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Reports

Cyclic Change in Late Triassic Lacustrine Communities

Abstract. *A new type of lake and shore assemblage has been found in the Late Triassic age rocks of North Carolina and Virginia (Dan River group). It includes abundant aquatic reptiles, fishes, at least seven orders of insects, crustaceans, and a diverse flora. Cyclic changes in the fauna and flora correlate with sedimentary cycles, which together reflect the repetitive development and extinction of large meromictic lakes.*

Evolutionary events of great moment, including the origin of mammals and teleosts, the rise to dominance of dinosaurs, and one of five commonly cited mass extinctions (*1*) took place during the Late Triassic against an ecological background which for continental environments has been known only at a very coarse level (*2*). A newly discovered Late Triassic lacustrine sequence with unique and diverse fossil communities has produced a detailed, perhaps year-by-year, record of this complex and critical period over hundreds of thousands of years.

This new assemblage occurs in the upper member of the Late Triassic Cow Branch formation of North Carolina and Virginia [Dan River group (*3*) and Newark supergroup (*4, 5*)] and consists of a large association of insects (seven orders), abundant remains of the only New World tanystropheid reptile, a phytosaur, dinosaur footprints, five genera of fishes, conchostracans, a phyllocarid, and at least 16 species of plants. In this report we outline the geology of the fossil locality and briefly describe the fauna and flora. Finally, the composition of the preserved biota is put into its sedimentological context, which gives the first reconstruction of fine-scale cyclic change in Triassic lacustrine communities.

The Dan River group (Fig. 1) is preserved in the Dan River Basin (trending southwest-northeast), which, like other Newark supergroup basins, developed on the northern flank of a broad fracture system formed during an early tectonic phase leading to the opening of the Atlantic and the separation of North America and Africa (*5*). The Cow Branch formation (Fig. 1) is composed of immense lenses of lacustrine sediments surrounded in time and space by fluviatile, mud-flat, and deltaic deposits [the Stoneville and Pine Hall formations (Fig. 1)]; near the site described here, the Cow Branch formation consists of two such members (= lenses). Evidence for the age relationships of the upper member of the Cow Branch formation is provided by the fauna and flora. The fishes and the phytosaurs strongly suggest a correlation with the Lockatong formation of the Newark Basin (Newark supergroup) and the upper part of the Chinle formation of the southwestern United States (*6*). The flora of the Cow Branch formation (*7*) and palynofloras from the Lockatong and Chinle formations (*8*) show these to be Carnian (early Late Triassic) in age. The Cow Branch formation is composed almost entirely of asymmetrical sedimentary cycles (*3*) (Fig. 1). They are all fossiliferous to some extent, three cycles being extremely rich (the cycles designated CB1-2, CB1-3, and CB1-16). These are exposed along with 15 other cycles (Fig. 1) at a locality here called CB1 in the upper member of the Cow Branch formation (*9*). Virtually all black shale formations of the Newark supergroup consist of similar sedimentary cycles (*10*), although the changes in faunal and floral composition through these cycles have never been described.

By far the most abundant vertebrate at CB1 is a new eosuchian reptile (*11*) closely allied to *Tanystropheus* (Middle Triassic of Europe) but smaller than it by an order of magnitude. This new reptile has a long neck and gracile proportions (Fig. 2, A–C) and can be distinguished from *Tanystropheus* by its very long limbs and relatively shorter cervical vertebrae which bear short, plowshare-shaped ribs posteriorly (Fig. 2A). This presumably aquatic eosuchian reptile (*11*) is about three times as common as all fish together in cycles CB1-2 and CB1-3 (*12*).

Three other types of reptile fossils occur in CB1. Teeth referable to the phytosaur *Rutiodon* have been found in cycles CB1-2 and CB1-3 (*13*), and a variety of small theropod dinosaur footprints (*Grallator* spp.) and phytosaur footprints (*Apatopus* sp.) occur in the upper parts of cycles at CB1 (Fig. 2, D–H).

Five genera of fishes, closely resem-

Tables 1. List of genera and species of plants to which specimens from CB1 have been referred.

Plant taxa present	YPM No. (paleobotany collection)
Lycopodiales (lycopods)	
cf. *Grammaephloios* sp.	230
Equisetales (scouring rushes)	
Neocalamites cf. *knowtonii* Berry	231
Filicales (ferns)	
Lonchopteris virginiensis Fontaine	232
cf. *Acrostichites linnaeafolius* (Bunbury) Fontaine	233
Dictyophyllum sp. (*30*)	234
Caytoniales (Mesozoic seed ferns)	
cf. *Sagenopteris* sp.	235
Coniferales (conifers)	
Glyptolepis cf. *G. platysperma* Mägdefrau (*31*)	236
Pagiophyllum sp. A (*27*)	237
Pagiophyllum sp. B (*32*)	238
Pagiophyllum sp. C (*33*)	239
Pagiophyllum cf. *Brachyphyllum conites* Bock	240
cf. *Compsostrobus neotericus* Delevoryas and Hope (*34*)	241
cf. *Dechellyia* sp. (*35*)	242
Podozamites sp. (*36*)	243
Bennettitales (cycad-like seed plants)	
Zamites powellii Fontaine (*37*)	244
Pterophyllum cf. *Ctenophyllum giganteum* Fontaine	245
Cycadales (cycads)	
cf. *Zamiostrobus lissocardus* Bock	246
Glandulozamites sp. (*38*)	247
Large androsporophylls?	248

Scoreboard for Reports. The acceptance rate for Reports during the last year has been about 25 percent. The number accepted has exceeded the number published, and publication delay has increased to about 4 months. For the next few months, our acceptance rate will be about 15 percent, or 10 Reports per week.

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bling those of the Lockatong formation (*14*), are associated with the new reptile at CB1. Most common are specimens of an unidentified holostean, possibly a pholidophorid (*15*); also common are morphologically diversified paleoniscids belonging to the genus *Turseodus* and the holostean *Semionotus brauni*. Several partial skeletons of the subholostean *Synorichthys*, and one very large specimen of the coelacanth *Diplurus newarki*, have also been recovered (Fig. 2, I-L).

In contrast to the other major animal taxa at CB1, the insects are remarkably diverse. In the collection there are over 300 specimens, more than 200 of which are aquatic Hemiptera. Close examination of the best preserved of the remaining specimens shows that few are convincingly conspecific. This diversity is unfortunately offset by the nature of the preservation (*16*) which obscures certain key characters.

This is the only substantial insect fauna of Triassic age known from North America and the only large Late Triassic assemblage in the world other than that of Issyk-Kul (*17*) (Russia and Central Asia), some taxa of which seem similar to CB1 forms. Almost half the taxa present at CB1 seem to be Coleoptera (Fig. 3, F-H), and a surprisingly large proportion are whole insects rather than the more usual isolated elytra. Although the ventral characters critical for placement of these beetles in families are not visible, some individuals suggest modern Buprestidae (metallic wood-boring beetles) and Nitidulidae (sap beetles). The most abundant individual specimens of insects are Heteroptera (Fig. 3, D and E), mostly referred to as the Hydrocorisae (water bugs). The best-preserved insect specimens, however, are definitely Diptera (true flies) (Fig. 3A), some Nematocera resembling Tipulidae (crane flies), and Bibionidae (March flies): these appear to be the oldest known New World Diptera. The Psocoptera are indicated by a single complete specimen, and the extinct order Glosselytrodea (*18*) is suggested by the venation of one wing fragment (Fig. 3C). Other specimens appear to be Neuroptera (Fig. 4B), and some are tentatively assigned to the Blattaria (roaches) although these too may prove to be Heteroptera.

The CB1 insect fauna seems to have included at least two major components: one, the water bugs and the tipulids, appears to be tied to a lacustrine environment; and the other, buprestid and nitidulid beetles and the March flies, suggests a forest assemblage (*19*). Interestingly, the only definite insect juveniles found are water bugs (Fig. 3D), an indication that, with the exception of these forms, the known insects probably drifted in with dead vegetation and algal flotants or were blown in over the water as adults.

Other invertebrates from CB1 are two forms of conchostracans and possibly a new phyllocarid. The larger of the two conchostracans is *Cyzicus* sp., probably *C. princetonensis* (*20*) (Fig. 4C). The smaller form is the most common invertebrate at CB1 (Fig. 4B) and resembles *Palaeolimnadia* (*21*) from the Triassic of Germany and Australia, but a positive identification cannot be made. The new "phyllocarid" shows few diagnostic characters (Fig. 4A) but most closely resembles, in its overall form, the otherwise Carboniferous family Sairocarididae (*22*).

Plant remains from CB1 are diverse (Table 1) and are preserved as silvery compressions with only the vascular material intact. Study of more than 80 specimens reveals the probable presence of horsetail rushes, lycopods, ferns, Caytoniales, conifers, Bennettitales, and cycads. However, identification is based only on gross similarity, without the aid of cuticle, which is necessary for positive identification in most cases. Table 1 is a list of genera and species to which

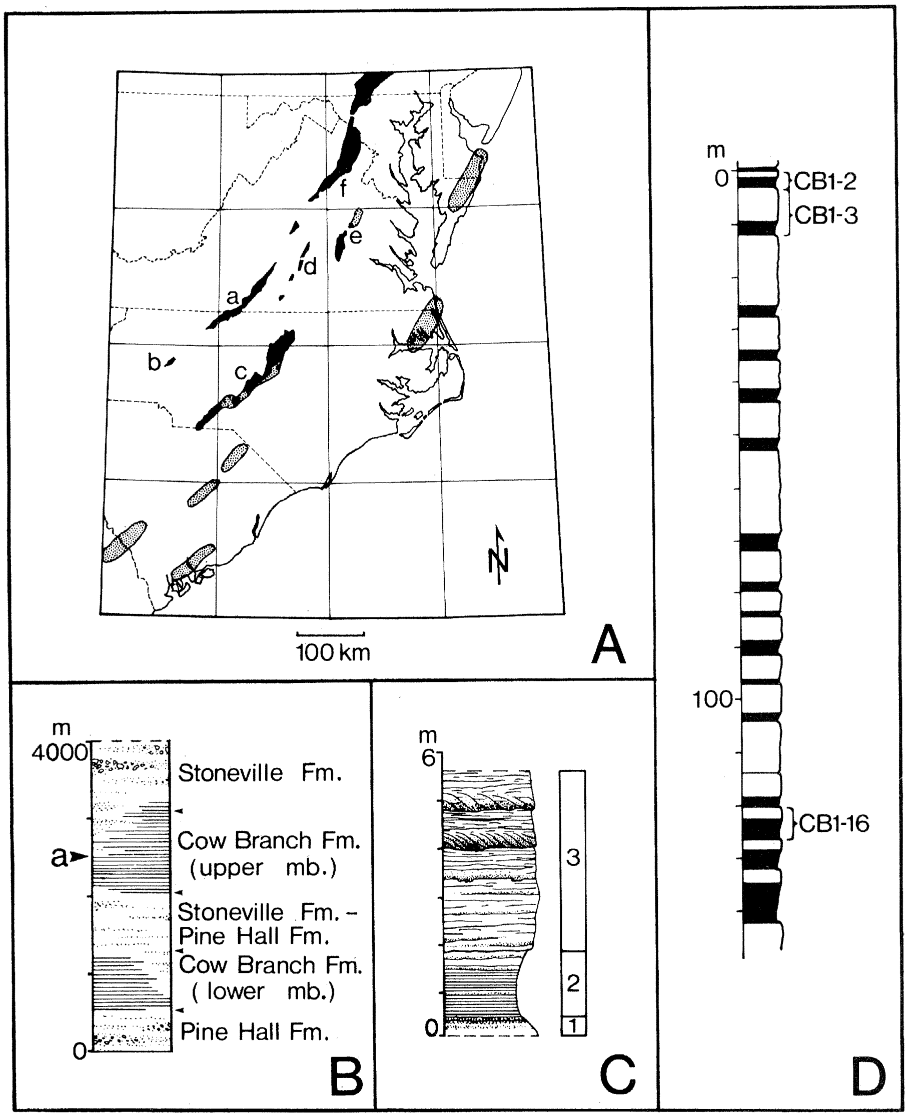


Fig. 1. (A) Map of the southeastern United States showing the outcrop (black) and subsurface extent (stippled) of the Newark supergroup (*39*): *a*, Dan River group; *b*, Davie County Basin; *c*, Chatham group; *d*, Farmville Basin and subsidiary basins to the south; *e*, Richmond Basin and Taylorsville group; and *f*, Culpeper Basin. (B) Diagrammatic cross section through the Dan River group (along the strike) showing the upper and lower members of the Cow Branch formation. The Stoneville and Pine Hall formations consist of coarse to fine buff, gray, and red clastics. The Cow Branch formation consists of mostly fine black and gray clastics. (C) Modal cycle of the upper member of the Cow Branch formation: division 1, gray to black calcareous siltstone with graded and current bedding; division 2, black platy to microlaminated calcareous siltstone; and division 3, gray siltstone and sandstone with current bedding and mud cracks. (D) Stratigraphic section at CB1 showing the position of cycles CB1-2, CB1-3, and CB1-16. Divisions 1 and 3 of the cycles are shown in white, and division 2 is shown in black.

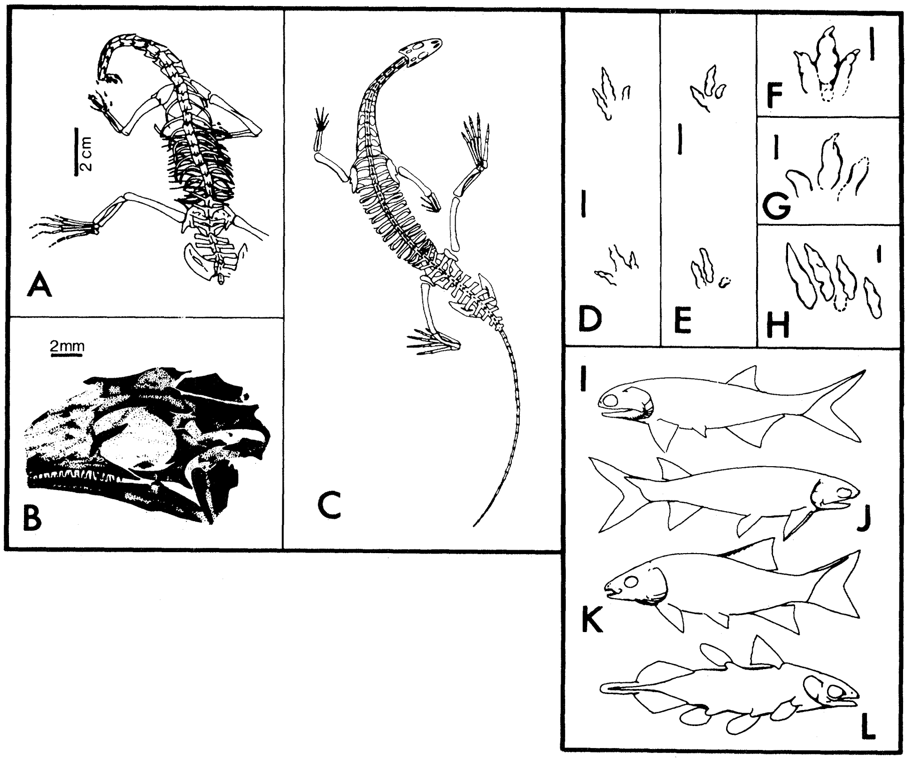
specimens have been tentatively referred.

Vertical changes in lithology provide the basis for interpreting the depositional environment and lake history for CB1 in terms of a modal cycle (*23*) of sedimentation (Fig. 1C). This type of cycle is virtually identical to those of the Lockatong formation of the Newark Basin (*9*), which have been interpreted as resulting from the waxing and waning of large lakes. According to this model of CB1 cycles, division 1 of the modal cycles was deposited as the lake level rose; division 2 formed during lake level maximum; and division 3 resulted from a sustained drop in water level with the eventual disappearance of the lake. Although this general model fits all the cycles of the upper member of the Cow Branch formation, the lithologic details of each cycle require individual historical interpretation.

Cycle CB1-2 has been studied more intensively than any other unit at CB1 (Fig. 5) and has provided most of the information on lake history in addition to the bulk of the fauna and flora. The key to understanding the history of the lake which deposited this cycle is the origin of unit b of the sequence (see Fig. 5). The delicate rhythmic laminations of this unit and the fauna contained in it (the individual members of which show little or no disruption) indicate an absence of bioturbation or physical disturbance (*24*). Sediments of this type are produced today in perennially stratified (meromictic) lakes, and such an origin is proposed for unit b. Varves, the microlaminated couplets now produced in such lakes (*25*), result from annual fluctuations in sedimentation. "Varve" counts show that unit b was deposited over a minimum of 780 years.

With this interpretation, the entire CB1-2 section can be placed in context. Unit a was produced by deposition in shallow, relatively oxygenated benthos. As the lake level rose to its maximum, meromixus (stratification) of biogenic origin set in, and this area (CB1) experienced the transgression of the anoxic monomolimnion (H_2S-enriched bottom waters) yielding unit b. Units c and d (Fig. 5) were deposited as the lake became more shallow and productivity increased. The lack of fine laminations in units c and d implies delicate bioturbation and a breakdown of stratification. As the lake became very shallow, it became playa-like, the fauna and flora became impoverished, and unit e was deposited. The common presence of clusters of allochthonous quartz grains in this fine-grained unit suggests rafting by algal flotants. Finally, mud-flat deposition dominated lacustrine sedimentation for unit f as the lake dried up completely.

The fauna and flora of cycle CB1-2 show a transition in composition which parallels the lithologic change due to the rise and fall of the lake. Thus, insects, fish, and tanystropheid reptiles are present only in unit b, that bed deposited during maximum lake transgression. The preservation of insects in the lower 2 cm of unit b depended on burial away from physical disturbance and scavengers and on proximity to the lakeshore (where insect density would be highest). Therefore, the greatest probability of insect preservation occurred just after the transgression of the monomolimnion. Surprisingly, tanystropheid skeletons are dispersed through 32 cm of the varved siltstone of unit b, and so their considerable density (*12*) cannot be explained on the basis of simple mass mortality (*26*). Perhaps fluctuations in reptile



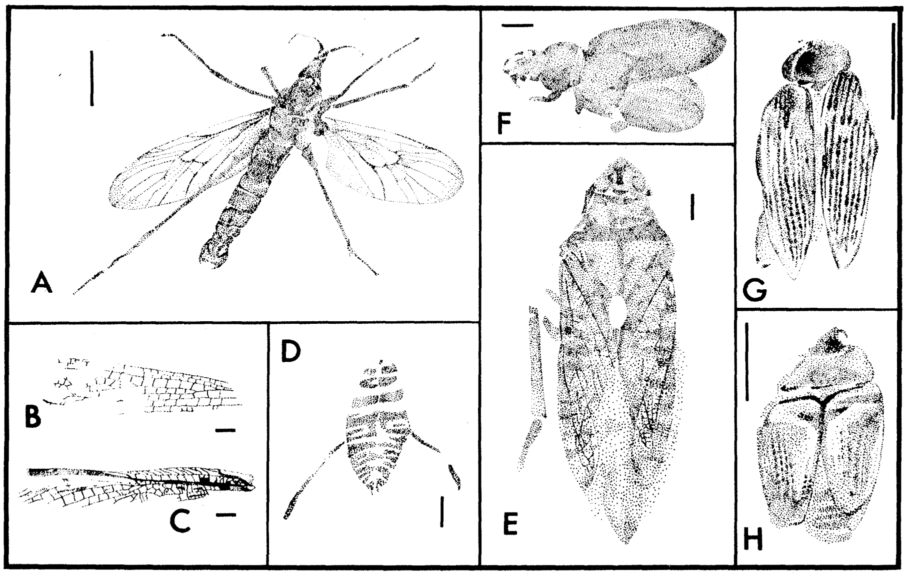
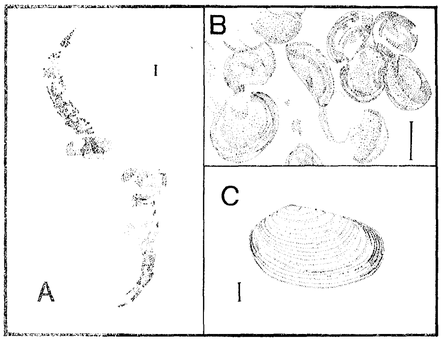


Fig. 3. Insects of CB1 with tentative determinations. (A) Diptera, Tipulidae? (YPM 16826); (B) Neuroptera, wing fragment (YPM 16831); (C) ?Glosselytrodea, wing fragment (YPM 16829); (D) Heteroptera, Hydrocorisae, juvenile (YPM 16837); (E) Heteroptera, Hydrocorisae, adult (YPM 16830); (F) Coleoptera (unspecified) (YPM 16838); (G) Coleoptera, ?Buprestidae (YPM 16827); and (H) Coleoptera, ?Nitidulidae (YPM 16828). Scale, 1 mm, drawn with the use of a microscope drawing tube.



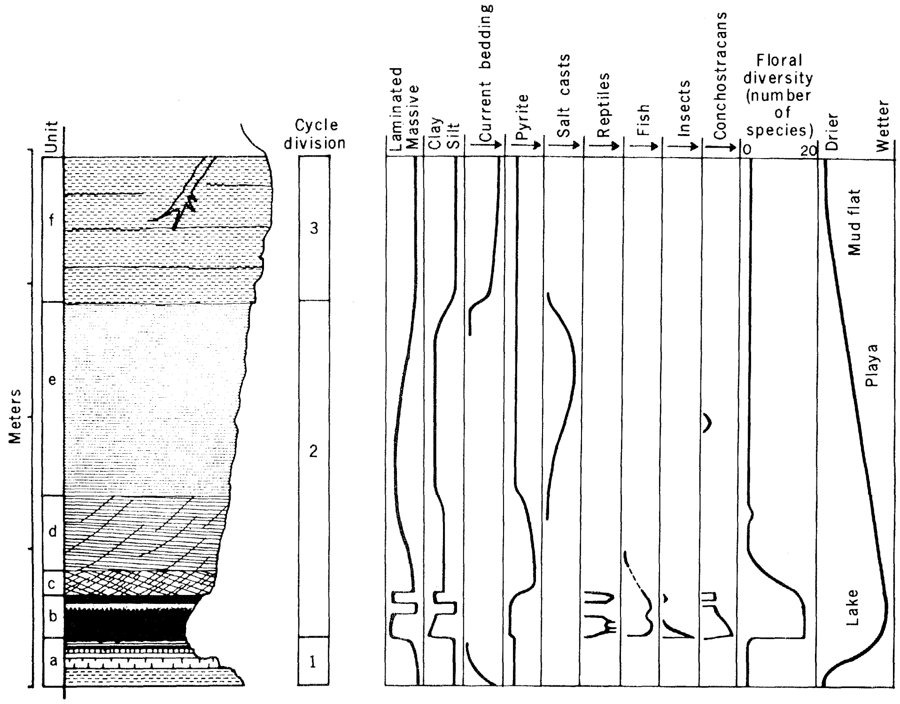


Fig. 4 (left). Other arthropods from CB1. (A) New ?phyllocarid (YPM 16836); (B) cf. *Palaeolimnadia* sp. (YPM 16834); and (C) *Cyzicus* cf. *princetonensis* (YPM 16835). Scale, 1 mm, drawn with the use of a microscope drawing tube. Fig. 5 (right). Stratigraphic section of cycle CB1-2 showing the change in certain key properties (arrow indicating the direction of increase). "Cycle division" refers to the divisions of the modal cycle (Fig. 1C), and "unit" refers to the following: *a*, black and dark gray micaceous siltstone and calcareous fine siltstone with some graded bedding; *b*, black, microlaminated calcareous siltstone; coarse graded siltstone near the top; *c*, black pyritic, well-bedded siltstone, intensely slickensided and disturbed; *d*, black, pyritic, well-bedded siltstone with common slickensided bedding planes; *e*, microlaminated siltstone with numerous crumpled casts of a salt; and *f*, gray, well-bedded siltstone with scour marks on bedding planes and large plant stems in growth position.

density reflect an aspect of behavior (such as schooling) and changes in the distribution of their food source, probably insects.

In unit a the flora consists of a single type of conifer (*27*). As the sediments change to the deepwater facies (unit b) cycadophytes, more species of conifers, ferns, equistetaleans, and lycopods appear. This increase in diversity indicates an amelioration of conditions around the lake. Floral diversity drops as the lithology changes upward to units c and d, and conifers (predominantly *Pagiophyllum* spp.) once again become dominant. The presence of what seem to be large stems and roots in situ suggests the existence of mud-flat conditions with infrequent flooding at the top of the cycle.

Perhaps the most interesting aspect of the CB1 site is that similar vertical changes in the fossil assemblages can be seen in many other cycles: the correlated transitions in lithology and biota seem to be characteristic of the modal cycle of this formation. Thus, tanystropheids, insects, and phyllocarids have been found in the basal portions of division 2 of cycles CB1-2, CB1-3, and CB1-16; in addition, fishes and conchostracans can be found in division 2, and reptile footprints (proving exposure or very shallow water) can be found in division 3 of cycles at nearly every exposure of the upper member of the Cow Branch formation (Fig. 1B). It is possible that there are specific differences among taxa in the same phase of different cycles.

The vertical changes in floral diversity through cycle CB1-2 (and other cycles) are most easily explained in terms of climatic change such as temperature or rainfall fluctuations, which, in turn, are controlled by the 21,000-year precession cycle. This explanation has been offered for the homologous cycles in the Lockatong formation (*28*). If the precession cycle did indeed control the rise and fall of these lakes, it places an absolute time scale on the sedimentary cycles and the whole sequence of events at CB1. The well-bedded cyclic upper member of the Cow Branch formation was probably deposited during a period of relative tectonic calm, for only during such periods could transitory climatic cyles have a consistent influence on lithology. The great proportion of the coarser Pine Hall and Stoneville formations (Fig. 1B) were probably deposited during phases of relatively high activity. Thus the facies relationships of the Dan River group resulted from periodic climatic fluctuations mediated by tectonic activity.

Interpretations of the position of eastern North America during the Late Triassic (*5*) place the Dan River group just north (about 10°) of the paleoequator: during the wetter parts of climatic cycles, the climate was warm and humid. We can imagine a large stratified lake surrounded by a strand tangled with hydrophilic plants, which gave way to highlands clothed in conifers. Insects of modern aspect populated the forests and shores or swam in the shallows along with great swarms of planktonic conchostracans and occasional phyllocarids; they supported the fish and tanystropheid reptiles which, in turn, were devoured by phytosaurs and other tetrapods. The lake, however, never stayed at maximum for more than a few thousand years; its depth and salinity changed with the climate, and as a result the fauna and flora shifted in composition. Within the section at CB1 alone, the lake cycled at least 18 times over a period of more than 370,000 years. Our understanding of the stratigraphy and depositional environment has now reached the level where excavations of individual cycles through these types of sequences will provide a record of communities responding to periodic stress on a microevolutionary level. Similar lacustrine sequences occur in most of the other basins of the Newark supergroup, and additional study will provide a look at fossil associations cycling on through the more than 35 million years of Newark deposition (*29*).

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2. For a discussion of the problems associated with looking at fossil communities through the Triassic, see C. B. Cox, in *The Fossil Record* (Geological Society of London, London, 1967), pp. 77–89.
3. P. A. Thayer, *Southeast. Geol.* **12**, 1 (1970); ______, D. S. Kirstein, R. L. Ingram, *Carolina Geological Society Field Trip Guidebook* (Carolina Geological Society, Raleigh, N.C., 1970).
4. P. E. Olsen, *Newsl. Stratigr.*, in press.
5. F. B. Van Houten, *Am. Assoc. Pet. Geol. Bull.* **61**, 79 (1977).
6. Four-fifths of the fish fauna in the Cow Branch formation is shared with the Lockatong formation and three-fifths with the Chinle formation.
7. The possible presence of *Glyptolepis platysperma* implies Middle Keuper age, possibly late Carnian, whereas the presence of *Zamites powellii* and *Dechellyia* seems to collaborate a Chinle correlation.
8. The age for the Chinle formation is based on palynological work by B. Cornet (in preparation) and R. E. Dunay, and M. J. Fisher [*Rev. Palaeobot. Palynol.* **17**, 197 (1974)]. The age of the Lockatong formation is based on a typical late Carnian palynoflora, which is dominated by *Patinosporites densus* and *Triadispora* spp. recovered from the upper part of the formation; *Camerosporites pseudoverrucatus* is also present [see B. Cornet, in *Geobotany*, R. C. Romans, Ed. (Plenum, New York, 1977), pp. 165–172].
9. The owners of this locality wish its exact location to remain unpublished; therefore, a code is used here, the key to which is recorded in the archives of the Peabody Museum of Natural History of Yale University (YPM).
10. F. B. Van Houten, in *Geology of Selected Areas in New Jersey and Eastern Pennsylvania and Guidebook of Excursions*, S. Subitzky, Ed. (Rutgers Univ. Press, New Brunswick, N.J., 1969), pp. 313–347.
11. On the basis of the skull, vertebral column, and pes, the new reptile is asigned to the family Tanystropheidae, suborder Prolacertiformes, of the order Eosuchia. This reptile is described in detail by P. E Olsen, *Postilla*, in press.
12. Reptiles occur with a density of about 37 per square meter, whereas fish occur at 10 per square meter in unit b of cycle CB1-2.
13. YPM 7500 and 7627.
14. B. Schaeffer and M. Mangus, *J. Paleontol.* **44**, 17 (1970).
15. All the specimens (including YPM 7553, 7573, and 7574) are very difficult to prepare; the only characters visible at this time are large rhombic ganoid scales, a hemiheterocercal caudal fin, ossified ring centrums, and a long mandible. Other fish genera present are *Turseodus* sp. (YPM 7457 and 7476), *Semionotus brauni* (YPM 7479, 7481, and 7901, *Diplurus newarki* (YPM 7516), and *Synorichthys* sp. (YPM 7576).
16. Specimens are preserved as silvery compressions with almost no relief and can be examined only under a wetting liquid such as glycerol.
17. B. Rohdendorf, *J. Paleontol. (U.S.S.R.)* **3**, 90 (1961); *The Historical Development of Diptera*, J. E. Moore and I. Thiele, Transls. (Univ. of Alberta Press, Alberta, 1974).
18. O. V. Martynova, *Bull. Acad. Sci. U.R.S.S. Ser. Biol.* **1938**, 187 (1938).
19. H. Oldroyd, *The Natural History of Flies* (Norton, New York, 1964); F. C. Craighead *et al.*, *Insect Enemies of Eastern Forests* [U.S. Dep. Agric. Misc. Publ. 657 (1950)].
20. The larger conchostracan is identical to W. Bock's *Howellisaura (Howellites) princetonensis* [*J. Paleontol.* **27**, 62 (1953)], which P. Tasch synonymizes with *Cyzicus* [in *Treatise on Invertebrate Paleontology*, R. C. Moore, Ed. (Geological Society of America, Boulder, Colo., 1969), pp. R128–R191)].
21. The smaller CB1 conchostracan is preserved without relief or detail. The resemblance to *Palaeolimnadia* [P. E. Raymond, *Bull. Mus. Comp. Zool. Harv. Univ.* **96**, 218 (1946); J.-C. Gall, *Mem. Serv. Carte Geol. Alsace Lorraine* **34**, 1 (1971)] is based only on gross form and size.
22. F. R. Schram, *Fieldiana Geol.* **27**, 77 (1973); W. D. I. Rolfe, *J. Paleontol.* **37**, 486 (1963).
23. The modal cycle is a generalization which best fits the observed section [P. M. Duff, A. Hallam, E. K. Walton, *Cyclic Sedimentation*, vol. 10, *Developments in Sedimentology* (Elsevier, Amsterdam, 1967)].
24. G. R. Davies and S. D. Ludlam, *Geol. Soc. Am. Bull.* **84**, 3527 (1973).
25. S. D. Ludlam, *Limnol. Oceanogr.* **14**, 846 (1969); see H. P. Eugaster and A. Hardie [*Geol. Soc. Am. Bull.* **86**, 1 (1975)] for a different interpretation of these types of microlaminated sediments.
26. Peaks of reptile density occur at 1.0, 4.8, 7.0, and 30.5 cm above the base of unit b of cycle CB1-2, but even in these thin zones reptile skeletons are found through several "varves," a possible indication that these fluctuations represent changes in the density of locally living reptile populations.
27. Most common conifer at cycle CB1-2; the leaves are variable, almost spherical to elongate, 1 to 3 mm long.
28. Similar cycles occur in the Early Jurassic East Berlin formation (Newark supergroup) [J. F. Hubert, A. A. Reed, P. J. Carey, *Am. J. Sci.* **276**, 1183 (1976)], the Devonian Caithness Flagstones of Scotland [C. B. Crampton, R. G. Carruthers, J. Peach, N. B. Flett, E. M. Anderson, [*Geol. Surv. G. B. Mem. Geol. Surv. Scot.* (1914)], and the Eocene Green River formation of Wyoming [W. H. Bradley, *U.S. Geol. Surv. Prof. Pap. 158E* (1929), p. 87]. These types of cycles may, like the cycles of the Lockatong formation, be produced by climatic changes governed by the precession cycle. Since such control has been plausibly argued for the Pleistocene glacial periods as well [J. D. Hays, J. Imbrie, N. J. Shackleton, *Science* **194**, 1121 (1976)], climatic control of this sort may be characteristic of the entire Phanerozoic.
29. That is, the Late Triassic in addition to the Early Jurassic is about 35 million years.
30. Similar to *D. exile* (Brauns) Nathorst, but each arm of the rachis possesses about 25 pinnae.
31. A single ovuliferous scale comparable to plate 4, figure 1 of K. Mägdefrau, *Geol. Bl. Nordost Bayern* **13**, 95 (1963).
32. *Stachyotaxus*-like foliage, much smaller than *Pagiophyllum* sp. C.
33. Superficially resembles *Stachyotaxus elegans* Nathorst.
34. Associated foliage and possible seed cones.
35. Associated seeds and foliage; seeds differ from *D. gormanii* Ash in that they have numerous veins in lanceolate lamina; *Equisetosporites* pollen, possibly produced by this type of plant, is occasionally found in Carnian strata of the Newark supergroup [see S. R. Ash, *Palaeontology* **15**, 598 (1972)].
36. Isolated leaves, 6 to 14 cm long, tapering at both ends, with about 21 parallel veins.
37. Most common cycadophyte at cycle CB1-2, frequently present as isolated pinnae and large fragments of fronds [see S. R. Ash, *Palaeontogr. Abt. B Palaeophytol.* **149**, 139 (1975)].
38. One leaf with a characteristic surface pattern of "bumps"; the leaf is 4.5 cm long and 2.2 cm wide, tapering proximally and blunt distally.
39. Data for the Taylorsville group and subsurface units are from R. Weems, in preparation; I. W. Marine and G. E. Siple, *Geol. Soc. Am. Bull.* **85**, 311 (1974).
40. Adapted from B. Schaeffer, *Bull. Am. Mus. Nat. Hist.* **135**, 285 (1967); *ibid.* **99**, 29 (1952).
41. We are grateful to the owners of the CB1 site for permission to excavate and for their help during the fieldwork. We also thank the following for their help in the excavation of the site, other field assistance, discussions on the subject, or criticisms of the manuscript: D. Baird, R. Broumbough, F. Carpenter, J.-C. Gall, C. H. Gover, W. Hartman, J. Hubert, G. E. Hutchinson, J. I. Johnson, P. H. Knappenberger, A. J. Litt, N. G. McDonald, A. R. McCune, J. H. Ostrom, K. Padian, S. P. Rachootin, J. Rodgers, R. Salvia, B. Schaeffer, P. Thayer, and K. Waage. This work was made possible by grant BMS 74-07759 from the National Science Foundation to K.S.T.

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A Search for Ultra-Narrowband Signals of Extraterrestrial Origin

Abstract. *Nearly 200 nearby stars similar to the sun were observed at the 21-centimeter neutral hydrogen wavelength (in the heliocentric frame) with a bandwidth of 1 kilohertz and a resolution of 0.015 hertz, using the Arecibo 305-meter antenna. At this resolution the effects of terrestrial interference are so slight that the detection limit of 4×10^{-27} watt per square meter was set by receiver noise alone. No evidence of artificial signals was found.*

A search for extraterrestrial intelligence (SETI) has been carried out at the National Astronomy and Ionosphere Center (NAIC) at Arecibo, Puerto Rico, based on a particular set of assumptions about the probable nature of signals that might be received. Although these ideas are not new (*1*, *2*), the survey itself was several orders of magnitude more sensitive than any SETI activity previously reported (*3*).

Briefly stated, this is the assumed scenario.

1) A narrowband acquisition beacon is transmitted near the neutral hydrogen frequency (21 cm, 1420 MHz); extremely narrow bandwidths would provide the simplest means of achieving a high signal-to-noise ratio, as well as suggesting the presence of artificial signals. The logic for this choice of frequency, originally put forth by Cocconi and Morrison (*4*), still seems strong, in spite of subsequent arguments: hydrogen is the simplest and most abundant atom in the universe, its hyperfine transition results in a single line, which constitutes the most abundant photon in the universe, and that line falls near the frequency of minimum background noise.

2) The beacon is directed at individual "interesting" targets, rather than being transmitted omnidirectionally; the presumption is that a superior knowledge of the processes of stellar and planetary evolution and of the evolution of life allows the transmitting civiilization to reduce its list of targets to a relatively small number. This assumption is required for the last step, which follows.

3) The beacon is transmitted at a frequency such that it arrives in our solar system at the laboratory hydrogen-line frequency, thus simplifying our search; the presumption is that a superior technology has given the transmitting civilization accurate observational values of the radial velocity of our sun. [Continued