments of the entire Glen Canyon Group of the southwestern United States, the Upper Stormberg Group, and the upper Lower Lufeng of China to the Early Jurassic (OLSEN and GALTON, 1977, In Press). Until recently, the prevailing view was that all these intervals were Late Triassic in age. With these new age designations in mind, we can look at the pattern of "climate sensitive" rocks and floral and faunal provinciality for the Late Triassic and Early Jurassic (Figure 6).

LATE TRIASSIC PROVINCIALITY

Prominent in the pattern of deposits of Late Triassic Age is a zone between north 40 and south 30 paleolatitude where phytosaur reptiles and metoposaur amphibians are common (the latter only in the Carnian) (Figure 6). They are present even in northern Gondwanaland (Morocco and India) but are absent in the rich continental assemblages of the Ischigualasto and related formations of South America and the Molteno and Lower Elliot formations of Africa. This equatorial assemblage is dominated by archosaurs whereas the more southern contemporaneous assemblages are dominated by mammal-like reptiles.

The metoposaur-phytosaur biogeographic province has floral counterparts. In the Late Triassic, all vertebrate assemblages south of 30 paleolatitude are associated with *Dicroidium*-type megafossil florules. Only in India do phytosaurs and metoposaurs occur with a *Dicroidium*-type florule. In all other areas, phytosaurs and metoposaurs occur with a typical Laurasian bennetitalean-conifer assemblage. The areas which have *Dicroidium*-type florules are dominated by palynoflorules of the Ipswich-Onslow-type (DOLBY and BALME, 1976; TRUSWELL, 1980), including India (KUMARAN and MAHESWARI, 1980). In the northern hemisphere, phytosaurs and metoposaurs are absent above 30 north; however, there does not seem to be a separate northern floral province in the region where these vertebrates are absent.

Coals are fairly common in Late Triassic rocks north of 30 north and south of 30 south latitude (ANDERSON and ANDERSON, 1970; ROBINSON, 1971, 1973). In between are scattered occurrences of evaporites and dune sands and much less common coals (Figure 6). Between north and south 30, the coals seem to be restricted to an equatorial belt, but there are so few occurrences, the pattern may not be meaningful. It is worth noting, however, that an arid-to-the-north trend has been noted within the Newark Supergroup which does conform to this postulated pattern (HUBERT and MERTZ, 1980; OLSEN, 1981; MANSPEIZER, 1982).

EARLY JURASSIC PROVICIALITY

In contrast to the Late Triassic, no continental vertebrate provinciality is visible in sediments of Early Jurassic age (Figure 6). This faunal homogenization extends to the intercontinental distribution of many terrestrial vertebrate genera, especially dinosaurs and mammals (OLSEN and GALTON, In Press). This lack of provinciality also seems to correspond to a reduction in the rate of turnover for faunal assemblages as a whole. A parallel pattern is apparent in Early Jurassic plants.

It has long been recognized that the strong floral provinciality which characterized the Late Triassic world gave way in the Early Jurassic to a more homogeneous world flora dominated in many areas by cheirolepidaceous conifers (ALVIN, 1982); this dominance is especially obvious in the preponderance of *Corollina* (*Classopollis*) pollen in many areas. HUGHES (1973) has shown that in the Late Jurassic, the relative abundance of *Corollina* was greatest in the equatorial region, and it seems clear that this pattern was establish-

Figure 5: Calibration of the Newark by published radiometric scales and correlation of the biostratigraphic subdivisions of the Newark Supergroup with other Early Mesozoic continental deposits. Source of data for these correlations same as Figure 4 and in addition, MANSPEIZER (1982).

Abbreviations as follows: Radiometric scales: A, Anisian; L, Ladinian; M-E C, Middle and Early Carnian; L C, Late Carnian; N, Norian; H, Hettangian; S, Sinemurian; P, Pliensbachian; T, Toarcian. Vertebrate Zones: A - E, designations of vertebrate asseblages discussed in text. Ourita Basin: AD, adensite; M-C, *Minutosaccus*-*Patinasporites* assemblage; T, tholeiitic extrusive basalts; JC, Jurassic marine and paralic carbonates.

Note that in this Figure the radiometric scales are all tied at the Pliensbachian-Toarcian, Norian-Hettangian, and Middle Carnian - Late Carnian boundaries as palynologically fixed in the Newark.

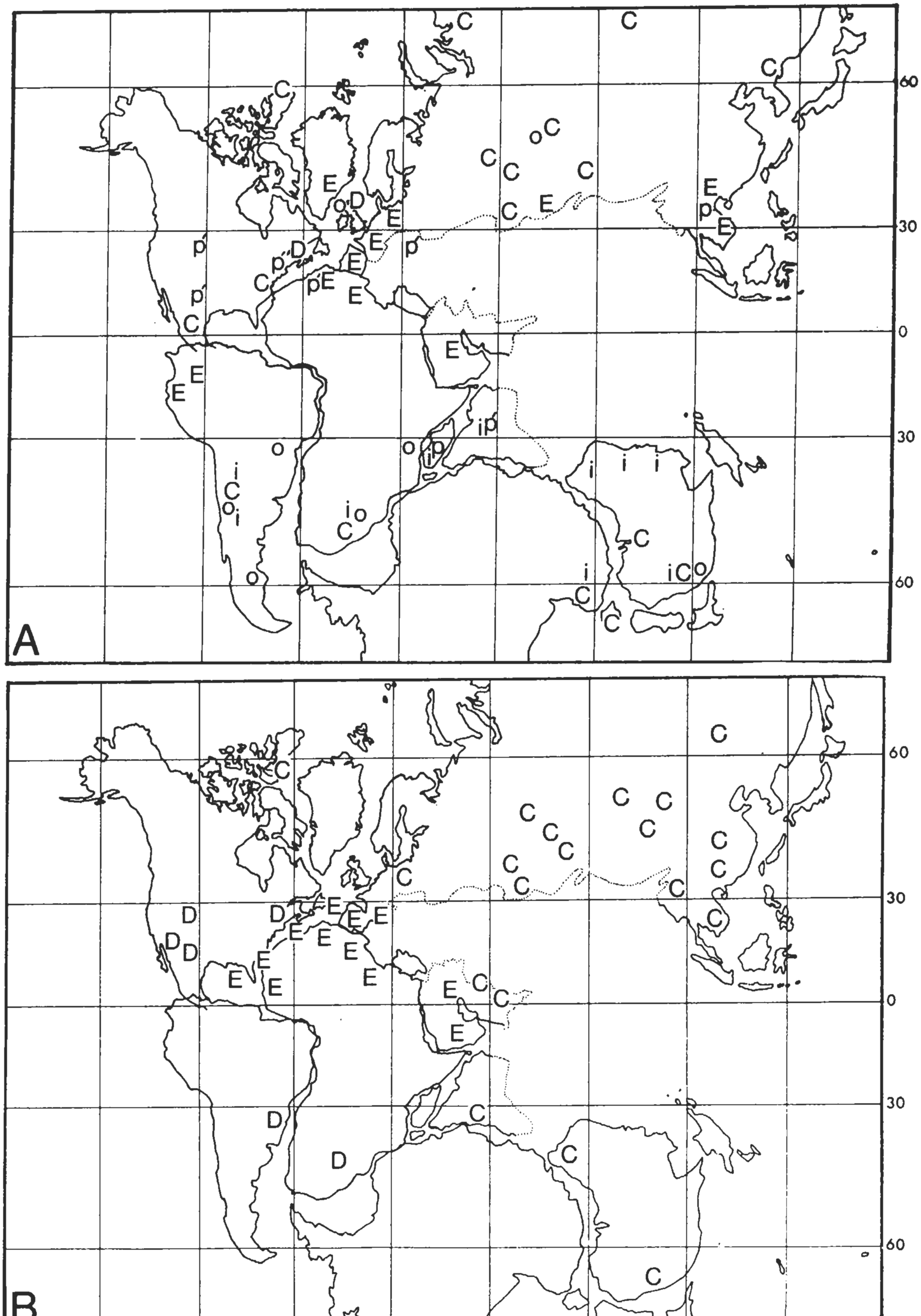


Figure 6

ed by the Early Jurassic. Going from south to north, there is a trend from *Corollina*-dominated (+90%) to *Corollina*-poor (-10%) microflorules (PEDERSON and LUND, 1980) with transitional assemblages occurring around a 25 north paleolatitude. This pattern is reflected in the megafossils as well, with conifers strongly dominant in the equatorial region and much less so in the north. Data are as yet insufficient to recognize a similar trend in the southern hemisphere.

Coals are virtually restricted to the high latitudes in the Early Jurassic (PARRISH, et al., In Press) (Figure 6) and dune sands are very common in the broad equatorial humid zone in the data available for the Early Jurassic.

CONCLUSIONS

Rocks of the Newark Supergroup were deposited during an interval greater than 35 million years, from the Middle Carnian of the Late Triassic through the Toarcian of the Early Jurassic. If the oldest beds datable by vertebrates are included, the range increases to 45 million years. Within this interval seven pollen and spore zones can be recognized and these allow the Newark to be correlated with the European standard stages and published radiometric scales.

Correlation by vertebrates is especially useful within the Newark and within areas of continental sedimentation where palynomorph data are lacking. Using all the available data, it appears that a number of sequences thought to be Late Triassic in age are actually Early Jurassic.

These correlations permit the conclusion that the transition from Late Triassic to Early Jurassic was marked by a strong decrease in floral and faunal provinciality and an increase in indicators of aridity in the equatorial zone.

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REFERENCES

ALVIN, K.L., 1982. Cheirolepidiaceae. Biology, structure, and paleoecology. Rev. Paleobot. Palynol., 37: 71-98.

ANDERSON, H.M. and J.M. ANDERSON, 1970. A preliminary review of the biostratigraphy of the uppermost Permian, Triassic, and lowermost Jurassic of Gondwanaland. Palaeontographica Africana, supplement to vol. 13: 1-22 (with 22 charts).

ARMSTRONG, R.L., 1982. Late Triassic-Early Jurassic time-scale calibration in British Columbia, Canada, *In* G.S. ODIN (ed.) Numerical Dating in Stratigraphy, John Wiley and Sons, New York: 509-514.

ASH, S., 1980. Upper Triassic floral zones of North America. *In*: D.L. DILCHER, and T.M. TAYLOR, (eds.) Biostratigraphy of fossil Plants. Dowden, Hutchinson and Ross, Stroudsburg: 153-170.

BOCK, W., 1952. New eastern Triassic Ginkgos. Bull. Wagner Free Inst. Sci., Philadelphia 27: 9-14.

- - - 1969. The American Triassic flora and global correlations. Geol. Center Res. Ser. 3-4, 340 p.

BROWN, AP., 1911. New cycads and conifers from the Triassic of Pennsylvania. Proc. Acad. Nat. Sci. Philadelphia, 63: 7-21.

CORNET, B., 1977a. The Palynostratigraphy and Age of the Newark Supergroup. Unpubl. Ph.D. Thesis, Department of Palynology, The

Figure 6: A) Position of the continents during the Late Triassic (Carnian-Norian) showing the occurrences of climate sensitive rocks (C, coals; D, dune sands; E, evaporites), the phytosaur-metoposaur province (p', phytosaurs and metoposaurs; p, only phytosaurs; o, good tetrapod assemblages lacking phytosaurs and metoposaurs), and the Gondwana floral province (i, Ipswich-Onslow microflora and *Dicroidium*- dominated macroflora).
B) Position of the continents during the Early Jurassic during the Early Jurassic (Pliensbachian) showing the occurrences of the "climate sensitive rocks" (abbreviations as in A, above).
Citations for A and B given in OLSEN and GALTON (in press).

Pennsylvania State University: 506 pp.

- - - 1977b. Preliminary investigation of two Late Triassic conifers from York County, Pennsylvania, *In:* R.C. ROMANS (ed.) Geobotany, Plenum Publishing, New York. 165-172.

- - - A, TRAVERSE, and N.G. MCDONALD, 1973. Fossil spores, pollen, and fishes from Connecticut indicate Early Jurassic age for part of the Newark Group. Science 182: 1243-1246.

- - - and A. TRAVERSE, 1975. Palynological contribution to the chronology and stratigraphy of the Hartford Basin in Connecticut and Massachusetts. Geosci. Man., 11: 1-33.

DELEVORYAS, T., and R.C. HOPE, 1971. A New Triassic cycad and its phyletic implications. Postilla 150: 22 p.

- - - 1975. *Voltzia andrewsii* n. sp., an Upper Triassic seed cone from North Carolina, U.S.A. Rev. Palaeobot. Palynol., 20: 67-74.

- - - 1976. More evidence for a slender growth habit in Mesozoic cycadophytes. Rev. Palaeobot. Palynol., 21: 93-100.

DOLBY, J.H. and B.E. BALME, 1976. Triassic palynology of the Carnarvon Basin, Western Australia. Rev. Paleobot. Palynol., 22: 105-168.

DOYLE, J.A., 1978. Origin of Angiosperms. Ann. Rev. Ecol. Syst., 9: 365-392.

EMMONS, E., 1856. Geological report of the midland counties of North Carolina. North Carolina Geol. Surv., 1852-1863, Putnum, New York: 352 p.

- - - 1857. American Geology, pt 5., Spraugue, Albany: 152 p.

FONTAINE, W.M., 1883. Contributions to the knowlege of the older Mesozoic flora or Virginia. U.S. Geol. Surv. Mongr., 6: 1-144.

FROELICH, A.J. and P.E. OLSEN, 1984. Newark Supergroup, a revision of the Newark Group in eastern North America. U.S. Geol. Surv. Bull., 1537-A, 1984: A55-A58.

HARLAND, W.B., 1982. A Geologic Time Scale, Cambridge University Press, New York: 150 p.

HOPE, R.C. and O.F. PATTERSON III, 1969. Triassic flora from the Deep River Basin, North Carolina. North Carolina Dept. Conserv. Dev., Spec. Publ., 2: 22 p.

- - - 1970. *Pekinopteris auriculata:* A new plant from the North Carolina Triassic. Jour. Paleo., 44: 1137-1139.

HUBERT, J.F., and K.A. MERTZ, 1980. Eolian dune field of Late Triassic age, Fundy Basin, Nova Scotia. Geology 8: 516-519.

HUGHES, N.F., 1973. Mesozoic and Tertiary distributions and problems of land plant evolution. *In:* N.F. HUGHES (ed.) Organisms and Continents Through Time, special Papers in Palaeont., London, Palaeontological Association, 12: 188-198.

KUMERAN, K.P.N. and H.K. MAHESWARI, 1980. Upper Triassic sporae dispersae from the Tiki Formation 2: Miospores from the Janar Nala Section, South Gondwana Basin, India. Palaeontographica Abt., B, 173: 26-84.

LINDHOLM, R.C., 1978. Triassic-Jurassic faulting in eastern North America - a model based on pre-Triassic structures. Geology 6: 365-368.

MANSPEIZER, W., 1982. Triassic-Liassic basins and climate of the Atlantic passive margins. Geol. Rund., 71 (3), 895-917.

ODIN, G.S. and LETOLLE, R., 1982. The Triassic time scale in 1981. *In:* G.S. ODIN (ed.) Numerical Dating in Stratigraphy, John Wiley and Sons, New York: 523-536.

OLSEN, P.E., 1978. On the use of the term Newark for Triassic and Early Jurassic rocks of eastern North America. Newsl. Stratigr., 7 (2): 90-95.

- - - 1980a. A comparison of the vertebrate assemblages from the Newark and Hartford Basins (Early Mesozoic, Newark Supergroup) of eastern North America. *In:* L. L. JACOBS, (ed.) Aspects of Vertebrate History: Essays in Honor of Edwin Harris Colbert., Museum of Northern Arizona Press, Flagstaff: 35-53.

- - - 1980b. Triassic and Jurassic Formations of the Newark Basin. *In:* W. MANSPEIZER, (ed.) Field Studies in New Jersey Geology and Guide to Field Trips, 52nd Ann. Mtg. New York State Geol. Assoc., Newark College of Arts and Sciences, Rutgers University, Newark: 2-39.

- - - 1980c. Fossil great lakes of the Newark Supergroup in New Jersey. *In:* W. MANSPEIZER (ed.) Field Studies in New Jersey Geology and Guide to Field Trips, 52nd Ann. Mtg. New York State Geol. Assoc., Newark College of Arts and Sciences, Rutgers University, Newark: 352-398.

- - - 1981. Comment on "Eolian dune field of Late Triassic age, Fundy Basin, Nova Soctia". Geology 9: 557-561.

- - - 1983a. Relationship between biostratigraphic subdivisions and igneous activity in the Newark Supergroup. Southeastern Sect., Geol. Soc. Amer., Abst. 15 (2): 71.

- - - 1983b. On the non-correlation of the Newark Supergroup by fossil fishes: biogeographic, structural, and sedimentological implications. Northeastern Sect., Geol. Soc. Amer., Abstr., 15 (3): 121.

- - - 1984a. Comparative Paleolimnology of the Newark Supergroup: A Study of Ecosystem Evolution. Unpublished Ph.D. Thesis, Biology Department, Yale University: 726 p.

- - - 1984b. Periodicity of lake-level cycles in the Late Triassic Lockatong Formation of the Newark Basin (Newark Supergroup, New Jersey and Pennsylvania). MILANKOVITCH and Climate. NATO symposium. Dordrecht, D. Reidel Publishing.

- - - and P.M. GALTON, 1977. Triassic-Jurassic tetrapod extinctions: are they real, Science 197: 983-986.

- - - In Press. A review of the reptile and amphibian assemblages from the Stromberg of southern Africa, with special emphasis on the footprints and the age of the Stormberg. Palaeontologia Africana, HAUGHTON Memorial Volume.

- - - C.L. REMINGTON, B. CORNET, and K. S. THOMSON, 1978. Cyclic change in Late Triassic lacustrine communities. Science 201: 729-733.

PARRISH, J.M., J.T. PARRISH, and A.M. ZIEGLER, In Press. Permo-Triassic paleogeography and paleoclimatology and implications for therapsid distributions. *In*: HOTTON, N., III. (ed.).

PEARSON, D.A.B., 1970. Problems of Rhaetian stratigraphy with special reference to the lower boundary of the stage. Quart. Jour. Geol. Soc. Lond., 126: 125-150.

PEDERSEN, K.R. and J.J. LUND, 1980. Palynology of the plant-bearing Rhaetian to Hettangian Kap Stewart Formation, Scoresby Sund, East Greenland. Rev. Palaeobot. Palynol., 31: 1-69.

PETERSON, T.A., L.D. BROWN, F.A. COOK, S. KAUFMAN, and J.E. OLIVER, 1984. Structure of the Riddleville Basin from COCORP seismic data and implications for reactivation tectonics. Jour. Geol., 92: 261-271.

ROBBINS E.I., 1983. "Fossil Lake Danville": The Paleoecology of a Late Triassic Ecosystem on the North Carolina-Virginia Border. Unpubl. Ph.D. Thesis, Department of Geosciences, The Pennsylvania State University: 400 pp.

ROBINSON, P.L., 1971. A problem of faunal replacement on Permo-Triassic continents. Palaeontology 14: 131-153.

- - - 1973. Paleoclimatology and continental drift. *In*: D.H. TARLING, and S.K. RUNCORN, (eds.) Implications of Continental Drift to the Earth Sciences, Academic Press, London 451-476.

RONA, P.A., 1982. Evaporites at passive margins, Geodynamics Series, Geol. Soc. Amer., 6: 116-132.

SUTTER, J.F. and T.E. SMITH, 1979. Ar/ Ar ages of diabase intrusions from Newark trend basins in Connecticut and Maryland: initiation of central Atlantic Rifting. Amer. Jour. Sci., 279: 808-831.

TOZER, E.T., 1979. Latest Triassic ammonoid faunas and biochronology, western Canada. Geol. Surv. Can. Pap., 79-aB: 127-135.

TRAVERSE, A., 1983. Fundy Group palynoflorules on the northern margin of the Bay of Fundy, New Brunswick, Canada. Northeastern Sect., Geol. Soc. Amer. Abst., 15 (3): 122.

TRUSWELL, E.M., 1981. Pre-Cenozoic palynology and continental movements. *In*: M.W. McELHNNY (ed.) Paleoreconstruction of the continents. Geodynamics Series, Geol. Soc. Amer., 2: 13-25.

VAN HINTE, J.E., 1976. A Jurassic time scale: Amer. Assoc. Petrol. Geol. Bull., 60: 489-497.

VAN HOUTEN, F.B., 1977. Triassic-Liassic deposits of Morocco and eastern North America. Assoc. Petrol. Geol. Bull., 61: 79-99.

WARD, L.H., 1900. The older Mesozoic, in Status of the American flora of the United States: United States Geological Survey 20th Annual Report, pt. 2: 213-748.

WEBB, J.A., In Press. The radiometric time scale for the Triassic: Jour. Geol. Soc. Australia.

WILLARD, B., J. FREEDMAN, D.B. MCLAUGHLIN, and others, 1959. Geology and mineral resources of Bucks County, Pennsylvania. Penn. Geol. Surv. 4th ser., Bull., C9: 243 p.