Paleontology and paleoecology of the Newark Supergroup (early Mesozoic, eastern North America)

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ABSTRACT

The diverse depositional environments and rich fossil assemblages of the early Mesozoic Newark Supergroup of eastern North America can be subdivided into six broad environmental categories ranging from fault-scarp breccias in synsedimentary grabens developed directly along master boundary fault zones to deep-water zones of lakes. Each environmental category is characterized by its own range of taxa and modes of preservation. Environmental zones, except those directly caused by faulting, shifted laterally as lake levels rose and fell. Overt analogy between the lower trophic levels of aquatic ecosystems of modern lakes and those of the early Mesozoic is not appropriate. Diatoms were absent from the phytoplankton and large (0.3 – 1.0 cm) clam-shrimp comprised most of the zooplankton in Newark lakes, despite the abundant planktivorous fish.

Like their modern counterparts, however, early Mesozoic ecosystems responded to a hierarchy of extrinsic environmental perturbations. Longer-term perturbations which left marked records in Newark Supergroup records include cyclical climate change controlled by orbital variations and perhaps the consequences of an asteroid impact. These perturbations affected the evolution and extinction of organisms and the metabolism of ecosystems in ways that differ both in magnitude and kind. The evolution of fish species-flocks and mass extinction at the Triassic – Jurassic boundary are but two examples at distant ends of the spectrum.

Introduction

The Newark Supergroup of eastern North America (Fig. 8-1) consists of the remnants of the fill of rift basins formed during the 45 million years of crustal thinning and stretching which led up to the Middle Jurassic breakup of Laurasia and the formation of the earliest oceanic crust. Once thought to be nearly devoid of fossils, the Newark Supergroup is now known to be one of the world's richest early Mesozoic continental sequences. Diverse and in many cases remarkably well preserved plants, invertebrates, and tetrapods are known from the oldest through youngest beds and from many localities from Nova Scotia to South Carolina. Because of the remarkable stratigraphic and geochronologic properties of the lacustrine sediments which dominate the 13 major Newark Supergroup basins, and the very long time span during which these sediments were deposited, Newark fossils can be placed in an increasingly fine-scale sedimentological and paleoecological framework. In this paper, I outline the distribution of fossils in the Newark Supergroup in relation to different environments and different times, examine the differences between modern and Mesozoic lacustrine lower trophic levels, and outline a hierarchy of environmental perturbations which drove Newark Supergroup lacustrine ecosystem evolution.

Olsen, P. E., 1988, Paleoecology and Paleoenvironments of the Continental Early Mesozoic Newark Supergroup of Eastern North America: In Manspeizer, W. (ed.), Triassic-Jurassic Rifting and the Opening of the Atlantic Ocean, Elsevier, Amsterdam, p. 185-230.

Major environmental categories and their fossils

I have classified the wide range of Newark Supergroup geographic, depositional, and ecological settings into six environmental categories which represent zones around and in a deep lake developed in a half-graben (Fig. 8-2). They are organized in order from the most 'upland' environments through those of the 'lowland' and 'shallow lake' though 'deep lake'. Although it is likely that this full range of environments was occasionally present, a far more restricted range was more typical for any given lake.

At all times the lakes and their surrounding environments were in flux. This is evident because most Newark lacustrine sediments are composed of sedimentary cycles, called Van Houten Cycles (Van Houten, 1969; Olsen, 1980a, 1985b, 1986e, in prep. a). These were formed by the periodic rise and fall of lake level tied to variations in the earth's orbit in accord with the Milankovitch theory of climate change (Olsen et al., 1978; Olsen, 1980c, 1984a, b,

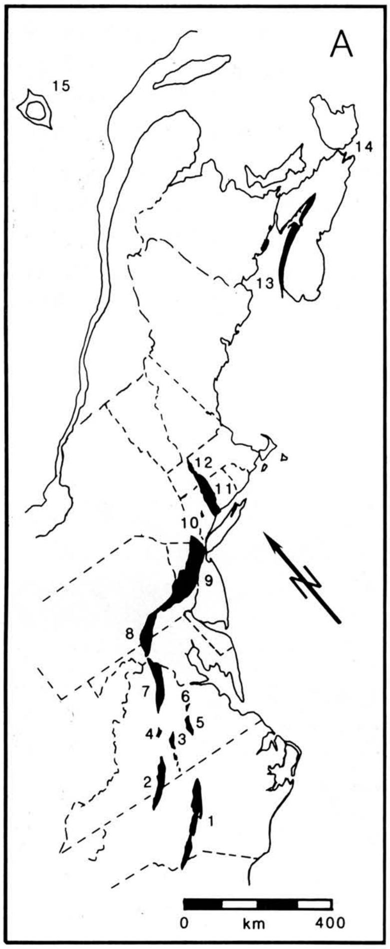

Fig. 8-1. The Newark Supergroup (black), showing the position of the Fundy Basin, other Newark Supergroup deposits, and the Manicouagan impact structure: *1* = Deep River basin; *2* = Dan River basin; *3* = Farmville and subsidiary basins; *4* = Scottville basin; *5* = Richmond basin; *6* = Taylorsville basin; *7* = Culpeper basin; *8* = Gettysburg basin; *9* = Newark basin; *10* = Pomperaug basin; *11* = Hartford basin; *12* = Deerfield basin; *13* = Fundy basin; *14* = Chedabucto basin (Orpheus graben); *15* = Manicouagan impact structure. Adapted from Olsen et al. (1987).

1986e, in prep. a). In addition, some environments, such as those producing coals or dune sands, may have been peculiar to the rift geometry, outlet position, geographic position, or altitude of individual basins.

Fault-scarp breccias and synsedimentary grabens

The basin edge and marginal fault zone of the Fundy basin in Nova Scotia, Canada are spectacularly exposed in the cliffs along the northern shore of the Minas basin and channel. In this area the Glooscap – Chedabucto geofracture (Keppie, 1982) forms the northern boundary of the basin and during the early Mesozoic this fault system exhibited left-lateral movement. Small synsedimentary basins developed along the fault zone with their long axes parallel to major left-lateral faults (Olsen and Schlische, in prep.).

The best exposed of these small basins occur in the Wasson Bluff area where the basal Hettangian (earliest Jurassic) North Mountain Basalt laps onto basement (Olsen, 1981). In this area the synsedimentary basins developed after the deposition of the North Mountain Basalt as half-grabens several hundred meters long and a hundred or so meters wide. The half-grabens filled with basalt talus and eolian material (Hubert and Mertz, 1981, 1984) within which four fossiliferous depositional environments are recognized: (1) Basalt slide blocks and basalt talus cones adjacent to basin-margin fault scarps; (2) lacustrine limestones and clastics and associated basalt talus cones; (3) lake-margin sands; and (4) eolian dunes with interdune areas. As these synsedimentary half-grabens formed adjacent to the main fault zone bordering the basin, they preserve elements of communities from as close to the highlands as we can expect to get. Only recently discovered (Olsen, 1986c; Olsen et al., 1986,

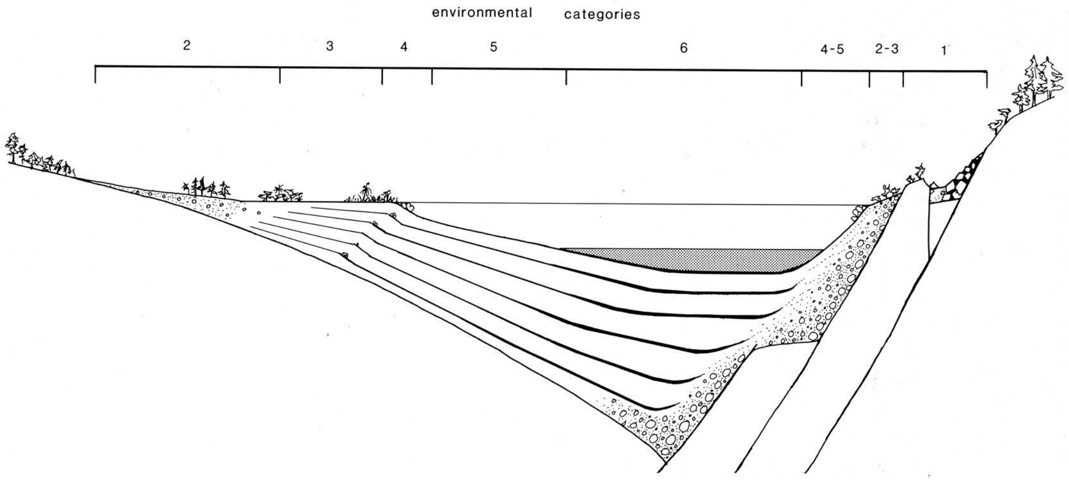

Fig. 8-2. Idealized and diagrammatic cross section of Newark Supergroup half-graben showing relationship of major environmental categories developed around and in a deep lake. Cross section is based mostly on combination of features seen in Newark and Fundy basins. These are organized in order from the most ‘upland’ environments through those of the ‘lowland’. Thick black lines indicate sediments deposited by deepest-water phase of lake; gray zone indicates zone of anoxic water. Environmental categories are: *1* = fault-scarp breccias and synsedimentary grabens; *2* = alluvial fans and river systems; *3* = swamp and marginal lake; *4* = deltas and shoreline; *5* = open/water, shallow lake; *6* = deep-water lake.

1987), this is the only Early Jurassic area in eastern North America which produces abundant and diverse skeletal remains of tetrapods.

Among the tetrapods, the sphenodontids such as cf. *Sigmala* (Figs. 8-4 and 8-5) and a possibly new protosuchid and sphenosuchid crocodylomorphs are numerically dominant, followed by the trithelodont mammal-like reptiles, prosauropod (cf. *Ammosaurus* – Fig. 8-4), a theropod, and 'fabrosaurid' ornithischian dinosaurs (Appendix I). The bulk of the tetrapod material consists of dissociated bones; however, partial to nearly complete skulls of sphenodontids and crocodylomorphs occur, and two skeletons of prosauropod dinosaurs have been found. One prosauropod skeleton is partially articulated and contains a cluster of 1 – 2 cm polished metamorphic clasts in the rib cage. As these are the only allochthonous clasts larger than sand grains present in the synsedimentary grabens, we can conclude they represent gastroliths used in the prosauropod crop. A *Sigmala* jaw was found with the

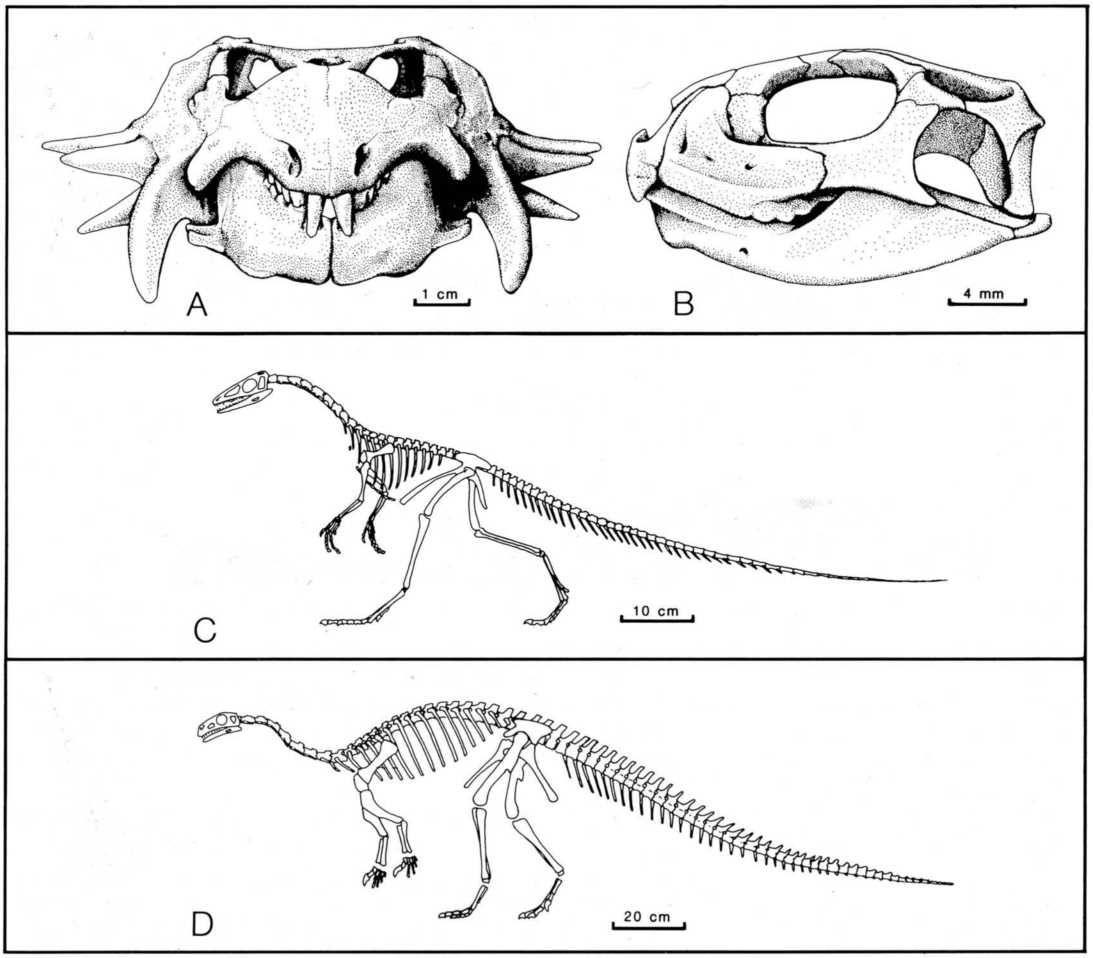

Fig. 8-3. Reptile skeletal remains from fluvial systems (A, C, D) and synsedimentary fault-margin graben.
A. The procolophonid reptile *Hypsognathus fenneri* of Late Triassic (Norian) age.
B. The sphenodontid reptile cf. *Sigmala* sp. of earliest Jurassic (early Hettangian) age.
C. The small theropod dinosaur *Podokesaurus holyokensis* from the ?lower Portland Formation of Early Jurassic age.
D. The prosauropod dinosaur *Ammosaurus solus* of Early Jurassic (?Toarcian) age.

gastroliths and it is apparently part of the prosauropod's last meal; formerly, many considered prosauropods to be completely herbivorous. Apart from the complete lack of any 'typical' Triassic forms such as procolophonids, phytosaurs, trilophosaurs, or labyrinthodont amphibians, the faunal assemblages of these synsedimentary grabens are similar to those from the British fissure fillings (Fraser and Walkden, 1983).

Associated lacustrine limestones and siltstones contain abundant disarticulated fish including *Semionotus* and hybodont shark teeth, and darwinulid ostracodes (Appendix) (Olsen and Baird, 1982). Plants are represented only by scarce root traces in the lacustrine marginal sandstones. It is not clear whether the lake waters which occasionally occupied these

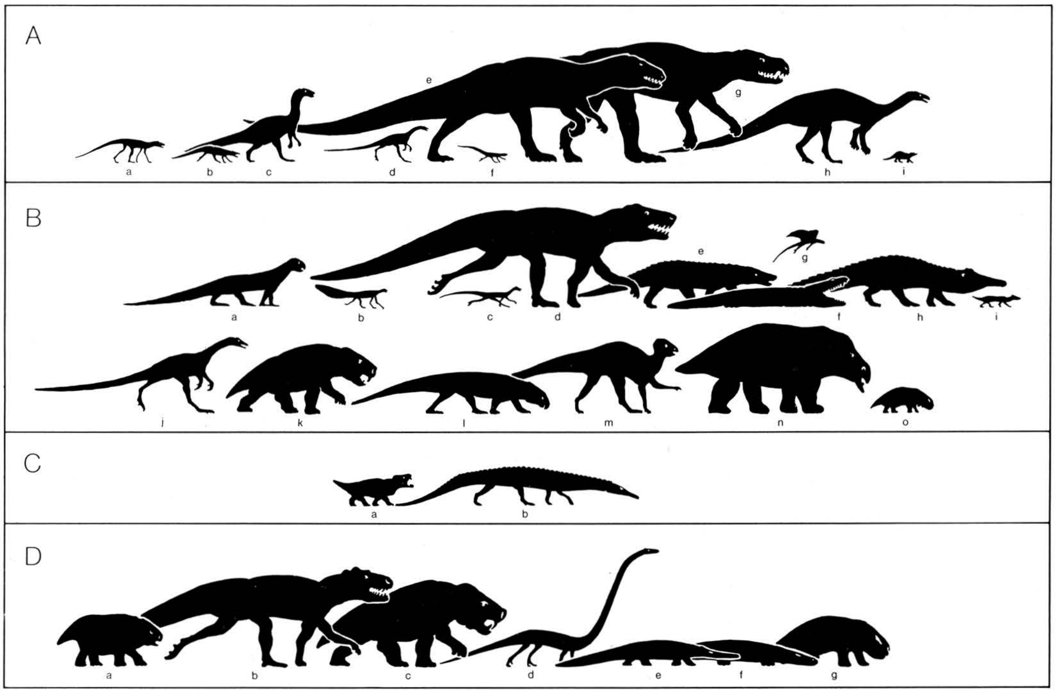

Fig. 8-4. Representative Triassic and Jurassic tetrapods from the Newark Supergroup.
A. Early Jurassic tetrapods: *a* = small sphenosuchid crocodylomorph; *b* = protosuchid crocodylomorph *Stegomosuchus*; *c* = 'fabrosaurid' ornithischian dinosaur; *d* = small theropod dinosaur *Podokesaurus*; *e* = large theropod dinosaur (known only from footprints); *f* = sphenodontid; *g* = trackmaker of *Otozoom*-type footprints, reconstructed as a large sphenosuchid crocodylomorph; *h* = prosauropod dinosaur *Ammosaurus*; *i* = trithelodont mammal-like reptile *Pachygenelus*.
B. Late Triassic (Middle – Late Carnian) tetrapods: *a* = trilophosaurid archosaur; *b* = 'deep-tailed swimmer'; *c* = tanystropheid *Tanytrachelos*; *d* = rauisuchid archosaur; *e* = aetosaurid archosaur *Stegomus*; *f* = labyrinthodont amphibian *Metoposaurus*; *g* = gliding lepidosaur *Icarosaurus*; *h* = phytosaur *Rutiodon*; *i* = chiniquodontid mammal-like reptile *Microconodon*; *j* = small theropod dinosaur cf. *Coelophysis*; *k* = traversodont cycnodont mammal-like reptile *Scalenodontoides*; *l* = rhynchosaur cf. *Paradapedon*; *m* = small ornithischian dinosaur; *n* = dicynodont mammal-like reptile *Placerias*; *o* = procolophonid *Leptopleuron*.
C. Early Late Triassic (Early Carnian) tetrapods: *a* = traversodont cycnodont mammal-like reptile *Massetognathus*; *b* = odd armoured archosauromorph *Doswellia*.
D. Middle Triassic (Anisian) tetrapods: *a* = dicynodont mammal-like reptile; *b* = rauisuchid archosaur; *c* = traversodont mammal-like reptile cf. *Exaeretodon*; *d* = tanystropheid lepidosaur *Tanystropheus*; *e* = labyrinthodont amphibian *Aphaneramma*; *f* = capitosaur labyrinthodont; *g* = procolophonid *Sclerosaurus*; *h* = trilophosaurid archosaur; *i* = aetosaurid archosaur.

synsedimentary basins were contiguous with larger lakes extending over the Fundy basin or were local ponds.

Alluvial fans and river systems

Newark Supergroup alluvial fan and river sequences never have been the subject of systematic collecting attempts [with the exception of Fundy basin (Baird and Take, 1959; Baird in Carroll, 1972; Baird and Olsen, 1983)]. On the other hand, fluvial deposits have produced a large variety of skeletal remains and footprints (Fig. 8-7) over the last century, and

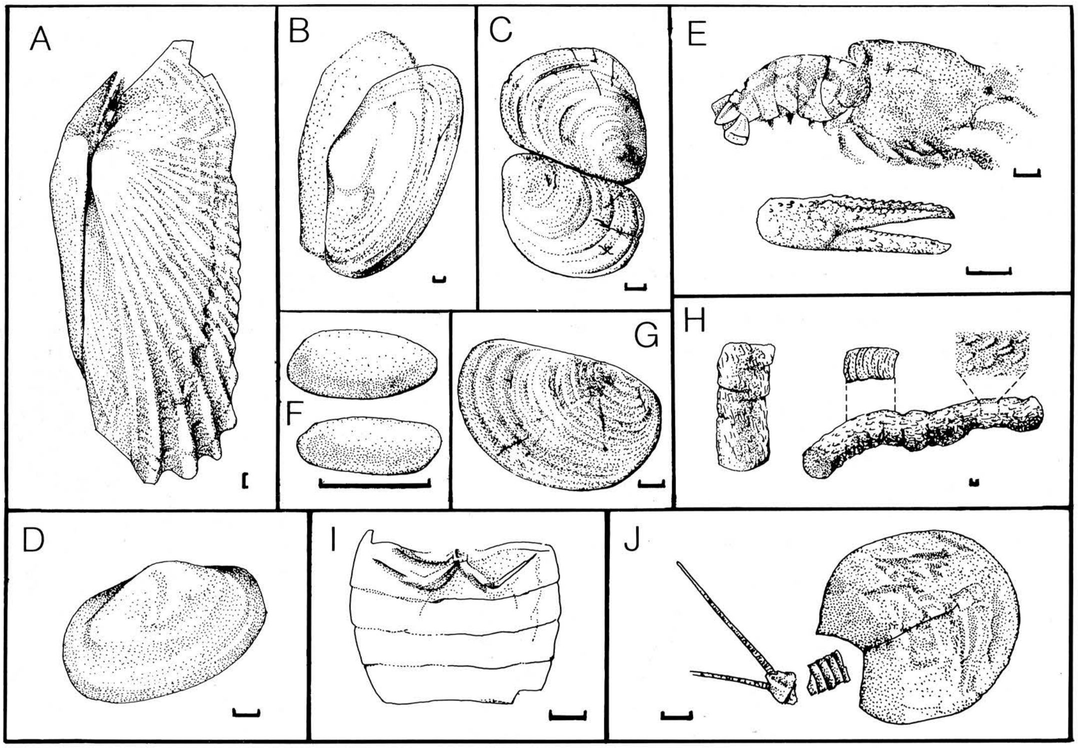

Fig. 8-5. Late Triassic age invertebrates from the delta and shoreline and the open water, shallow lake environments of the Newark Supergroup (scale is 1 mm).
A. Diplodontid (unionid) clam from probable siliclastic deltaic environment.
B. Unionid clam from open water, shallow lake environment.
C. Corbiculid clam from open water, shallow lake environment.
D. Unionid clam from open water, shallow lake environment.
E. Body and claw of astacoid decapod (cf. *Cytioclopsis*) from open water, shallow lake environment.
F. *Darwinula* - type ostracodes from open water, shallow lake environment.
G. *Cyzicus* - type clam-shrimp from open water, shallow lake environment.
H. Trace fossil *Scoyenia* possible from open water, shallow lake environment.
I. Insect (?water bug) abdomen from open water, shallow lake environment.
J. Notostracan crustacean *Triops* sp. from the open water, shallow lake environment.
A, D, from Late Carnian age Lockatong Formation of Newark Basin at Phoenixville, Penn. (from Olsen, 1980c); B, C, E – H, from the Late Carnian age ?Sanford Formation of the Durham subbasin of the Deep River basin at Genlee, N. C. (from Olsen, 1977); I, from the ? Middle Carnian age Briery Creek basin (?Middle Carnian), Hampden-Sydney, Va.; J, from the Norian Balls Bluff Formation of the Culpeper basin, Va. (drawn from Gore, 1986, fig. 3.2).

fluvial and alluvial fan deposits have been the major focus of sedimentological work (Arguden and Rodolfo, 1986).

As a rule, plant fossils are limited to rooted zones, comminuted hash, fusinized or silicified tree trunks, and pollen and spores. Invertebrates are largely limited to trace fossils (notably the arthropod burrow *Scoyenia* – Fig. 8-5), although thick shelled unidentified clams occur in Nova Scotian fluvial conglomerates. Skeletal material is not rare, ranging in completeness from abraded fragments to articulated skeletons (Fig. 8-3).

Early Middle Triassic age (Anisian) of Lower Economy, Nova Scotia comprise the oldest fossiliferous fluvial sequences (Baird and Olsen, 1983; Olsen and Galton, 1984; Baird, 1986b). Here fossiliferous calcite-cemented clay pebble conglomerates and sandstones are interbedded with eolian sandstones (Hubert and Mertz, 1981, 1984) in what may be another synsedimentary graben. Bones occur as clasts within the conglomerate. The assemblage is dominated by trematosaur (notably the long-snouted *Aphaneramma*) and capitosaur amphibians and procolophonids (Fig. 8-4, Appendix). The assemblage is similar to the upper Buntsandstein assemblage of Germany, also of Anisian age.

Skeletal assemblages from Late Triassic fluvial intervals are dominated by procolophonids, phytosaurs, aetosaur and rauisuchid pseudosuchians, and rhynchosaurs (Figs. 8-3 and 8-4)

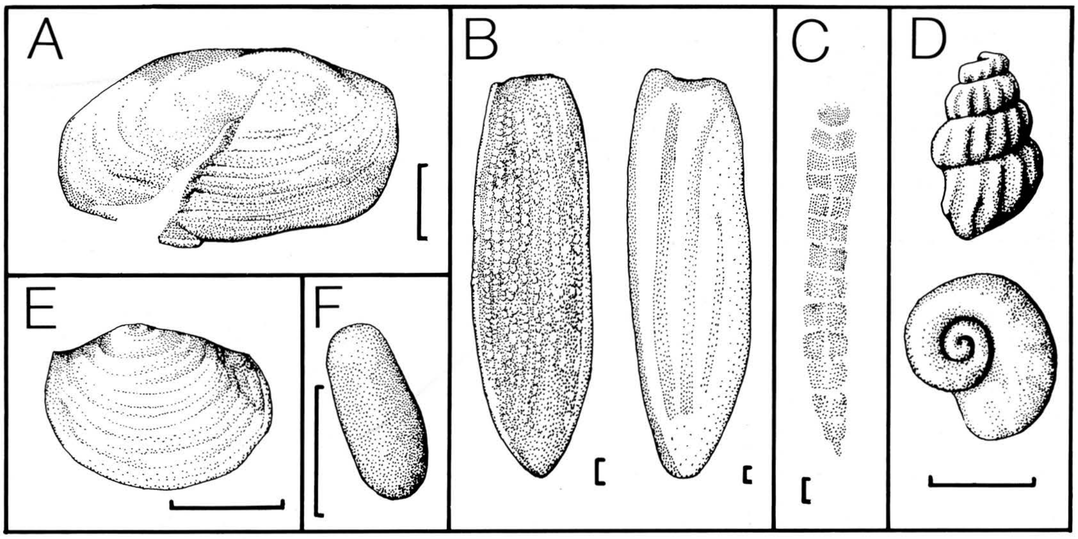

Fig. 8-6. Early Jurassic age invertebrates from the delta and shoreline and the open water, shallow lake environments of the Newark Supergroup (scale, 1 mm).

A. Unionid clam from delta environment of the Sinemurian lower Portland Formation of the Hartford basin, Stony Brook, Suffield, Conn. (drawn from McDonald and LeTourneau, in press).

B. Beetle elytra from the Hettangian Towaco Formation of the Newark basin, Roseland, N.J. (left) and the Sinemurian lower Portland Formation of the Hartford basin, Kelsey and Ferguson Quarry, Suffield, Conn. (N.G. McDonald Collection).

C. Insect (?fly) larva from the Hettangian lower Portland Formation of the Hartford basin, Cromwell, Conn. (Wesleyan University Collection).

D. Small snails (cf. *Hydrobia*, above; cf. *Gyraulus*, below) from Hettangian carbonate shoreline environment of the Scots Bay Formation, Kings County, Nova Scotia.

E. *Cyzicus*-type clam-shrimp from the Sinemurian lower Portland Formation of the Hartford basin, Kelsey and Ferguson Quarry, Suffield, Conn. (N.G. McDonald Collection).

F. Darwinulid ostracode from the Sinemurian lower Portland Formation of the Hartford basin, Kelsey and Ferguson Quarry, Suffield, Conn. (N.G. McDonald Collection).

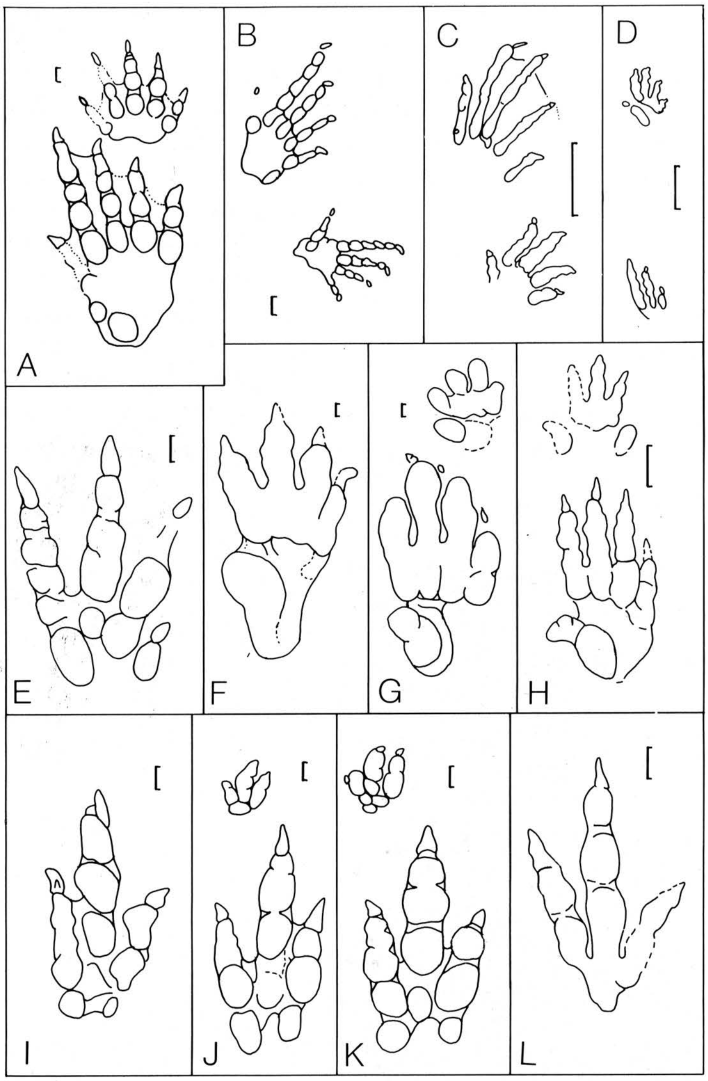

Fig. 8-7. Late Triassic (late Carnian and Norian) footprints and their likely trackmakers from the Newark Supergroup (principally the Newark basin) (scale is 1 cm).
A. *Apatopus lineatus* (phytosaur).
B. *Rhynchosauroides hyperbates* (sphenodontid).
C. *Gwyneddichnium majore* (tanystropheid *Tanytrachelos*).
D. *Rhynchosauroides brunswickii* (?sphenodontid or lacertilian).
E. *Coelurosaurichnus* sp.2 (? dinosaur).
F. *Brachychirotherium eyermani* (? rauisuchid archosaur).
G. *Brachychirotherium parvum* (? aetosaur archosaur).
H. *Chirotherium lulli* (? rauisuchid archosaur).
I. *Grallator* sp. (theropod dinosaur).
J. *Atreipus sulcatus* (? ornithischian dinosaur).
K. *Atreipus milfordensis* (? ornithischian dinosaur).
L. *Coelurosaurichnus* sp. 1 (? dinosaur).
A, F, G, I from Baird (1957); H, I from Baird (1957); D, from Olsen (1980d); J, K from Olsen and Baird (1986b).

(Marsh, 1893; Gilmore, 1928; Colbert, 1946; Baird and Take, 1959; Carroll et al., 1972; Olsen, 1977, 1980d; Baird and Olsen, 1983; Olsen and Galton, 1984; Baird, 1986a). Dinosaurs, including small theropods, possible prosauropods, and ornithischians, although present, comprise a minor part of the assemblages as do other archosauromorphs, therapsids and amphibians (Fig. 8-4, Appendix). There are no obvious differences between assemblages from braided or meandering river sequences: for example, the Passaic Formation sequences near Paterson, New Jersey (Weddle and Hubert, 1983) and the New Haven Arkose near Meriden, Connecticut (Hubert, 1978); both produce the bizarre procolophonid *Hypsognathus* (Baird, 1986a; Olsen and Baird, in prep.) (Fig. 8-3).

With very minor exceptions, Early Jurassic outcrops of fluvial sequences are more or less confined to the Fundy, Deerfield, and Hartford basins, and only the Hartford basin has thus far produced any tetrapod remains other than bone scraps. In contrast to the fluvial assemblages of the Triassic, dinosaur skeletons, notably prosauropods are dominant, although the number of specimens is admittedly small (Marsh, 1893, 1896a; Emerson and Loomis, 1904; Lull, 1953; Walker, 1968; Galton, 1976; Olsen, 1980d; Hubert et al., 1982).

Fig. 8-8. Left manus impression of *Rhynchosauroides hyperbates* from the lower Lockatong of the Newark basin, Arcola, Pennsylvania (from Olsen, 1984a). Scale is 1 cm.

Flood-plain siltstones and sandstones have also produced a variety of footprint faunules from the same areas which produce bones. Definitive Late Triassic fluvial footprint assemblages are rare compared to their marginal lacustrine counterparts. Presently, they are known only from three localities: one each from the upper Stockton Formation of the Newark basin (late Carnian) (Olsen, 1980c), the upper Wolfville Formation of the Fundy basin (Norian) (Olsen and Baird, in prep.), and the upper Passaic Formation of the Newark basin (late Norian) (Baird, 1986a). The assemblages found to date include tracks assigned to lepidosaurs (*Rhynchosauroides* and *Gwyneddichnium*, Figs. 8-7 and 8-8), dinosaurs (predominately *Atreipus* and *Grallator*), phytosaurs (*Apatopus*), pseudosuchians (*Brachychirotherium*, Fig. 8-7) and procolophonids (*Procolophonichnium*).

Jurassic flood plain ichnites are known only from the Portland Formation of the Hartford basin (Hubert et al., 1982) and are dominated by the tracks of dinosaurs, particularly small theropods (*Grallator*) and crocodylomorphs (*Batrachopus*) (Lull, 1953). There are no apparent differences between flood plain footprint associations and the much more common marginal lacustrine occurrences of equivalent age.

Swamp and marginal lake environments

In this category are included deposits formed in shallow standing water in which there were abundant rooted plants (e.g., a swamp) and deposits formed in a lake but subject to significant exposure (e.g., margin of a lake or a desiccated lake floor). I exclude higher-energy environments such as deltas which are handled separately below.

True swamp environments are difficult to identify in the Newark Supergroup because of the difficulty in separating rooted intervals formed subaqueously or under very wet conditions from those formed under much drier conditions but subsequently drowned by a transgressing lake. Nonetheless, there are some relatively clear examples, all from the early Late Triassic (early and middle Carnian) of the southern Newark basins.

The oldest occurrences are from early Carnian age strata of the productive coal measures of the Richmond basin. Here, sequences of gray claystone with abundant root traces are succeeded by coal or coaly siltstone. Based on the well preserved megafossil plants present in the coals and associated siltstones (Fig. 8-9) the swamp flora was dominated by ferns, equisetalians, and cycadeoids. The rich florules described by Bunbury (1847), Fontaine (1883), Ward (1900) and Bock (1969) are from these units and are now badly in need of revision. Associated aquatic fossils include fish fragments (mostly *Dictyopyge*), clam-shrimp, and coprolites. Similar occurrences of similar age occur in the Taylorsville (Weems, 1980) and Farmville basins.

A rich, newly discovered vertebrate locality in the early (or middle?) Carnian age Otterdale Sandstone of the Richmond basin may represent a swamp deposit. In addition to poorly preserved root traces, unionid clams, fish fragments (*Dictyopyge*), and reptile bones occur abundantly. The reptiles include several apparently new forms (all as yet known from isolated teeth and bones), but the most common form is the advanced mammal-like reptile *Massetognathus* otherwise known from Middle Triassic deposits of South America.

Probable swamp deposits dominate the fossiliferous sequences in the Sanford subbasin of the Deep River basin. Megafossil florules in the early to middle Carnian Pekin Formation have been described by Emmons (1856, 1857), Hope and Patterson (1969, 1970), and Delevoryas and Hope (1971, 1975). Unionid clams (Appendix 1) and clam-shrimp (Hope and

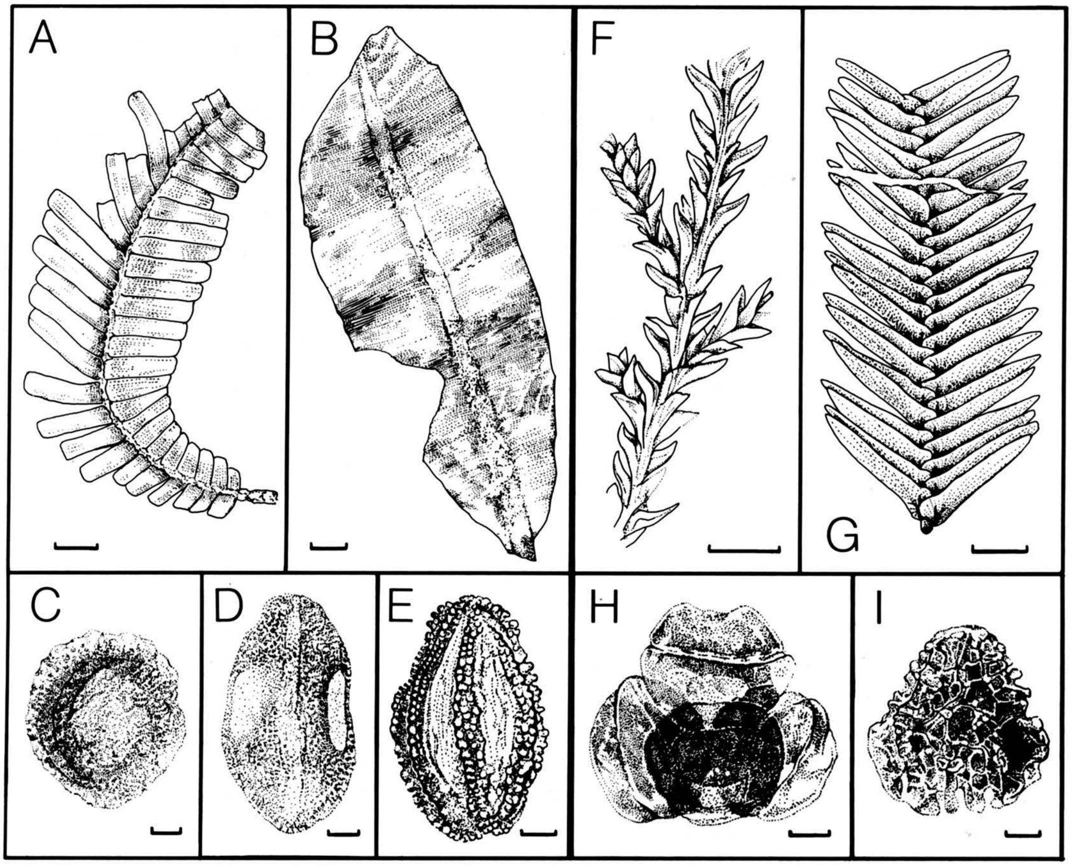

Fig. 8-9. Newark Supergroup plants. Characteristic megafossils (A, B) and pollen taxa (C – E) of Late Triassic age. Characteristic megafossils (F, G) and pollen and spores (H, I) of early Jurassic age.

A. The cycadeoid *Zamites powelli* from the swamp deposits of Late Triassic age (early Carnian) Productive Coal Measures of the Richmond basin, Va. (drawn from Bock, 1969, fig. 269).

B. The probable cycadeoid *Macrotaeniopteris magnifolia* from the same formation and environment as (A) (redrawn from Bock, 1969, fig. 422).

C. The conifer pollen taxon *Patinasporites densus* from the open water, shallow lake deposits of latest Triassic age (late Norian) upper Passaic Formation of the Newark Basin, Pa. (drawn from Cornet, 1977a, Pl. 14, fig. 3).

D. The cycadeoid pollen taxon *Ovalipollis ovalis* from the same locality and horizion as (C) (drawn from Cornet, 1977a, Pl. 13, fig. 2).

E. Angiosperm-like pentasulcate pollen taxon from the open water, shallow lake environment of Late Triassic age (early Carnian) Vinita beds of the Richmond basin, Va. (redrawn from Cornet, pers. comm., 1977).

F. The conifer *Pagiophyllum* sp. from the open water shallow lake environment of Early Jurassic age (Sinemurian) lower Portland Formation of the Hartford basin, South Hadley Falls, Mass. (N.G. McDonald Collection).

G. The cycadeoid *Otozamites* sp. from the deep-water lake environment of Early Jurassic age (Hettangian) lower Shuttle Meadow Formation of the Hartford basin, Durham, Conn. (Wesleyian University Collection).

H. Conifer pollen tetrad *Corollina meyeriana* from the ? swamp environment of Early Jurassic age (Hettangian) Shuttle Meadow Formation of the Hartford basin, Northampton, Mass. (drawn from Cornet and Traverse, 1975, Pl. 6, fig. 6).

I. Pteridophyte spore *Convolutospora klukiforma* from the open water, shallow lake environment of Early Jurassic age (Hettangian) lower Shuttle Meadow Formation of the Hartford basin, North Guilford, Conn. (drawn from Cornet and Traverse, 1975, Pl. 1, fig. 1).

Scale for A, B, F, G is 1 cm; for C – E, H, I scale is 10 microns.

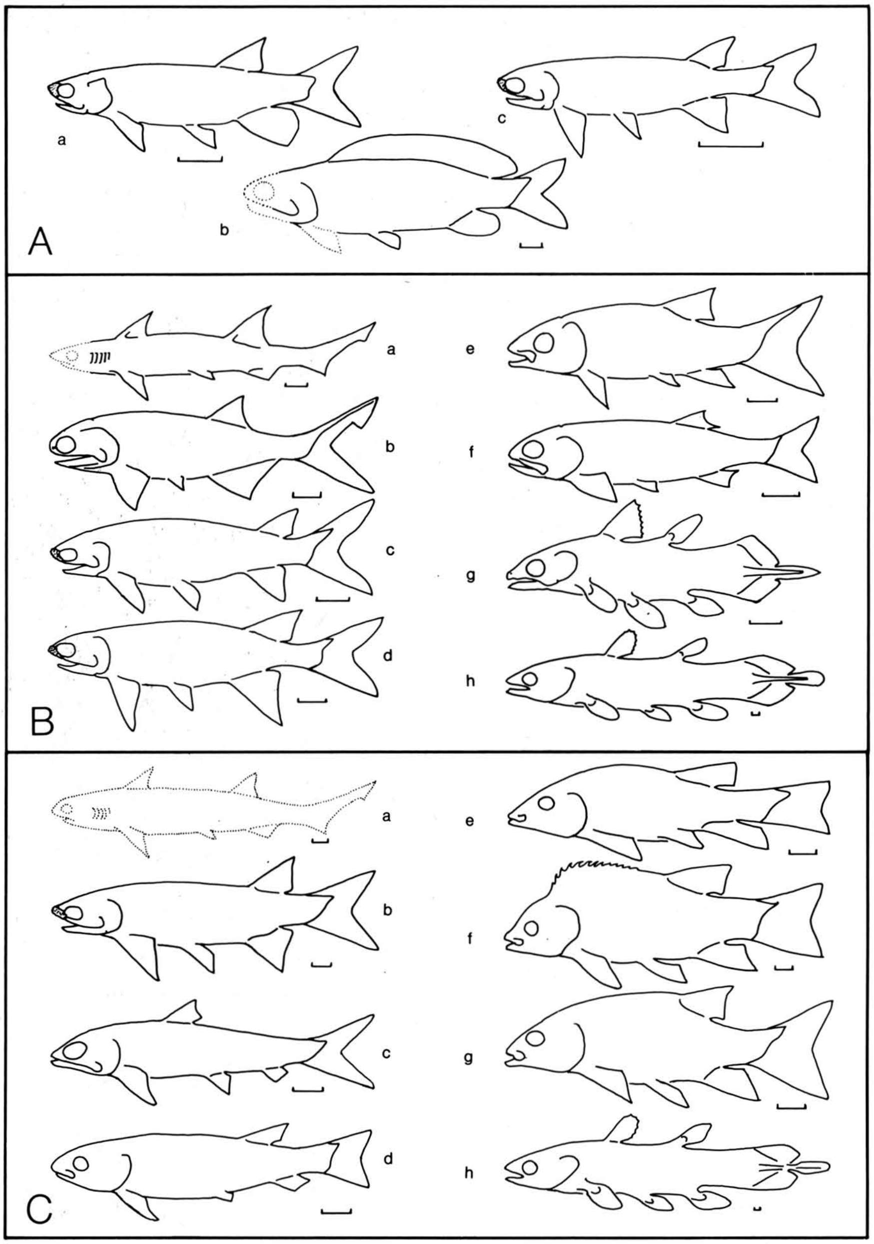

Fig. 8-10. Late Triassic and Early Jurassic age fish from the Newark Supergroup.

A. Early Late Triassic (early Carnian) age fish: *a* = redfieldiid palaeonisciform *Dictyopyge*; *b* = palaeonisciform *Tanaocrossus*; *c* = redfieldiid palaeonisciform *Cionichthys*.

B. Middle Late Triassic (late Carnian) age fish: *a* = hybodont shark *Carinacanthus*; *b* = palaeoniscoid *Turseodus*; *c* = redfieldiid palaeonisciform *Synorichthys*; *d* = redfieldiid palaeonisciform *Cionichthys*; *e* = holostean of the *Semionotus brauni* group; *f* = undeterminined holostean (Cow Branch Formation only); *g* = coelacanth *Osteopleurus newarki*; *h* = coelacanth *Pariostegus*.

C. Early Jurassic (Hettangian – ?Toarcian) age fish: *a* = hybodont shark cf. *Hybodus* (known from teeth only from the McCoy Brook Formation); *b* = redfieldiid palaeonisciform *Redfieldius*; *c* = palaeonisciform *Ptycholepis*; *d* = holostean '*Acentrophorus chicopensis*'; *e* = semionotid holostean of the 'simple scale species group'; *f* = holostean of the *Semiontus tenuiceps* species group; holostean of the *Semiontus elegans* species group; coelacanth *Diplurus longicaudatus*.

Aa – c from Olsen et al. (1982); Ba – d, Bg from Olsen (1980c); Cb adapted from Schaeffer and McDonald (1978), Cc adapted from Schaeffer et al. (1975), Ce from McCune et al. (1984). Scale is 1 cm.

Patterson, 1969) occur locally. Vertebrates are at least locally common in middle Carnian sequences. These include redfieldiid fishes (Olsen et al., 1982), the dicynodont mammal-like reptile *Placerias*, aetosaur and giant rauisuchid pseudosuchians, and phytosaurs (Baird and Patterson, 1967).

Middle Carnian coals of the Cumnock Formation of the Sanford subbasin and the Dan River basin consist predominantly of conifer wood (Cornet, 1977a), but also contain abundant reptile bones, fish fragments, coprolites, clam-shrimp, and ostracodes. The fish include coelacanths and redfieldiids (Fig. 8-10) (Olsen et al., 1982) and the tetrapod assemblages are dominated by phytosaurs (*Rutiodon*) but also include metoposaur amphibians, small chinquidontid (*Microconodon*) and cynodont (*Dromatherium*) mammal-like reptiles, and an orthithischian dinosaur (Olsen, 1980b).

Definitive swamp deposits are not known from younger Newark deposits although possible occurrences are the various Triassic and Jurassic megafossil plant localities described by Newberry (1888), Brown (1911), Wherry (1916), Cornet (1977b).

Mud flats exposed by receding lake waters are the major source of vertebrate ichnofossils in the Newark Supergroup and bones, although present, are not common. Generally, the se-

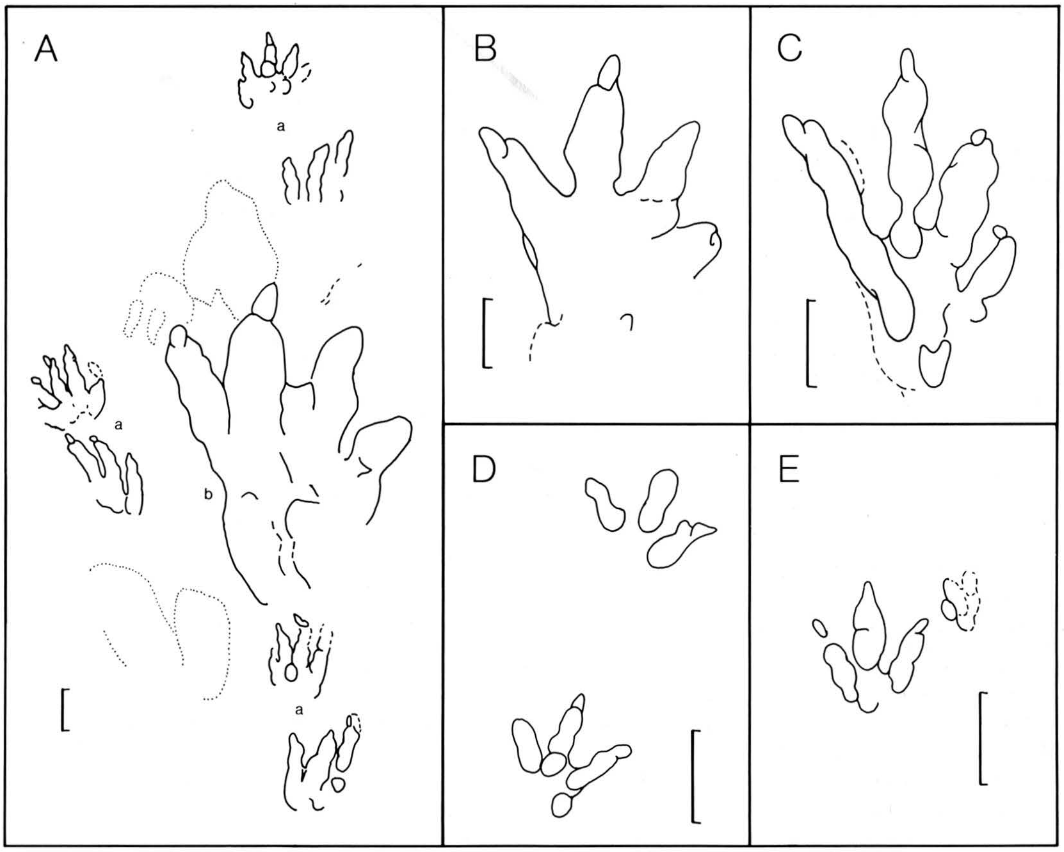

Fig. 8-11. Footprints from the middle Carnian Pekin Formation of the Sanford subbasin of the Deep River basin, North Carolina.

A. natural cast of right pes impression of *Brachychirotherium* sp. with *Apatopus* trackway.

B – C. left pes impressions of *Brachychirotherium* sp.

D. natural casts of successive pes impressions, possibly dinosaurian.

E. natural cast of ?right pes impression and possible manus impression, possibly dinosaurian. Scale is 10 cm.

quences consist of thin-bedded siltstone and ripple-bedded sandstone with desiccation cracks, burrows (particularly *Scoyenia*), and sometimes root traces. In gray beds, fusinized plant remains can also be very common and ostracodes and clam-shrimp are sometimes common.

Footprint faunules have now been recovered from all but the oldest Newark strata (i.e. Anisian – early Carnian). Carefully established ichnotaxa provide a basis for a parallel, but independent, basis for biostratigraphy. Footprints also provide a better record of animal communities than bones and are the only record of extinct reptiles and amphibians in motion.

Middle Carnian footprint assemblages from the Pekin Formation of the Sanford subbasin are the oldest known from the Newark. Apart from the phytosaurian ichnogenus *Apatopus* none of the Pekin forms occur in younger Newark deposits. Apparently bipedal *Brachychirotherium* spp., representing large psedosuchians, are dominant followed by short-toed, possibly dinosaurian forms (Fig. 8-11).

Late Carnian ichnofaunules are much more common, although until recently very poorly known (Fig. 8-7). Valid forms include the lepidosaurian tracks of the ichnospecies *Rhynchosauroides brunswickii, R. hyperbates* (Fig. 8-8), and *R.* spp., *Apatopus* spp., the strange dinosaurian form *Atreipus* spp., the pseudosuchian ichnites *Chirotherium lulli, Brachychirotherium parvum, B. eyermani,* and *B.* spp., and the theropodian dinosaur ichnite *Grallator* (*Grallator*) sp. (Olsen, 1980c, 1980d; Olsen and Baird, 1986a; Baird, 1954, 1957).

Newark Supergroup ichnofaunules of Norian age contain the same forms as are present in the late Carnian (Fig. 8-10). However, larger theropod footprints such as *Grallator* (*Anchisauripus*) spp. become common in younger Norian deposits. There are also a number of peculiar possibly dinosaurian forms now classified as *Coelurosaurichnus* spp. (Baird, 1954) and apparently the dicynodont ichnite *Dicynodontipes* (Olsen and Baird, 1986a,b).

Gwyneddichnium (Bock, 1945) is a small five toed quadrupedal form represented by excellent material from the Lockatong Formation of the Newark basin. It is not common but is known from a wide stratigraphic range in the Newark basin (lower Lockatong through

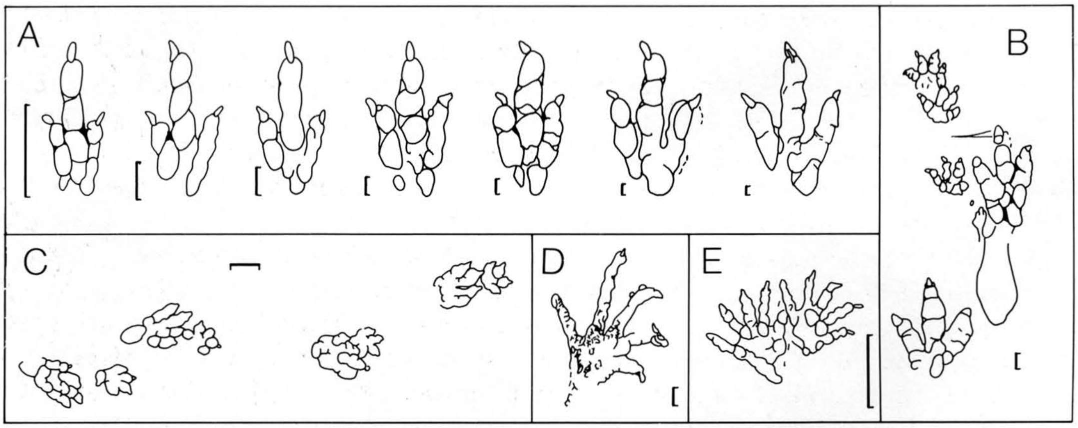

Fig. 8-12. Footprints from the Early Jurassic of the Newark Supergroup.
A. *Grallator* spp. (theropod dinosaurs).
B. *Anomoepus scambus* sp. (ornithischian dinosaur).
C. *Batrachopus deweyii* (crocodylomorph).
D. *Rhynchosauroides* sp. (? sphenodontid).
E. *Ameghinichnus* sp. (trithelodont mammal-like reptile).
A – C, E, from Olsen, (1980c); scale is 1 cm. D, from Olsen and Baird (1986a), scale is 1 mm.

middle Passaic Formation). Structurally, this ichnogenus finds a remarkably close and unique osteological counterpart in the tanystropheid reptile *Tanytrachelos* (Olsen, 1979, 1980c) known from very complete material (Fig. 8-16) (Baird, 1986a).

Recent taxonomic revisions have whittled down the number of Early Jurassic valid ichnogenera from the 47 cited in Lull's (1904, 1915, 1953) compendia of E. Hitchcock's (1858, 1865) taxa to 8 (Fig. 8-12) (Olsen, 1980c, 1980d; Olsen and Galton, 1984; Olsen and Baird, 1986a,b; Olsen and Padian, 1986). Most common are tracks assignable to small to large theropods (*Grallator* [*Grallator*] spp., *G.* [*Anchisauripus* spp.], and *G.* [*Eubrontes*) spp.], small ornitischian dinosaurs (*Anomoepus* spp.), small crocodylomorphs (*Batrachopus* spp.), and a large archosaur (*Otozoum*). In addition, there are the very rare lepidosaur track *Rhynchosauroides* sp., the mammal or mammal-like reptile track *Ameghinichnus* sp. (Olsen, in prep. c), and two uncertain but possibly valid dinosaurian forms, *Hyphepus* and *Gigandipus*.

Earliest Jurassic (pre-extrusive) footprint assemblages are known from only a few localities in the Newark basin (Olsen and Baird, 1986b) and these consist of *Grallator* (*Grallator*) spp., *G.* (*Anchisauripus*) spp., *G.* (*Eubrontes*) sp., *Batrachopus* sp., and *Rhynchosauroides* sp. (Olsen and Baird, 1986b). *Anomoepus* is thus far absent, but this could be due to the small sample size.

These Triassic and Jurassic assemblages are better gauges of large-scale community change through time than bones because they sample what are more likely to be true communities (in the ecological sense), they sample the same kind of environment repeatedly through time, and they are much more common than bones. Unfortunately, what we gain in sampling density and ecological knowledge with footprints, we lose in taxonomic refinement. It is very likely that a footprint species corresponds to an osteological family, or if we are very lucky, an osteological genus. Thus, footprint assemblages show us faunal assemblages at a rather coarse taxonomic level, but with a much higher sampling density.

It is useful to compare the footprint assemblages with osseous assemblages from the same stratigraphic intervals (Fig. 8-4) (Table 8-1). Most Triassic bone assemblages are dominated by phytosaurs with other tetrapods being much rarer, and *Apatopus* is a major component of Triassic ichnofaunules. Interestingly, the other common components of the ichnofauna are represented only by fragments, single specimens, or nothing at all (*Atreipus*) while the less common *Gwyneddichnium* (Bock, 1952) and *Procolophonichnium* are plausibly represented by abundant *Tanytrachelos* and procolophonids, respectively (Baird, 1986a). Some Newark Triassic osseous taxa such as metoposaur amphibians, rhynchosaurs, and most therapsids, have no known ichnological counterparts.

What we see in comparisons of tracks and bones in Newark Triassic assemblages is partially mirrored in Jurassic ones. The most common Jurassic tracks, the grallatorids, are represented by bones of only one skeleton and several small associations of bones – and these are all small forms. Prosauropods – the most common Newark Jurassic dinosaurs – are conspicuous by their absence in the footprint assemblages (see discussion by Galton, 1976; Baird, 1980). Likewise, apart from a single large tooth (incorrectly ascribed to a phytosaur in Hentz, 1985) bones of large theropods or the enigmatic trackmaker of *Otozoum* are unknown. The rarest elements of the Jurassic footprint assemblages, *Rhynchosauroides* and *Ameghinichnus*, find a match in some of the more common skeletal forms from Nova Scotia, sphenodontids and trithelodonts, respectively. Only crocodylomorphs are abundant in both osseous and ichnological assemblages.

It is likely that the footprint assemblages represent, in large part, different communities than bones and the latter are much more likely to represent a mix of members from several communities. Further, because most assignments of ichnotaxa to osseus taxa involve only family-level characters, there is no guarantee that any particular osseus *species*, no matter how common, was the trackmaker of any Newark ichnotaxon.

There are a few occurrences of bones in Triassic and Jurassic mud-flat environments. In Triassic sediments, scraps of phytosaurs occur, and one locality has produced abundant *Tanytrachelos* debris. In Jurassic sediments, footprint-bearing units have produced sandstone casts of the limb bones of a small theropod (Colbert and Baird, 1958) and a few indeterminate fragments. Otherwise, the footprint-bearing facies are remarkably devoid of bones.

Deltas and shoreline features

True deltaic and shoreline sequences have only recently been recognized in Newark Supergroup rocks (Smoot, 1985; LeTourneau, 1985a,b; LeTourneau and McDonald, 1985; McDonald and LeTourneau, in press). Most of these consist of small-scale deltas formed in a few meters of water. They consist of inclined sets of fining-upward, climbing-ripple cross-laminated sandstone and siltstone which fine down the dip of the incline, and which often toe into siltstones. Topset beds are rarely preserved. Larger-scale delta sequences no doubt exist, but their recognition is hampered by small outcrop size and the high probability that the largest deltas, built during deep-lake intervals, were not preserved within the depositional basin. Other shoreline features are notoriously cryptic and require stable water levels to build up identifiable bed forms and structures.

A common feature of many Newark deltaic sequences is the presence of algal tufa conglomerates. Large transported pieces of tufa encrusted logs and smaller oncholites are often present. Unionid clams are locally common as are isolated fish and tetrapod bones and teeth. Associated siltstones produce darwinulid ostracodes and clam-shrimp. Triassic deltas and shorelines have also produced phytosaur bones and teeth while those of the Jurassic have produced several genera of fish (Appendix 8-1).

Shoreline features include beach bars, tufa mounds and reefs, and oolite and oncholite layers. These are most common in transgressive intervals of Van Houten cycles and are dominant in the Scots Bay Formation (Early Jurassic) of the Fundy basin (Birney, 1985). At one locality in the Passaic Formation, in situ fusinized small tree trunks are encased in stromatolites, surrounded by oscillatory rippled oolitic sand and overlain by black siltstone with pinch and swell lamination (Smoot and Olsen, 1988, this volume). In the Scots Bay Formation, hemispherical stromatolites, gastropod coquinas, charophyte hash, and oscillatory rippled carbonate sands make up shoreline features (Birney, 1985; Cameron, 1986).

Open-water shallow lake

Laterally persistent, thin-bedded siltstones or limestones with pinch and swell laminae and/or oscillatory rippled sandstones with few or no desiccation cracks and with occasional to frequent burrows constitute this class of lacustrine environments. Root traces are generally absent or postdepositional. Some of these sequences can be traced laterally into deeper water intervals of a large lake while others represent the deepest water lacustrine facies for the lake. The latter class of deposit has only been recognized within the past few years but already has produced diverse and well-preserved fossils. This corresponds to Schaffer's (1972) vital pantostrat biofacies.

Zooplankton are represented by clam-shrimp and some insects while surface zoobenthos consists of ostracodes, locally snails, insect larvae, and tadpole shrimp (Gore, 1986). Infauna are represented by *Scoyenia* and its possible maker, the crayfish-like cf. *Cyticlopsis*, unionid and corbiculid clams, and various unstudied burrows. *Cyticlopsis* and corbiculid clams are known thus far only from Triassic (late Carnian) strata of the Durham subbasin. Fish fragments, coprolites, and, in Triassic strata, reptile bones are often very common (Appendix 1). The early Carnian age Doswell Formation of the Taylorsville basin has produced the bizarre archosauromorph reptile *Doswellia* while Late Triassic beds have produced ubiquitous phytosaurs, including some skeletons, and occasional metoposaurs. No tetrapod bones are known from shallow-water lake deposits from Jurassic age strata anywhere in the Newark Supergroup.

Scoyenia is a very distinctive ichnotaxon, often present in Newark shallow-lake sequences in addition to shoreline, delta, swamp, mud-flat, and fluvial facies. *Scoyenia* consists of a back-filled burrow showing meniscus-type infilling (Spreiten) and rice-grain like prod marks on the outside of the burrow (Fig. 8-5). Known world-wide from deposits of late Paleozoic age to the recent, it characterizes Seilacher's (1974) *Scoyenia* facies and is the most common ichnofossil in the Newark Supergroup (Smoot and Olsen, 1988, this volume). Even though recent examples of *Scoyenia* are known (Frey et al., 1984; Smoot and Olsen, 1988, this volume), its maker remains very uncertain. The association of small crayfish-like decapod crustaceans (cf. *Cyticlopsis*) and *Scoyenia* in a shallow-lake deposit in the Durham basin (late Carnian) suggested to me that the ichnotaxon may have been produced by crayfish-like decapods (Olsen, 1977).

Crayfish are one of the major bioturbating agents in modern soils with a high freshwater table in the Coastal Plain of eastern Texas and in the Mississippi River flood plain (Smoot and Olsen, 1988, this volume). Small (2 – 4 cm) crayfish of several species (mostly *Cambarus diogenes*) live in large numbers (+ 20,000/acre) in pine and oak woodlands, cultivated fields, and residental lawns where there is no standing water; they can be major agricultural pests. Their burrows extend into the water table which can be deeper than 2 m. Many burrows have an opening to the surface surrounded by the well-known mud chimney. The burrows are similar in size and morphology to the common fossil burrow *Scoyenia* and the crayfish which inhabit the burrows are similar in size to those from the Durham basin (contra Frey et al., 1984). Crayfish thoroughly bioturbate soils and their burrows should be abundant ichnofossils. Chimney-bearing burrows are common in paleosols of the Eocene Willwood Formation of Wyoming and these appear to be assignable to *Scoyenia*, but chimneys have not yet been found in association with Newark forms. The modern examples of *Scoyenia* have been found in areas where crayfish are common. Thus, the Willwood ichnofossils and the undoubted Newark *Scoyenia* from the Newark Supergroup could have been produced by crayfish or similar decapods, but assignment of *Scoyenia* to crayfish is premature because crayfish have not yet been shown to back-fill their burrows.

Deep-water lake

Deep-water lacustrine strata in the Newark are recognized by a lack of bioturbation or infauna, contemporaneous desiccation cracks, or pinch and swell lamination. The sequences are dominated by suspended and precipitated material. Graded and sometimes crossbedded sequences are sometimes present and these have been interpreted as lacustrine turbidites (Olsen, 1980c; Hentz, 1985). Body fossils are often preserved whole, occasionally with soft-tissue preservation (Olsen, 1979). In Schaffer's (1972) terminology this is a lethal-pantostrat biofacies with a well-preserved taphocoenosis.

At their maximum development some Newark lakes appear to have been deep and very large. Based on the lateral distribution of the best laminated black units in division 2 of some Van Houten cycles, the minimum areas of the largest Lockatong lakes were in excess of 7000 km^2 and their depth exceeded 100 m (Manspeizer and Olsen, 1981). Individual Van Houten cycles may extend from the Newark through Gettysburg and Culpeper basins and the area of the lakes which produced these cycles would have been as great as the present Lake Tanganyika (Olsen, 1984a, 1985c). The maximum sizes of the Jurassic lakes, however, are constrained by the lack of correspondence between fish assemblages of adjacent basins, which suggests that the basins were not connected and were probably not much larger than the areas of the existing basins (Olsen, 1983a, 1984a, 1985c).

Allochthonous plant material is often present, its volume and completeness possibly being related to basin morphology. The Danville – Dan River basin of Virginia and North Carolina is very elongate with a maximum width of 9.3 km. Deep-water facies of Van Houten cycles

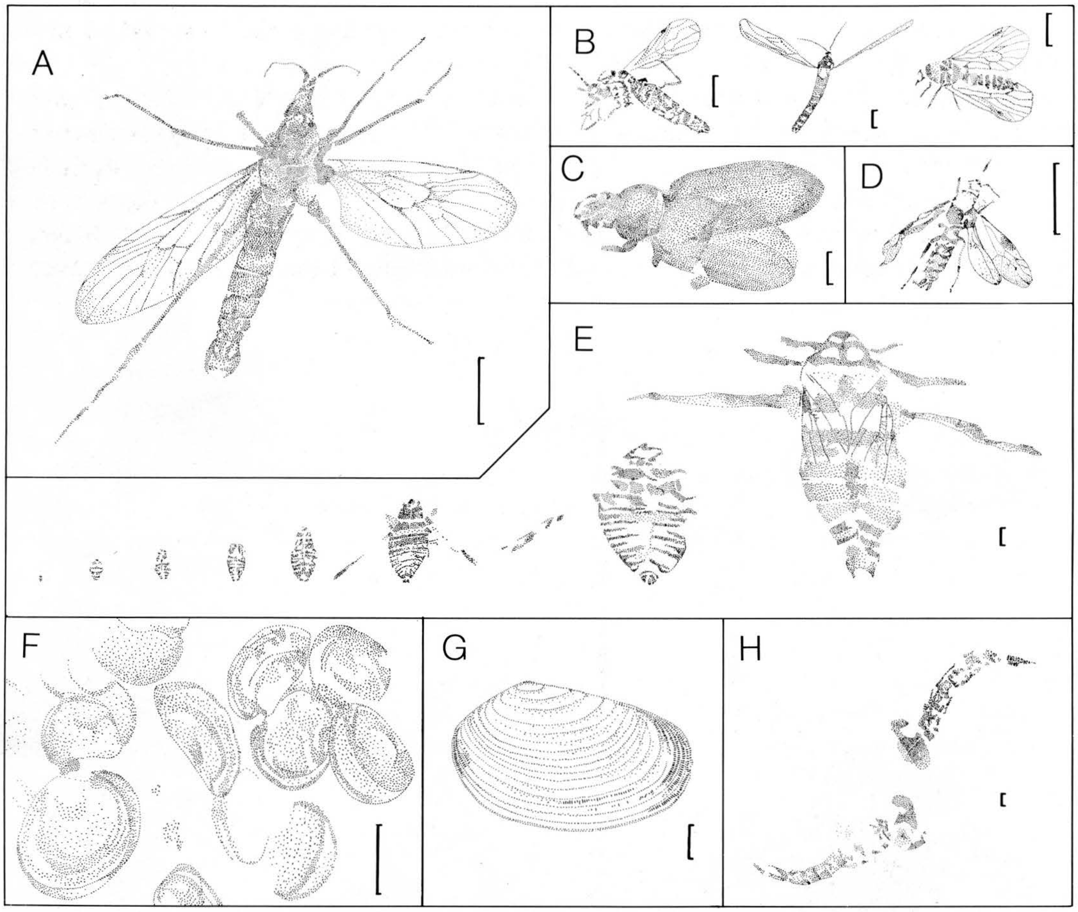

Fig. 8-13. Examples of Late Triassic (late Carnian) invertebrate fossils from the deep-water lake environment: A – D, allochthonous adult insects; E – H, planktonic arthropods.
A, B, true flies (Diptera, ?Tipulidae); C, beetle; D, psocopteran; E, partial growth series of ?hydrocoricid water bugs; F, clam-shrimp of the *Palaeolimnadia* type; G, clam-shrimp of the *Cyzicus* type; H, possible phyllocarids. All specimens from the upper member of the Cow Branch Formation of Leaksville Junction, North Carolina-Virginia, A, C, F – H, from Olsen et al. (1978). Scale 1 mm.

which make up the upper member of the late Carnian Cow Branch Formation preserve an extremely rich taphoceonosis with abundant large plants (Olsen et al., 1978) including ferns, cycadeoids, conifers, and equisetalians. Deep-water facies of Van Houten cycles of the contemporaneous Lockatong Formation of the Newark basin rarely contain megascopic plant material despite their almost identical aquatic faunas. The Newark basin has a maximum width of over 50 km. The high density of plant material in the Cow Branch Formation is plausibly linked to proximity to shore during high lake levels and possible high relief at the basin edge. Jurassic deep-water facies often contain isolated, although well-preserved, cycadeoid, fern, and conifer shoots, leaves and branches.

Zooplankton is represented by abundant clam-shrimp (Figs. 8-13 and 8-14), possibly some ostracodes, possible phyllocarids, and insect larvae and adults. In the Newark Supergroup, complete insects are known to be common only at one locality in the upper member of the Cow Branch Formation (Fig. 8-13). Aquatic forms include the oldest known adult and larval water bugs (Hemiptera), fly larvae, and possibly a beetle. Clearly allochthonous insects include the oldest known adult flies (Tipulidae and Bibionodae), roaches, psocoptera, flies, neuroptera, and most of the beetles. Unfortunately, this assemblage has been studied only superficially (Olsen et al., 1978).

Fish are the most common representatives of higher trophic levels in Newark deeper-water lacustrine assemblages (Figs. 8-10 and 8-15). Quarries developed for the collection of fish have produced tens of thousands of remarkably well preserved fishes (Olsen, 1980c; McCune et al., 1984; McCune, 1987). Middle Triassic, Late Triassic, and Early Jurassic deposits all have their own distinct fish assemblages. Earliest Late Triassic (early Carnian) assemblages are very strongly dominated by the redfieldiid *Dictyopyge*. Those from the later Late Triassic

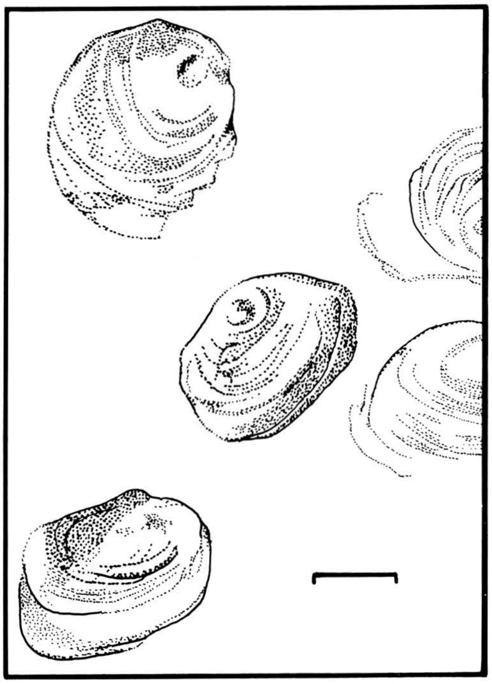

Fig. 8-14. *Cornia* sp. clam-shrimp from the deep-water lake environment of the Early Jurassic (Hettangian) East Berlin Formation of the Hartford basin, Branford, Conn. (N.G. McDonald Collection). Scale is 1 mm.

are dominated by either the palaeoniscoid *Turseodus* (Fig. 8-10), the coelacanth *Osteopleurus*[*Diplurus*] *newarki*, or *Semionotus* spp. Other fishes present include *Synorichthys* (Fig. 8-10) and *Cionichthys*, ?*Pariostegus*, and a new pholidophorid-like form. In contrast, with the exception of the very youngest assemblages, Newark Jurassic fish faunules are dominated by species of *Semionotus* (Fig. 8-10) (Olsen et al., 1982). Other fishes present include the redfieldiid *Redfieldius*, the 'subholostean' *Ptycholepis*, and the coelacanth *Diplurus longicaudatus*.

On the generic level, Newark fish assemblages appear depauperate compared to the faunas of most modern lakes. However, recent work on these fishes shows that some Newark lakes may have contained dozens or even hundreds of species of some of these genera (Olsen, 1980c; McCune, 1982; McCune et al., 1984). These are examples of ancient species-flocks

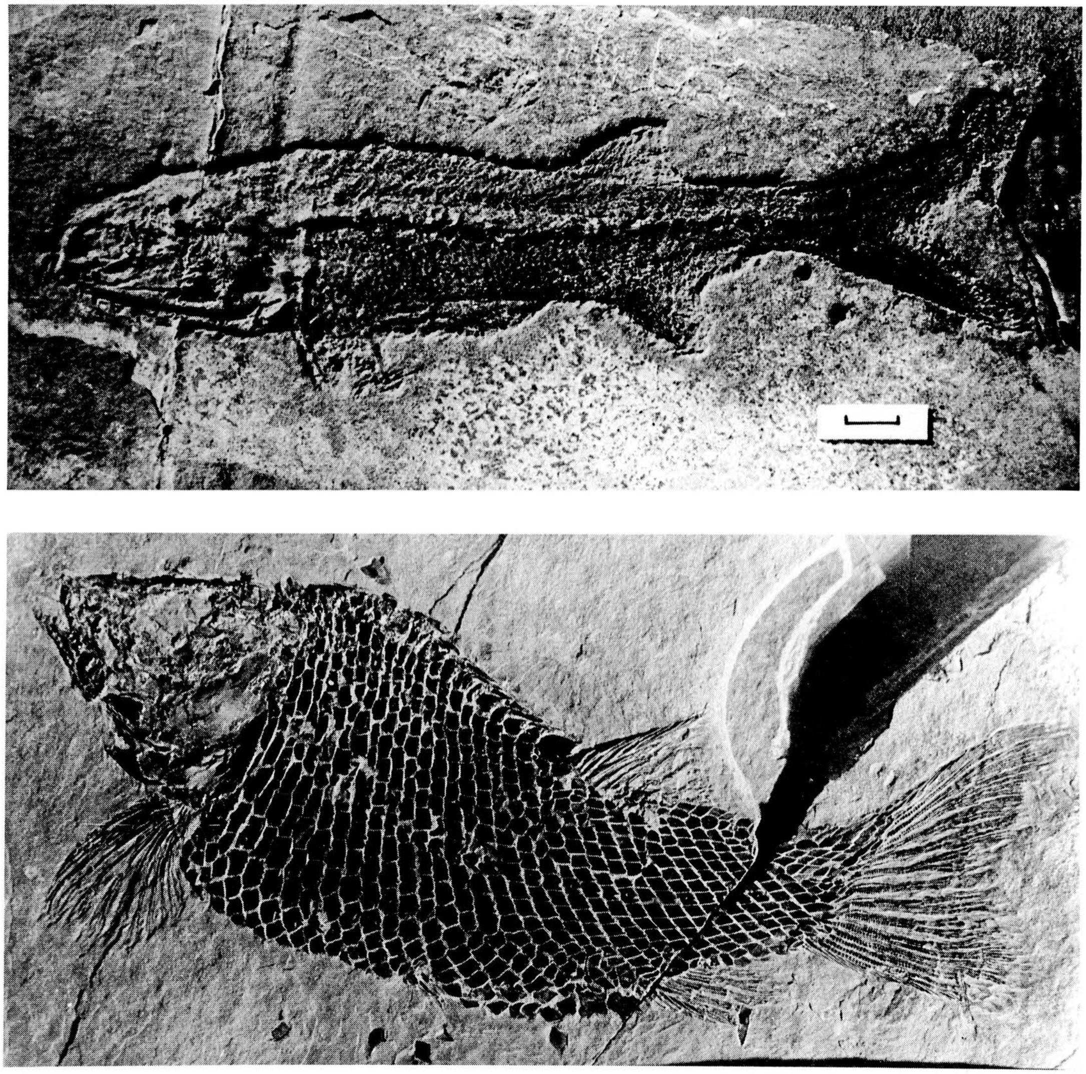

Fig. 8-15. Late Triassic and Early Jurassic age fish from the Newark Supergroup, both from the deep water lake environment.

A. *Turseodus* sp. from the lower Lockatong of Pennsylvania. B. *Semionotus* sp. from the Early Jurassic (Hettangian) Feltville Formation.

comparable to the cichlid species-flocks of the African Great Lakes (Fryer and Iles, 1972; Greenwood, 1981).

In Late Triassic Newark lacustrine sequences, evidence for multiple, closely related sympatric species is restricted to the Lockatong Formation of the Newark basin. Here, the paleaoniscoid *Turseodus* frequently dominates the deepest-water phase of lacustrine cycles (Olsen, 1980c). Within some of these intervals, there are at least several *Turseodus* species differentiated on the basis of scale and skull bone ornamentation, body shape, scale and fin ray counts, and tail shape (particularly the presence or absence of an accessory flap on the dorsal lobe). Some of these species were named as separate genera by Bock (1959).

Well-developed and well-documented species-flocks occur in semionotid fishes of Newark Jurassic lakes (McCune et al., 1984; Mc Cune, 1987). About 21 mostly endemic species of *Semionotus* (Figs. 8-10 and 8-15) have been identified from a sample of about 3000 fish collected from lake cycle 'P-4' of the Towaco Formation (McCune, 1982, 1987), and 9 species (again mostly endemic) have been identified from museum collections from the 'Boonton Fish Bed' of the Boonton Formation (Thomson and McCune, 1984; Olsen and McCune, in prep.). There are no other genera of fishes from the Towaco example and there are three other genera in the Boonton Fish Bed, although none of these appear to be represented by more than one or two species each. While not directly comparable in diversity to species lists from modern lakes, these Jurassic species-flocks are remarkably diverse compared to other fossil assemblages such as the well studied Eocene Green River Formation of the western United States. In the most diverse Green River units there are no more than two or three species of the most specious genus.

Ecological release in the absence of competitors in newly formed great lakes may be a major factor in the evolution of Newark species-flocks. Newly formed Newark rift-valley lakes were presumably repopulated by fishes living in the surrounding rivers or brought in by the chance tornado (e.g., Gudger, 1929; Kornfeld and Carpenter, 1984). The vast new lake, with its myriad environments, could be populated by semionotids which would speciate and specialize in the absence of other more specialized fishes. This is supported by preliminary data which suggest an inverse relationship between the number of semionotid species present and the number of non-semionotid genera present (Olsen, 1980c; McCune et al., 1984). A similar relationship seems to hold for cichlid and other fishes in several giant African lakes (Greenwood, 1984).

Higher trophic levels represented by fossils within deep-water Newark sediments include a number of surprisingly common small reptiles, often found as complete skeletons (Fig. 8-16). Earliest Late Triassic (early Carnian) microlaminated sediments have thus far produced only isolated small teeth of a reptile (Schaeffer and McDonald, 1978), but Late Triassic (late Carnian) deposits of the Danville – Dan River basin and the Newark basin have produced over 160 skeletons and thousands of dissociated bones of *Tanytrachelos* and the so-called 'deep tailed swimmer' (Fig. 8-16) (Olsen, 1980c). Also found in these sediments are skeletons of the gliding 'lizard' *Icarosaurus* (Fig. 8-16) (Colbert, 1970), almost certainly allochthonous, and phytosaur fragments, mostly teeth. As yet, deep-water sediments from Norian intervals have not produced any remains of reptiles. This may be due, however, to the almost complete lack of prospecting, because, as previously noted, tanystropheid footprints do occur in late Norian fluvial facies. This explanation does not hold, however, for Newark Jurassic deep-water sediments. Tens of thousands of fish have been collected from dozens of Jurassic localities for over a century, and the only tetrapod found from this facies has been two isolated dinosaur teeth (Cornet et al., 1973; Hentz, 1985), and a small dinosaur vertebra (Appendix 1). Apparently, small aquatic reptiles were absent from Jurassic Newark lakes.

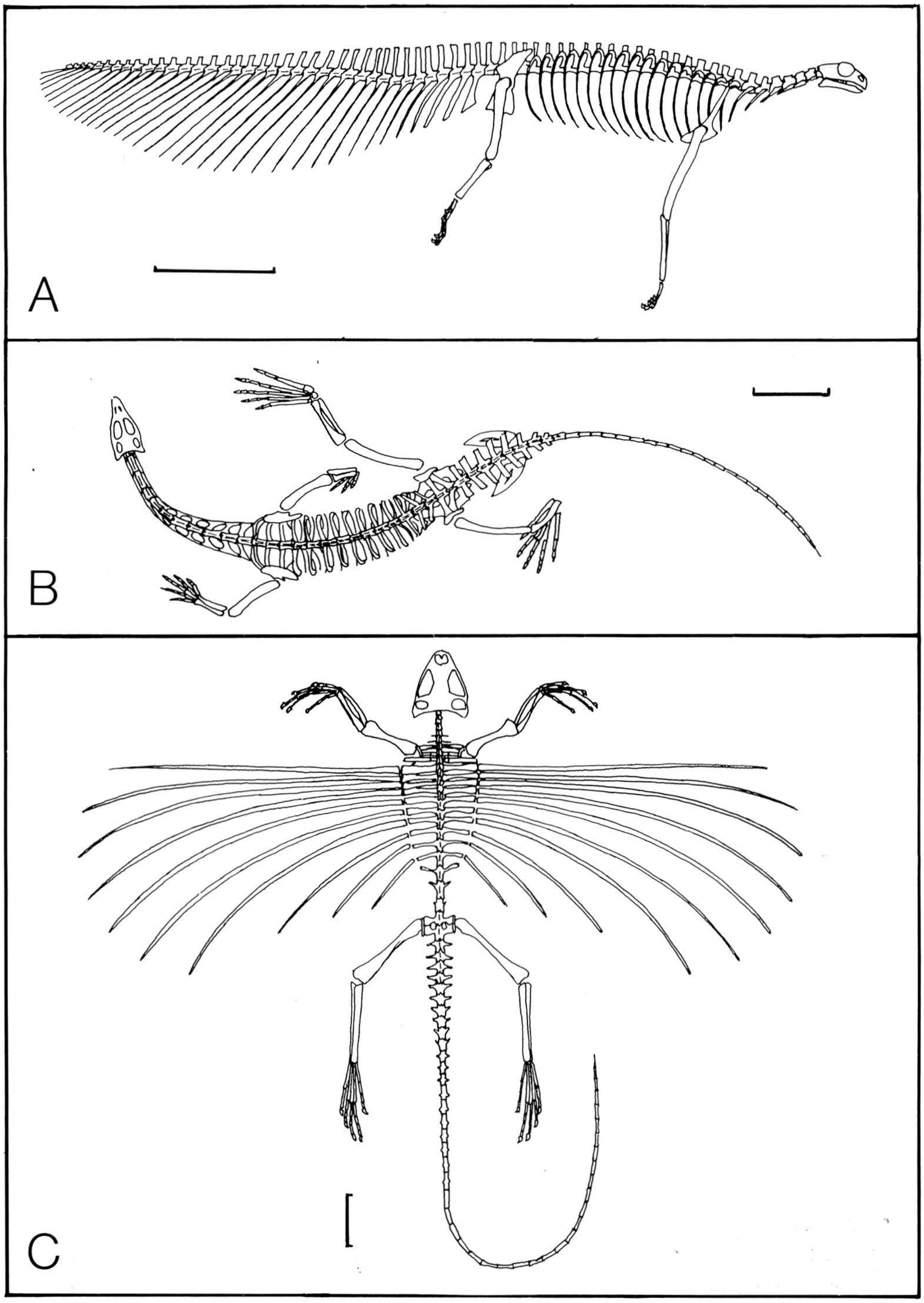

Fig. 8-16. Reconstructions of articulated reptiles from deep water lake environments of late Carnian age strata of the Newark and Dan River – Danville basins.
A. The 'deep-tailed swimmer'. B. *Tanytrachelos ahynis*. C. *Icarosaurus siefkeri*. All from Olsen (1980c); scale is 1 cm.

Newark phytoplankton and zooplankton

The lower trophic levels of Newark lakes were evidently quite different in composition from modern ones, despite our usual assumption that these lower levels are somehow primitive and ancient. In the phytoplankton, the modern dominant algae (the diatoms) were certainly absent (Bignot, 1983), and we do not know if there was an ecological replacement. Most likely the phytoplankton of Newark Supergroup lakes was dominated by cyanobacteria (blue green algae) because they are prevalent in modern lakes in which diatoms are rare.

The zooplankton of large, perennial Newark lakes was also definitely not modern in aspect. Relatively large (3 – 10 mm) bivalved crustaceans, the clam-shrimp, were dominant in contrast to modern lakes in which minute (< 1 mm) crustaceans such as water fleas and copepods are dominant. Presently, clam-shrimp are limited to ephemeral pools and pond without fish, although there are some exceptions (Junk, 1970, 1973; Hartland-Rowe, 1982; Battish, 1981) – all cryptic habitats. Nonetheless, from their present distribution one would expect clam-shrimp in the fossil record to be indicators of temporary bodies of water, and that is exactly how their presence in Newark lacustrine rocks has been interpreted (Tasch and Zimmerman, 1961; Gore, 1983, 1986).

In contrast to the present distribution of clam-shrimp, the Newark genera *Cyzicus, Cornia,* and *Paleolimadia* are normally found with fish in deposits of perennial lakes (Olsen, 1984a). Newark *Cyzicus* commonly occurs on the same bedding planes as complete fish, in fish gastric ejections, and in fish coprolites. Microlaminated calcareous claystones containing complete fish, fish coprolites, and extremely common clam-shrimp have been traced for over 180 km in the Newark basin (Olsen, 1984a), and there is no sign of desiccation of the unit over this distance. In these cases, clam-shrimp clearly lived in perennial lakes and were frequently eaten by fish (Olsen, in prep. b). I conclude that the present distribution and faunal associations of clam-shrimp are no guide to their past.

Thus, the evidence from Newark Supergroup lacustrine sediments suggests that the adaptive zone of Mesozoic clam-shrimp was much broader than it is now. The cause the apparent narrowing of the clam-shrimp adaptive zone is not readily apparent. It does not seem to have been a consequence of the evolution of modern forms of plantivorous fish, because clam-shrimp are found with teleosts of modern aspect in the Eocene Green River Formation (Bradley, 1966; Grande, 1980; Buchheim and Surdam, 1981). Perhaps the evolution of competitors such as water fleas plus predation by fish was the driving force behind the exclusion of clam-shrimp from modern perennial lakes. Whatever the cause of the changes, the lower trophic levels in Newark Supergroup lakes were quite different from their modern counterparts and extrapolation from modern lakes is demonstrably inappropriate. In lakes, in general, it seems that the transition to a modern phyto- and zooplankton occurred long after the higher trophic levels (fish) had attained a more or less modern aspect (Olsen, 1984a).

Extrinsic controls on ecosystem development

Organisms respond to a hierarchy of environmental perturbations and each level is characterized by different effects. At the lower levels, organisms must adapt to change on the scale of days and years. These time scales are short compared to the life span of organisms, which can adapt their behavior and morphology though evolution to anticipate predictable changes. On longer time scales it may be difficult for organisms to evolve anticipatory adaptations but there can still be an evolutionary response by speciation and extinction. It is at the latter level that the fossil record, particularly that of the Newark, can contribute unique information.

The most obvious environmental changes recorded in the Newark Supergroup are the Van Houten cycles so characteristic of lacustrine sequences (Fig. 8-17). Fourier analysis of long sections of Van Houten cycles in the Lockatong and Passaic formations of the Newark basin

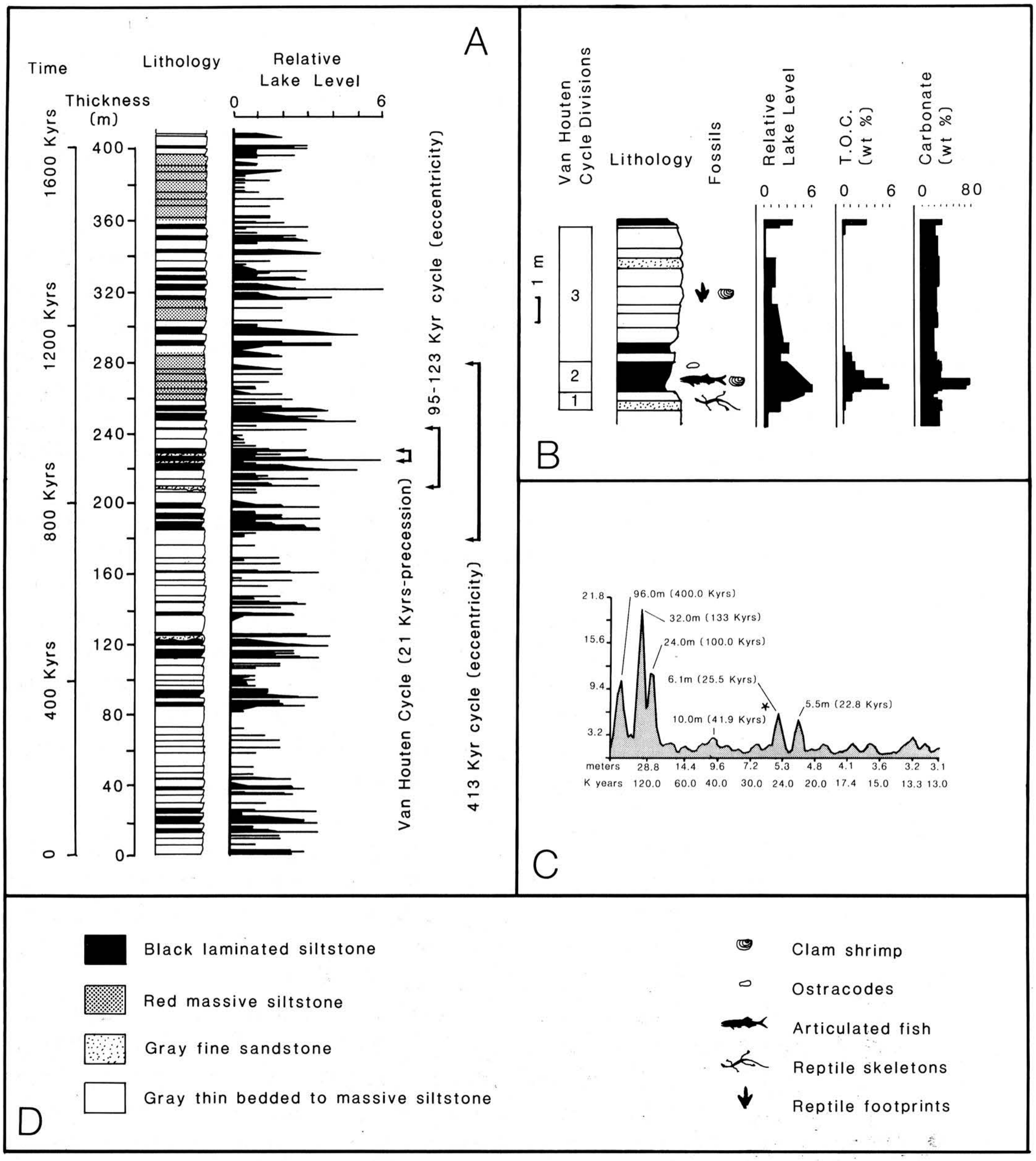

Fig. 8-17. Representative lacustrine cycles caused by orbital variations in the Earth's orbit from the Lockatong Formation of the Newark basin.
A. Measured section of upper middle Lockatong Formation (Late Carnian age) showing variation in interpreted relative lake level, based on sediment fabric, though time (0, represents a mostly dry lake floor: 6, represents a lake probably more than 100 m deep).
B. Single Van Houten cycle (that marked 21 kyr in A).
C. Power spectrum of relative lake depth of section shown in A D. Key to lithology. A and C adapted from Olsen (1986e).

show thickness periodicities of 5.9, 10.5, 25.2, 32.0, and 96.0 m thick corresponding to periodicities in time of roughly 25,000 44,000 100,000 133,000 and 400,000 years, based upon biostratigraphically correlated radiometric time scales and varve-calibrated sedimentation rates (Fig. 8-17) (Olsen, 1986d,e). There also appears to be long a cycle of about 1.6 – 2.0 million years. Most of the rest of the Newark Supergroup apparently conforms to this pattern (Olsen, 1984a, 1986e, in prep. a; Olsen et al., in prep.; Smoot and Olsen, 1988, this volume).

These periods are very similar to the present orbital cycles of precession of the equinoxes (21 kyr), obliquity of the Earth's axis (41 kyr), and eccentricity of the Earth's orbit (98, 125, 400, and 1600 – 2000 kyr). They also correspond to the Milankovitch-type orbitally induced climate cycles documented in Neogene marine deposits by many other workers (Hays et al., 1976).

Lacustrine ecosystems responded in two rather different ways to these orbitally controlled lake-level cycles. First, the change in the depth of lakes (such as those which deposited the Newark Supergroup) seems to be one the most important controls on lake metabolism. In particular, the relative rate at which carbon is cycled through a lake ecosystem is dependent on the efficiency of wind mixing which, in turn, is dependent on the area and depth of a lake (Manspeizer and Olsen, 1981; Olsen, 1984a, 1985a,d). Primary production by the phytoplankton and allochthonous input such as terrestrial plant debris are the ultimate source of the carbon, but it is ecosystem efficiency (Olsen, 1982, 1984a) which controls the fraction of carbon trapped in the sediments.

In lakes, ecosystem efficiency is depressed by increasing depth with chemical stratification, and is very low in lakes exhibiting perennial chemical stratification. In Newark microlaminated sediments deposited during lake high stands, low ecosystem efficiency is shown not only by the elevated levels of total organic carbon (1.0 – 8.0 wt. %) but also by the preservation of delicate whole organisms such as insects, fish, and whole reptiles as well as the microlaminations themselves. Ecosystem efficiency is promoted in shallow water. Higher salinity levels in the shallower lakes promotes higher productivity, the net result is high ecosystem efficiency and low carbon burial in shallow water. Thus, changing ecosystem efficiency, not changing productivity, produced the total organic carbon pattern seen in Van Houten cycles (Fig. 8-17).

Thus, water depth in closed Newark basins was the main control of ecosystem efficiency which in turn controlled the amount of carbon entering the sediments. Climate change controlled lake levels. This model, which uses periodic climate change as the main control on metabolism of lakes is very different from the standard models of ecological succession and eutrophication used to explain the ontogenies of lakes.

The second way lacustrine ecosystems responded to lake level change is by evolution and adaptation within populations in the lake itself. The species-flocks characteristic of the largest Newark lakes were a dramatic evolutionary response to lake-level change with dozens to perhaps hundreds of fish species evolving from a few, presumably riverine, species in the newly deepened lake. However, when lake level dropped, most if not all of these new species became extinct. Some of the same riverine forms which spawned the earlier species-flocks would presumably survive and give rise to successive flocks. Thousands of fish species evolved and went extinct during the 40 million years of Newark lake-level cycling. Despite all this change, the net result involves no apparent long-term trends.

Another even more surprising ecosystem pattern, recently identified in the Newark Supergroup, is that the pattern of generic and family dominance of fish seen in individual Van Houten cycles is recapitulated in the longer cycles. As seen in the lower Lockatong Formation (Olsen, 1980c) the complete sequence of genera, in order of increasing salinity, for the Lockatong was *Semionotus, Osteopleurus, Turseodus*. Each Van Houten cycle is, in succession, dominated by one of the above genera in the same order, through a 100,000-year cycle. Similarly, each successive 100,000-year cycles is dominated by one of these genera, in the same order, and this pattern is mirrored again in successive 400,000-year cycles, which make up the 1.6 – 2.0 million year cycle seen in the lower Lockatong Formation. Preliminary analysis of pyrite sulfur levels in the fish-bearing units suggest that the fish cycles are tracking cycles in salinity (Olsen, 1984a).

Global catastrophic events are some of the largest scale ecological perturbations. The Triassic – Jurassic boundary is one of most pronounced of the 13 or so often cited intervals of mass extinction which punctuate the Phanerozoic record. First recognized as a mass extinction in marine sections (Newell, 1967; Hallam, 1981; Raup and Sepkoski, 1982) roughly 43 % of terrestrial vertebrate families were apparently extinguished (Olsen and Sues, 1986; Olsen et al., 1987).

The Triassic – Jurassic boundary falls near the middle of the Newark Supergroup section and represents an unprecedented oppurtunity to examine the nature of a mass extinction (Olsen, 1986b,c; Olsen and Sues, 1986; Olsen et al., 1986, 1987). Van Houten cycles continue on through the boundary unchanged and their quasiperiodic astronomical origin provides a level of temporal control unknown for pre-Holocene continental environments.

The Early Jurassic assemblages from the fault-scarp breccias and fault-margin synsedimentary basins from Nova Scotia are crucial to the interpretation of the terrestrial record of the Triassic – Jurassic boundary. Compilations of undoubted Triassic tetrapods from the Newark and other parts of the world show that the new Nova Scotian assemblages consist of representatives of families surviving from the Triassic, and there are apparently no new families added (Figs. 8-4 and 8-18).

Newark footprints show the same basic pattern. A marked increase in taxonomic diversity through the Late Triassic (Figs. 8-7 and 8-11) is punctuated by a dramatic drop at or close below the palynologically defined Triassic – Jurassic boundary (Fig. 8-12). Newark ichnological assemblages never recover their previous levels of diversity.

Plants show a pattern with some similarities to that seen in vertebrates. Late Triassic pollen and spore assemblages include many of very high species richness (Cornet and Olsen, 1985). Literally, hundreds of taxa (many undescribed) are present. Diverse conifers, cycadeoids, gnetalians, seed ferns, true ferns, and equisetalians are represented as palynomorphs and sometimes as megafossils (Fig. 8-9). Also present, but never abundant, are diverse pollen types which appear to span the morphological gap between gnetalians (mormon tea and its relatives) and angiosperms (flowering plants) (Cornet, 1979, 1986). Although such high diversity and intriguing assemblages occur just below the Triassic – Jurassic boundary, they are completely absent above it. About 30 % of all palynomorph species drop out at the boundary in the Newark Supergroup (Cornet and Olsen, 1985), and the Early Jurassic assemblages are uniformly of much lower diversity, with an overwhelming dominance by the conifer pollen genus *Corollina* (+90 %) (Cornet et al., 1973; Cornet and Traverse, 1975; Cornet, 1977a).

Using Van Houten cycles as a guide, the oldest Jurassic tetrapod assemblages (ie. the McCoy Brook faunules) were preserved less than 500,000 years after the Triassic – Jurassic boundary (Olsen et al., 1987). Examination of fossils in successive Van Houten cycles will allow the rate of taxonomic change around the boundary, both for tetrapods and plants, to be determined. Only at this scale of resolution is it possible to tell if the extinctions were catastrophic.

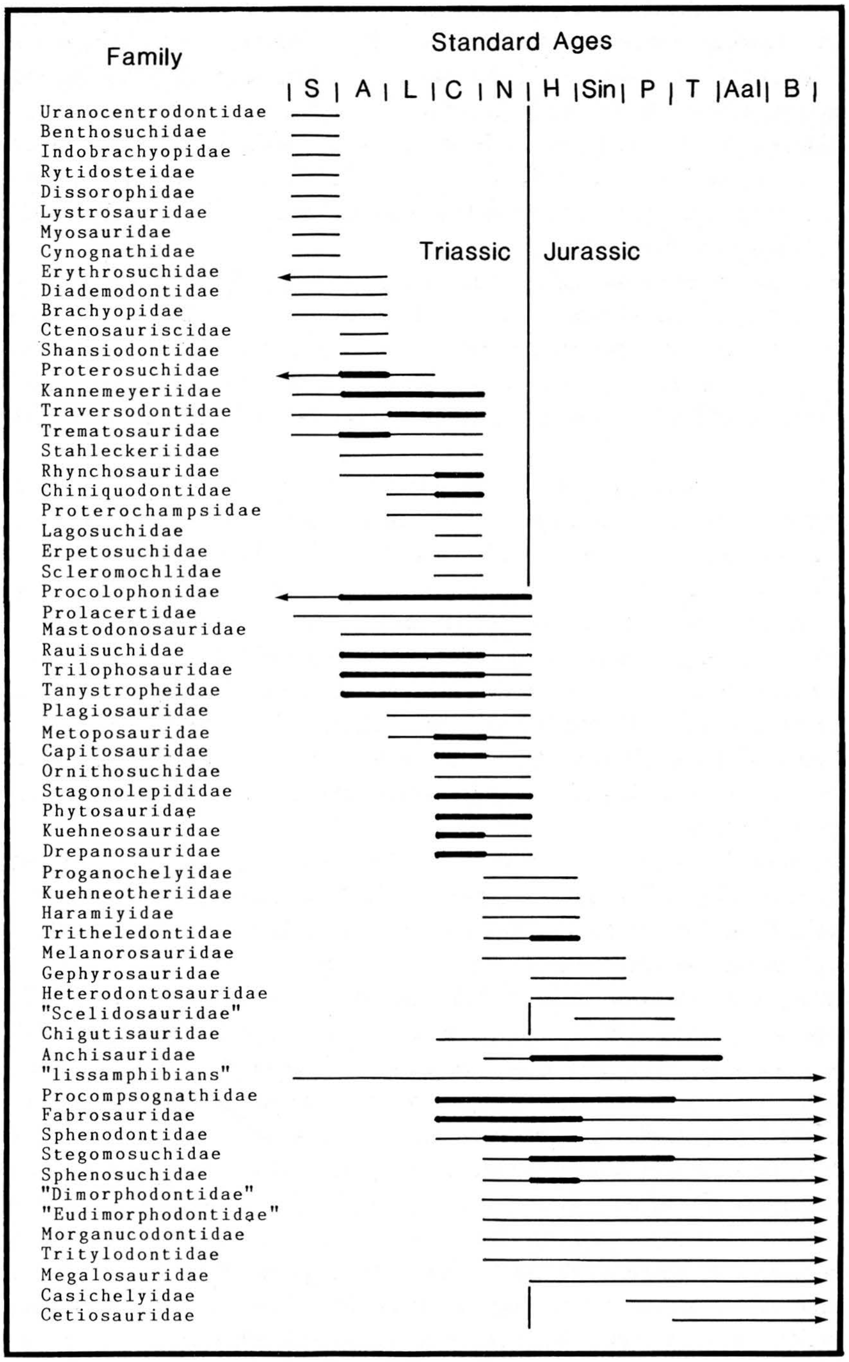

Fig. 8-18. Range chart for Triassic and Early Jurassic continental reptiles and amphibians (from Olsen et al., 1987). Thin bars indicate compiled global ranges while thick bars represent ranges in Newark Supergroup. Abbreviations for Standard Ages as follows: *S* = Scythian; *A* = Anisian; *L* = Ladinian; *C* = Carnian; *N* = Norian; *H* = Hettangian; *Sin* = Sinemurian; *P* = Pliensbachian; *T* = Toarcian; *Aal* = Aalenian; and *B* = Bajocian.

At this point, however, the pattern of extinctions and survivor families seen though the Newark Triassic – Jurassic boundary is consistent with a catastrophic cause. Throughout the Newark Supergroup there is no basic change in the climate-sensitive sediments through the Triassic – Jurassic boundary, other than that seen in the continuing repetitive pattern of Van Houten cycles. The widespread volcanism of the Early Jurassic does not begin until after the extinction event and on a world-wide scale the boundary sits in the middle of an unimpressive transgressive-regressive cycle. Following the Alvarez et al. (1980) paradigm for the Cretaceous – Tertiary boundary, Olsen (1986b) and Olsen et al. (1986, 1987) hypothesize that the cause of the extinctions may have been a major asteroid or comet impact. A possible site for such an impact is already known – the 70 km Manicouagan structure of Quebec, radiometrically dated at near the Triassic – Jurassic boundary (206 – 213 Ma). However, before a direct connection, between this impact and the extinctions can be made, some ejecta, either shocked quartz or a geochemical anomaly, must be found in Newark Supergroup sections. Discovery of such an ejecta layer will allow crucial tests of the generality of the Alvarez et al. (1980) theory of the impact origin of mass extinctions. Only if the ejecta layer is directly tied to the interval of extinctions will the impact theory be supported. If it occurs anywhere else, it will show that giant impacts need not cause mass extinctions and some other cause must be sought for the Triassic – Jurassic extinctions.

The taxonomic recovery after the Triassic – Jurassic extinction differed in many ways from that of the Cretaceous – Tertiary. About seventy-five million years followed the Late Triassic extinction event before the family-level diversity of terrestrial vertebrates surpassed Late Triassic levels (Padian and Clemens, 1985). In contrast, it took less than 10 million years for the number of Tertiary terrestrial vertebrate families to recover to their Late Cretaceous levels. On the other hand, the recovery time for marine invertebrates was roughly 20 million years for both extinction events (Raup and Sepkoski, 1982). The reasons for the difference between the recovery times of the terrestrial vertebrate patterns of the Late Triassic and Late Cretaceous extinctions are not at all apparent. Perhaps the differences have something to do with the extremely uniform Jurassic and Early Cretaceous global flora which contrasts with the much more provincial flora of the Tertiary.

Our understanding of the evolutionary patterns of the recovery period following a catastrophe of the magnitude predicted by the impact model is very poor at the population and species levels. However, we might gain some insight by speculative analogy with the microcosm of the evolutionary patterns seen in the fishes of Newark Jurassic Van Houten cycles. Within the first few thousand years after the catastrophe, the world biota would consist only of the remaining survivor species, but the numbers of individuals would increase exponentially as the base of the food chain recovered. Presumably, individual populations and species dominance would be highly unstable and subject to occasional crashes. However, within a few tens of thousands of years, certain of these surviving species might radiate explosively into hundreds and thousands of new, morphologically rather similar species, filling the newly vacated ecological space with more specialized and more stable occupants. Other forms would speciate at lower rates, some changing little, other showing considerable morphological and ecological change. Eventually, on a scale of several million years, we might expect some groups of species to have become so different from their ancestors that we would recognize them as new higher taxa such as families. Much more specialized members of these new, more distantly related families might after 10 or more million years crowd out the opportunistically speciating groups and eventually surpass the precatastrophic levels of family diversity. Of course, the precise response would ultimately depend on the intrinsic properties of the surviving groups and the phase relations and magnitude of effect of the other levels in the hierarchy of environmental perturbations.

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Appendix

Fluvial sequences

AGE Taxon	Formation	Environment	Reference
ANISIAN			
Mollusca (mollusks)			
?Unionidae (?fresh water mussels)			
undetermined clams	L. Wolfville (F)	1 – 2	Caroll et al., 1972
Labyrinthodontia (labyrinthodont amphibians)			
Trematosauridae			
Aphaneramma sp.	L. Wolfville (F)	1 – 2	Baird, 1986b
cf. Capitosauridae			
undetermined form	L. Wolfville (F)	1 – 2	Baird, 1986b
Procolophonia (procolophonids)			
cf. *Sclerosaurus* sp.	L. Wolfville (F)	1 – 2	Baird, 1986b
Anomoiodon sp.	L. Wolfville (F)	1 – 2	Baird, 1986b
Synapsida (mammal-like reptiles)			
Traversodontidae (chisel-toothed mammal-like reptiles)			
cf. *Exaeretodon* sp.	L. Wolfville (F)	1 – 2	Baird, 1986b
?Dicynodontia (beaked mammal-like reptiles)			
indet. (jugal)	L. Wolfville (F)	1 – 2	Baird, 1986b
Sauria (saurian reptiles)			
Tanystropheidae (long-necked lizard-like forms)			
Tanystropheus sp.	L. Wolfville (F)	1 – 2	Baird, 1986b
cf. Proterosuchidae (primitive long snouted archosaurs)			
indet. (jaw)	L. Wolfville (F)	1 – 2	Baird, 1986b
?Aetosauridae (herbivorous advanced non-dinosaur archosaurs)			
indet. (scute)	L. Wolfville (F)	1 – 2	Baird, 1986b
Rauisuchidae (carnivorus advanced non-dinosaur archosaurs)			
indet. (teeth)	L. Wolfville (F)	1 – 2	Baird, 1986b
Trilophosauridae (chisel-toothed archosauromorphs)			
indet. (teeth)	L. Wolfville (F)	1 – 2	Baird, 1986b

AGE Taxon	Formation	Environment	Reference
EARLY CARNIAN			
Mollusca (mollusks)			
Unionidae (fresh water mussels)			
undetermined clams	Coal Measures (R)	3	this paper
undetermined clams	L. Otterdale (R)	3–5	this paper
undetermined clams	Doswell (T)	3–5	Weems, 1980
undetermined clams	Briery Creek (B)	5	this paper
undetermined clams	Scottsville (Sc)	5	this paper
Crustacea			
Conchostraca (clam shrimp)			
Cyzicus spp.	?Barren Beds (R)	6	this paper
Cyzicus spp.	Coal Measures (R)	3–6	this paper
Cyzicus spp.	Vinta (R)	5–5	this paper
Cyzicus spp.	L. Otterdale (R)	3–5	this paper
Cyzicus spp.	Scottsville (Sc)	5	this paper
Cyzicus spp.	Doswell (T)	3–5	Weems, 1980
Cyzicus spp.	Briery Creek (B)	5–6	Tucker, 1979
Cyzicus spp.	Scottsville (Sc)	5	this paper
Darwinulidae (darwinulid ostracodes)			
Darwinula spp.	Coal Measures (R)	3–6	this paper
Darwinula spp.	Vinta (R)	5–5	this paper
Darwinula spp.	L. Otterdale (R)	3–5	this paper
Darwinula spp.	Scottsville (R)	5	this paper
Darwinula spp.	Doswell (T)	3–5	this paper
Darwinula spp.	Briery Creek (B)	5–6	Tucker, 1979
Darwinula spp.	Scottsville (Sc)	5	this paper
Darwinula spp.	Farmville (Fv)	5	this paper
?Decapoda			
**Scoyenia* sp.	Otterdale (R)	2–5	this paper
**Scoyenia* sp.	Doswell (T)	2	this paper
Insecta			
?Heteroptera (true bugs)			
indet.	Briery Creek (B)	5	this paper
?Ephemoptera			
indet.	Briery Creek (B)	5	Tucker, 1979
Coleoptera			
indet.	Briery Creek (B)	5	Tucker, 1979
indet.	Coal Measures (R)	5	this paper
Pisces (fish)			
Redfieldiidae			
Dictyopyge macrurus	?Barren Beds (R)	6	Schaeffer and McDonald, 1978
Dictyopyge macrurus	Coal Measures (R)	3–6	Schaeffer and McDonald, 1978
Dictyopyge macrurus	Vinta (R)	5–6	Schaeffer and McDonald, 1978
Dictyopyge macrurus	L. Otterdale (R)	3–5	this paper
Dictyopyge macrurus	Scottsville (Sc)	5	Schaeffer and McDonald, 1978
Dictyopyge macrurus	Doswell (T)	3–6	Schaeffer and McDonald, 1978
Cionichthyes sp.	?Barren Beds (R)	6	Olsen et al., 1982
indeterminate	Farmville (Fv)	5	this paper
Palaeonisciformes incertae sedis			
Tannaocrossus sp.	Coal Measures (R)	6	Schaeffer and McDonald, 1978
Labyrinthodontia (labyrinthodont amphibians)			
?Capitosauridae			
Calamops paludosus	L. Stockton (N)	?3	Sinclair, 1917

AGE Taxon	Formation	Environment	Reference
Synapsida (mammal-like reptiles)			
Traversodontidae (chisel-toothed mammal-like reptiles)			
cf. *Massetognathus* sp.	L. Otterdale (R)	3	this paper
Sauria (saurian reptiles)			
Doswellidae (odd long-snouted and armoured archosauromorphs)			
Doswellia kaltenbachi	Doswell (T)	3 – 5	Weems, 1980
Archosauromorpha			
various bones and teeth	L. Otterdale (R)	3	this paper
MIDDLE AND LATE CARNIAN			
Annelida (segmented worms)			
?Polychaeta			
?*Spirorbis*	M. New Oxford (G)	2 – 3	Wanner, 1921
Mollusca			
Unionidae			
Diplodon spp.	M. New Oxford (G)	2 – 3	Wanner, 1921
Diplodon sp.	L. Lockatong (N)	4	Olsen, 1980c
undetermined	L. Lockatong (N)	5	Conrad, 1858
undetermined	U. Stockton (N)	5	Olsen, 1980b
undetermined	L. Cow Branch (Dd)	3 – 4	Olsen et al., 1978
undetermined	M. Pekin (S)	5	this paper
undetermined	Cumnock (S)	5	Olsen, 1980c
undetermined	Sanford (D)	5	Olsen, 1977
undetermined	M. Wolfville (F)	2	Caroll et al., 1972
Corbiculidae			
indet.	Sanford (D)	5	Olsen, 1977
Xiphosura (horseshoe crabs)			
?indet. (partial carapace)	Lockatong (N)	5	Wheatley, 1861
**Kophichnium* sp.	Stockton (N)	3	Caster, 1939
**Kophichnium* sp.	Lockatong (N)	5	this paper
Crustacea			
Conchostraca (clam shrimp)			
Cyzicus spp.	M. Pekin (W)	3 – 5	this paper
Cyzicus spp.	M. Pekin (S)	5	Hope and Patterson, 1969
Cyzicus spp.	Cumnock (S)	3 – 5	this paper
Cyzicus spp.	Sanford (S)	5	this paper
Cyzicus spp.	Sanford (D)	5	Olsen, 1977
Cyzicus spp.	Cow Branch (Dd)	3 – 6	Olsen et al., 1978
Cyzicus spp.	M. New Oxford (G)	5	this paper
Cyzicus spp.	U. Stockton (N)	5	Olsen, 1980b
Cyzicus spp.	Lockatong (N)	3 – 6	Olsen, 1980b
Cyzicus spp.	M. Wolfville (F)	?2	Klein, 1962
cf. *Palaeolimnadia*	Cumnock (S)	5	this paper
cf. *Palaeolimnadia*	U. Cow Branch (Dd)	6	Olsen et al., 1978
cf. *Palaeolimnadia*	L. Lockatong (N)	6	this paper
Ostracoda (ostracodes)			
Darwinula spp.	M. Pekin (W)	3 – 5	this paper
Darwinula spp.	Cumnock (S)	3 – 5	this paper
Darwinula spp.	Sanford (S)	5	this paper
Darwinula spp.	Sanford (D)	5	Bain and Harvey, 1977
Darwinula spp.	Cow Branch (Dd)	5	Olsen et al., 1978
Darwinula spp.	M. New Oxford (G)	5	this paper
Darwinula spp.	U. Stockton (N)	5	Olsen, 1980b

AGE Taxon	Formation	Environment	Reference
Darwinula spp.	Lockatong (N)	3 – 5	Olsen, 1980b
undetermined	Cumnock (S)	5	this paper
Decapoda			
cf. *Cyticlopsis* sp.	Sanford (D)	5	Olsen, 1977
cf. *Cyticlopsis* sp.	U. Cow Branch (Dd)	6	this paper
**Scoyenia*	Pekin (W)	2 – 5	this paper
**Scoyenia*	Pekin (S)	2 – 5	this paper
**Scoyenia*	Sanford (S)	2 – 5	Olsen, 1977
**Scoyenia*	Sanford (D)	2 – 5	this paper
**Scoyenia*	Cow Branch (Dd)	2 – 5	this paper
**Scoyenia*	New Oxford (G)	2 – 5	this paper
**Scoyenia*	M. – U. Stockton (N)	2 – 5	this paper
**Scoyenia*	Lockatong (N)	2 – 5	this paper
**Scoyenia*	L. Passaic (N)	2 – 5	this paper
**Scoyenia*	M. Wolfville (F)	2 – ?5	this paper
?Phyllocarida			
indet.	U. Cow Branch (Dd)	6	Olsen et al., 1978
?Euthycaridae			
undetermined	U. Cow Branch (Dd)	6	this paper
undetermined	L. Lockatong (N)	6	this paper
Insecta			
Glosselytrodida			
undetermined wing	U. Cow Branch (Dd)	6	Olsen et al., 1978
Hemiptera (true bugs)			
undetermined	U. Cow Branch (Dd)	6	Olsen et al., 1978
Blattoidea (roaches)			
undetermined	U. Cow Branch (Dd)	6	Olsen et al., 1978
Neuroptera (nerve wings)			
undetermined wing	U. Cow Branch (Dd)	6	Olsen et al., 1978
Coleoptera (beetles)			
several undetermined genera	U. Cow Branch (Dd)	6	Olsen et al., 1978
undetermined	U. Stockton (N)	5	Olsen, 1980b
undetermined	Cumnock (S)	5	Olsen, 1980c
undetermined	Sanford (D)	5	Olsen, 1977
Psocoptera			
undetermined genus	U. Cow Branch (Dd)	6	Olsen et al., 1978
Diptera (true flies)			
several undetermined genera	U. Cow Branch (Dd)	6	Olsen et al., 1978
Pisces (fish)			
Hybondontidae (hybodont sharks)			
Carinacanthus jepseni	L. Lockatong (N)	6	Bryant, 1934
Palaeoniscidae			
'Amblypterus'	L. Cumnock (S)	5	Emmons 1856
Turseodus acutus	Lockatong (N)	5 – 6	Schaeffer, 1952b
Turseodus spp.	Lockatong (N)	3 – 6	Olsen, 1980c
Turseodus spp.	M. New Oxford (G)	5	Olsen et al., 1982
Turseodus spp.	Cow Branch (Dd)	6	Olsen et al., 1978
Turseodus sp.	Sanford (D)	5	Olsen, 1977
Redfieldiidae			
Cionichthyes oberi	L. Lockatong (N)	6	Bock, 1959
Cionichthyes sp.	Lockatong (N)	3 – 6	Olsen et al., 1982
Cionichthyes sp.	L. Cumnock (S)	3 – 5	Olsen et al., 1982
Cionichthyes sp.	M. Pekin (W)	5	Olsen et al., 1982

AGE Taxon	Formation	Environment	Reference
Cionichthyes sp.	M. Pekin (S)	5	Olsen et al., 1982
Cionichthyes sp.	M. New Oxford (G)	5	Olsen et al., 1982
Synorichthyes sp.	Lockatong (N)	3 – 6	Olsen et al., 1982
Synorichthyes sp.	Cumnock (S)	3 – 5	Olsen et al., 1982
Synorichthyes sp.	Cow Branch (Dd)	6	Olsen et al., 1978
Synorichthyes sp.	M. New Oxford (G)	5	Olsen et al., 1982
Synorichthyes sp.	Sanford (D)	5	Olsen, 1977
Semionotidae			
Semionotus brauni	L. Lockatong (N)	5 – 6	Olsen, 1980c
Semionotus brauni	U. Cow Branch (Dd)	6	Olsen et al., 1982
Semionotus sp.	Lockatong (N)	3 – 6	Olsen et al., 1982
Semionotus sp.	'Sanford' (D)	5	Olsen et al., 1982
Semionotus sp.	?Cumnock (S)	5	Emmons, 1857
?Pholidophoridiformes			
undescribed form	U. Cow Branch (Dd)	6	Olsen et al., 1982
Coelacanthidae			
Pariostegus myops	L. Cumnock (S)	3	Cope, 1868, 1875
?*Pariostegus* sp.	Cumnock (S)	3 – 5	this paper
?*Pariostegus* sp.	U. Cow Branch (Dd)	6	this paper
?*Pariostegus* sp.	Lockatong (N)	3 – 6	this paper
Osteopleurus newarki	L. Lockatong (N)	3 – 6	Schaeffer, 1952a
Osteopleurus newarki	U. Cow Branch (Dd)	5 – 6	Olsen et al., 1982
Labyrinthodontia (labyrinthodont amphibians)			
Metoposauridae			
Metoposaurus bakeri	M. Wolfville (F)	2	Baird, 1986a
Metoposaurus sp.	M. New Oxford (G)	2	Colbert and Imbrie, 1956
Metoposaurus sp.	M. New Oxford (G)	5	Baird, 1986a
Eupelor durus	L. Lockatong (N)	5	Cope, 1866
Dictyocephalus myops	L. Cumnock (S)	3	Emmons, 1856
indeterminate scarps	M. Pekin (W)	2	this paper
Procolophonia (procolophonids)			
Leptopleuron sp.	M. Wolfville (F)	2	Baird and Olsen, 1983
3 new genera	M. Wolfville (F)	2	Baird and Olsen, 1983
Synapsida (mammal-like reptiles)			
Chiniquidontidae (advanced mammal-like reptiles)			
Microcodon tenuis	L. Cumnock (S)	3	Emmons, 1856
Cynodontia indet. (advanced mammal-like reptiles)			
Dromatherium elegans	L. Cumnock (S)	3	Emmons, 1856
Kannemeyeriidae (large-beaked mammal-like reptiles)			
Placerias sp.	M. Pekin (S)	3	Baird and Patterson, 1967
indet.	M. Wolfville (F)	2	Baird and Olsen, 1983
Traversodontidae (chisel-toothed mammal-like reptiles)			
Scalenodontoides sp.	M. Wolfville (F)	2	Hopson, 1984
Drepanosauridae (odd ?mammal-like reptiles)			
'deep tailed swimmer'	L. Lockatong (N)	5 – 6	Olsen, 1980c
Sauria (saurian reptiles)			
?Sphenodontidae (tuatara and its relatives)			
**Rhynchosauroides hyperbates*	L. Lockatong (N)	3	Olsen and Baird, 1986
**Rhynchosauroides brunswickii*	L. Lockatong (N)	3	Olsen and Baird, 1986
Trilophosauridae (chisel-toothed archosauromorphs)			
indet. (jaw)	M. Wolfville (F)		Baird and Olsen, 1983
Rhynchosauridae (split-beaked archosauromorphs)			
Hyperdapedon sp	M. Wolfville (F)		Baird and Olsen, 1983

AGE Taxon	Formation	Environment	Reference
Tanystropheidae (long-necked lizard like forms)			
Tanytrachelos ahynis	U. Cow Branch (Dd)	6	Olsen, 1979
Tanytrachelos ahynis	Lockatong (N)	4 – 6	Olsen, 1980c
Gwynnedichnium majore	L. Lockatong (N)	3	Bock, 1952
Gwynnedichnium sp.	M. Pekin (W)	3	this paper
Kuehneosauridae (gliding lizard-like forms)			
Icarosaurus seifkeri	L. Lockatong (N)	6	Colbert, 1970
Aetosauridae (herbivorous advanced non-dinosaur archosaurs)			
cf. *Stagonolepis* sp.	M. Wolfville (F)	2	Olsen and Baird, 1982
Stegomus sp.	Sanford (D)	2	Olsen, 1977
cf. *Stegomus* sp.	M. Wolfville (F)	2	Olsen and Baird, 1982
Rauisuchidae (carnivorous advanced non-dinosaur archosaurs)			
teeth	M. Wolfville (F)	2	Baird and Olsen, 1982
?*Zatomus sacrophagus*	Cumnock (S)	?5	Cope, 1871
Parasuchia (phytosaurs)			
Rutiodon carolinensis	L. Cumnock (S)	4	Emmons, 1856
Rutiodon carolinensis	M. Pekin (W)	2	Baird and Patterson, 1967
Rutiodon carolinensis	M. Pekin (S)	4	Baird and Patterson, 1967
Rutiodon carolinensis	L. Lockatong (N)	3 – 5	Cope, 1871; Colbert, 1965
Rutiodon carolinensis	Cow Branch (Dd)	3 – 5	Emmons, 1856
Rutiodon carolinensis	M. New Oxford (G)	5	Baird, 1986a
teeth, bones, and scutes	Sanford (D)	2	Olsen, 1977
Rutiodon manhattenensis	U. Stockton (N)	2	Huene, 1913
Apatopus lineatus	U. Stockston (N)	3	Olsen, 1980c
Apatopus sp.	Lockatong (N)	3	Olsen, 1980c
Apatopus sp.	M. Pekin (S)	3	this paper
Pseudosuchia incertae sedis (advanced non-dinosaur archosaurs)			
Brachychirotherium (Rigalites)	M. Peking (S)	3	Olsen and Galton, 1984
Brachychirotherium spp.	M. Pekin (S)	3	this paper
Brachychirotherium eyermani	L. Lockatong (N)	3	Olsen and Baird, 1986b
Brachychirotherium eyermani	U. Stockton (N)	3	Olsen, 1980c
Theropoda (carnivorous lizard-hipped dinosaurs)			
cf. *Coelophysis*	M. Wolfville (F)	2	Baird and Olsen, 1983
Grallator (Grallator) spp.	L. Lockatong (N)	3	Olsen and Baird, 1986b
Grallator (Grallator) spp.	U. Stockton (N)	2	Olsen, 1980c
'Fabrosauridae' (poorly defined primitive bird-hipped dinosaurs)			
new genus (jaw)	M. Wolfville (F)	2	Caroll et al., 1972
new genus (teeth)	M. Pekin (W)	4 – 5	this paper
'Thecodontosaurus gibbidens'	M. New Oxford (G)	2	Olsen, 1980d
'Dinosauria' indet.			
partial skeleton and bones	M. Wolfville (F)	2	Baird and Olsen, 1983
**Atreipus milfordensis*	L. Lockatong (N)	3	Olsen and Baird, 1986b
?**Atreipus* sp.	U. Stockton (N)	2	Olsen and Baird, 1986b
inderminant tracks	M. Pekin (S)	3	this paper
NORIAN			
Mollusca			
Unionidae (fresh water mussels)			
indet.	Bull Run (C)	5	Gore, 1983
Crustacea			
Darwinulidae (darwinulid ostracodes)			
Darwinula sp.	Bull Run (C)	5	Gore, 1983
Darwinula sp.	Passaic (N)	5	this paper
Darwinula sp.	Blomidon (F)	5	this paper

AGE Taxon	Formation	Environment	Reference
Candonidae (candonid ostracodes)			
undetermined	Blomidon (F)	5	B. Cameron, pers. commun., 1987
undetermined	L. Passaic (N)	5	this paper
Conchostraca (clam shrimp)			
Cyzicus sp.	Bull Run (C)	5	Gore, 1986
Cyzicus sp.	Gettysburg (G)	5	this paper
Cyzicus sp.	Passaic (N)	5	Olsen, 1980b
Cyzicus sp.	Blomidon (F)	5	Caroll et al., 1972
?*Palaeolimnadia*	Bull Run (C)	5	Gore, 1983
cf. *Palaeolimnadia*	L. Passaic (N)	5	this paper
Ellipsograpta sp.	L. Passaic (N)	5	this paper
?Decapoda (crawfish etc.)			
**Scoyenia*	U. Sanford (S)	2 – 3	this paper
**Scoyenia*	U. Sandord (D)	2 – 3	this paper
**Scoyenia*	Bull Run (C)	2 – 5	this paper
**Scoyenia*	Gettysburg (G)	2 – 5	this paper
**Scoyenia*	Passaic (N)	2 – 5	Olsen, 1980b
**Scoyenia*	New Haven (H)	2 – 3	Hubert et al., 1978
**Scoyenia*	Sugarloaf (Df)	2 – 3	Stevens and Hubert, 1980
**Scoyenia*	New Britain (P)	2 – 3	Hubert et al., 1978
**Scoyenia*	Blomidon (F)	3	this paper
Xiphosura (horseshoe crabs)			
**Kophichnium* sp.	L. Passaic (N)	3	Olsen, 1980b
Insecta			
Coleoptera (beetles)			
undetermined staphylinid	Bull Run (C)	5	Gore, 1983
Pisces (fish)			
Redfieldiidae			
Synorichthyes sp.	L. Passaic (N)	5	Olsen et al., 1982
indeterminate	M. Blomidon (F)	5	Olsen et al., 1982
Semionotidae			
Semionotus sp.	L. Passaic (N)	5 – 6	Olsen et al., 1982
Semionotus sp.	M. Bull Run (C)	5	Olsen et al., 1982
Coelacanthidae (coelacanths)			
Osteopleurus sp.	L. Passaic (N)	5	Olsen et al., 1982
indeterminate	U. Passaic (N)	?2	Colbert, 1946
Procolophonia (procolophonids)			
Hypsognathus fenneri	U. Passaic (N)	2	Colbert, 1946; Baird 1986a
Hypsognathus fenneri	U. New Haven (H)	2	Olsen, 1980d
Hypsognathus cf. *fenneri*	U. Wolfville (F)	2	Olsen and Baird, in prep.
**Procolophonichnium* sp.	U. Passaic (N)	2	Baird, 1986
?Kannemeyeriidae (large-beaked mammal-like reptiles)			
?**Dicynodontipes* sp.	M. Gettysburg (G)	3	Olsen and Baird, 1986a
Sauria (saurian reptiles)			
Tanystropheidae (long-necked lizard-like forms)			
**Gwyneddichnium majore*	U. Passaic (N)	2	Baird, 1986a
Sphenodontidae (tuatara and relatives)			
cf. *Sigmala*	U. New Haven (H)	2	Olsen, 1980d
**Rhynchosauroides hyperbates*	L. Passaic (N)	3	Baird, 1957
**Rhynchosauroides brunswickii*	L.-U. Passaic (N)	3	Baird, 1957
**Rhynchosauroides* sp.	U. Passaic (N)	3	this paper
**Rhynchosauroides* sp.	M. Blomidon (F)	3	this paper

AGE Taxon	Formation	Environment	Reference
**Rhynchosauroides* sp.	U. Wolfville (F)	2	Olsen and Baird, in prep.
**Rhynchosauroides* sp.	Bull Run (C)	3	RE. Weems, pers. commun., 1985
Rhynchosauridae (split-beaked archosauromorphs)			
Sphodrosaurus pennsylvanicus	L. Passaic (N)	?3	Baird, 1986a
Parasuchia (phytosaurs)			
Clepsysaurus pennsylvanicus	L. Passaic (N)	2	Lea, 1853
Belodon validus	M. New Haven (H)	2	Marsh, 1893
Rutiodon sp.	M. Passaic (N)	3	Baird, 1986a
Rutiodon sp.	L. Balls Bluff (C)	2–3	Weems, 1980
**Apatopus lineatus*	L. Passaic (N)	3	Baird, 1957
**Apatopus* sp.	U. Passaic (N)	2	Baird, 1986a
Aetosauridae (armoured advanced non-dinosaur archosaurs)			
Stegomus arcuatus	L. Passaic (N)	2–3	Baird, 1986a
Stegomus arcuatus	L. New Haven (H)	2	Marsh, 1896b
Pseudosuchia incertae sedis (advanced non-dinosaur archosaurs)			
**Chirotherium lulli*	L. Passaic (N)	3	Baird, 1954
**Brachychirotherium parvum*	L. Passaic (N)	3	Baird, 1957
**Brachychirotherium* cf. *parvum*	U. Wolfville (F)	2	Olsen and Baird, 1986b
**Brachychirotherium eyermani*	L. Passaic (N)	3	Baird, 1957
**Brachychirotherium eyermani*	M. Gettysburg (G)	3	Olsen and Baird, 1986
**Brachychirotherium* sp.	L.–U. Passaic (N)	2–3	Olsen and Baird, 1986
Theropoda (carnivorous lizard-hipped dinosaurs)			
**Grallator (Grallator)* spp.	L.–U. Passaic (N)	3	Olsen and Baird, 1986
**Grallator (Grallator)* spp.	M. Gettysburg (G)	3	Olsen and Baird, 1986
**Grallator (Grallator)* spp.	M. Blomidon (F)	3	this paper
**Grallator (Anchisauripus)* spp.	M.–L. Passaic (N)	3	Olsen, 1980b.
**Grallator (Anchisauripus)* sp.	M. Blomidon (F)	3	this paper
Anchisauridae (prosauropod dinosaurs)			
indet. prosauropod	Chedabucto (CO)	2	Caroll et al., 1972
'Dinosauria' indet.			
**Atreipus milfordensis*	L. Passaic (N)	3	Olsen and Baird, 1986b
**Atreipus milfordensis*	M. Gettysburg (G)	3	Olsen and Baird, 1986b
**Atreipus milfordensis*	U. Cow Branch (Dd)	3	Olsen and Baird, 1986b
**Atreipus sulcatus*	L. Passaic (N)	3	Olsen and Baird, 1986b
**Atreipus acadianus*	U. Wolfville (F)	2	Olsen and Baird, 1986b
**Atreipus sp.*	U. Passaic (N)	3	Baird, pers. commun., 1987.
'dinosaur limb'	U. Passaic (N)	2	Colbert, 1947
HETTANGIAN–?TOARCIAN			
Mollusca (mollusks)			
Unionidae (fresh water mussels)			
undetermined	Shuttle Meadow (H)	4	this paper
undetermined	L. Portland (H)	4	McDonald and Letourneau, in press
'Unio' wilbrahamensis	? Portland (H)	?4	Emerson, 1900
undetermined	Scots Bay (F)	5	this paper
undetermined	McCoy Brook (F)	5	this paper
Gastropoda (snails)			
Hydrobia sp.	Scots Bay (F)	4–5	Cameron, 1986
Valvata sp.	Scots Bay (F)	4–5	Cameron, 1986
Gyraulus sp.	Scots Bay (F)	4–5	Cameron, 1986
undetermined	Waterfall (C)	?4	Hentz, 1985

AGE Taxon	Formation	Environment	Reference
Crustacea			
Conchostraca			
Cyzicus sp.	U. Passaic (N)	5	Cornet, 1977a
Cyzicus sp.	U. Blomidon (F)	4	Caroll et al., 1972
Cyzicus sp.	L. Portland (H)	5	McDonald and LeTourneau, in press
Cyzicus sp.	Scots Bay (F)	5	this paper
Cornia sp.	Waterfall (C)	6	Gore, 1983
cf. *Cornia* sp.	Midland (C)	6	Gore, 1983
cf. *Cornia* sp.	East Berlin (H)	6	McDonald, pers. commun., 1987
Darwinulidae (darwinulid ostracodes)			
Darwinula sp.	Feltville (N)	5	Olsen, 1980b
Darwinula sp.	Midland (C)	5	Gore, 1983
Darwinula sp.	Waterfall (C)	5 – 6	Hentz, 1985
Darwinula sp.	L. Portland (H)	5	McDonald and LeTourneau, in press
Darwinula sp.	East Berlin (H)	5	Hubert et al., 1978
Darwinula sp.	Shuttle Meadow (H)	5	Hubert et al., 1978
Darwinula sp.	Scots Bay (F)	4 – 5	Birney, 1986
Darwinula sp.	McCoy Brook (F)	5	this paper
Metacypris sp.	Scots Bay (F)	4 – 5	Cameron, 1986
?Decapoda (crawfish etc.)			
**Scoyenia*	U. Passaic (N)	2 – 3	this paper
**Scoyenia*	New Haven (H)	2 – 3	this paper
**Scoyenia*	U. Sugarloaf (Df)	2 – 3	this paper
**Scoyenia*	Portland (H)	2 – 5	Hubert et al., 1982
**Scoyenia*	Turners Falls (Df)	2 – 5	this paper
Xiphosura (horseshoe crabs)			
**Kophichnium* sp.	U. Blomidon (F)	4	Caroll et al., 1972
Insecta			
?*Neuroptera* (lace wings)			
Mormolucoides articulatus	Turners Falls (Df)	5	Scudder, 1886
Coleoptera (beetles)			
undetermined	Towaco (N)	5	Olsen, 1980b
undetermined	L. Portland (H)	5	McDonald, pers. commun., 1987
undetermined			
undetermined larvae	L. Portland (H)	5	McDonald, pers. commun., 1987
?Insecta			
various tracks and trails	Portland (H)	2 – 5	Lull, 1953
various tracks and trails	Turners Falls	2 – 5	Lull, 1953
Pisces (fish)			
Hybondontidae (hybodont sharks)			
cf. *Hybodus* sp.	L. McCoy Brook (F)	1	Olsen et al., 1987
Redfieldiidae			
Redfieldius spp.	Midland (C)	6	Olsen et al., 1982
Redfieldius spp.	Waterfall (C)	6	Olsen et al., 1982
Redfieldius spp.	Boonton (C)	6	Olsen et al., 1982
Redfieldius spp.	Shuttle Meadow (H)	3 – 6	Olsen et al., 1982
Redfieldius spp.	East Berlin (H)	2 – 6	Olsen et al., 1982
Redfieldius spp.	Portland (H)	4 – 6	Olsen et al., 1982
Redfieldius spp.	Turners Falls (Df)	6	Olsen, 1983b

AGE Taxon	Formation	Environment	Reference
Redfieldius sp.	Shuttle Meadow (P)	5 – 6	Olsen et al., 1982
undetermined	L. McCoy Brook (F)	1	Olsen et al., sub.
Ptycholepidae			
Ptycholepis marshii	Midland (C)	6	Schaeffer et al., 1975
Ptycholepis marshii	Feltville (N)	6	Schaeffer et al., 1975
Ptycholepis marshii	Shuttle Meadow (H)	6	Schaeffer et al., 1975
Ptycholepis sp.	East Berlin (H)	6	McDonald, pers. commun., 1975
Ptycholepis sp.	Waterfall (C)	6	Schaeffer et al., 1975
Ptycholepis sp.	Boonton (N)	6	Schaeffer et al., 1975
Semionotidae			
'*Semionotus tenuiceps*' group	Feltville (N)	6	Olsen et al., 1982
'*Semionotus tenuiceps*' group	Towaco (N)	6	Olsen et al., 1982
'*Semionotus tenuiceps*' group	Turners Falls (N)	5 – 6	Olsen et al., 1982
'*Semionotus tenuiceps*' group	Waterfall (N)	6	Olsen, 1984a
'*Semionotus elegans*' group	Towaco (N)	6	Olsen et al., 1982
'*Semionotus elegans*' group	Boonton (N)	6	Olsen et al., 1982
'*Semionotus elegans*' group	Portland (H)	6	Olsen et al., 1982
'*Semionotus elegans*' group	Waterfall (H)	6	Olsen et al., 1982
'*Semionotus micropterus*' group	Towaco (N)	6	Olsen et al., 1982
'*Semionotus micropterus*' group	Shuttle Meadow (H)	6	Olsen et al., 1982
'*Semionotus micropterus*' group	Midland (C)	6	Olsen et al., 1982
'*Semionotus micropterus*' group	Waterfall (C)	6	Olsen et al., 1982
'*Semionotus micropterus*' group	Waterfall (C)	6	Olsen et al., 1982
Semionotus sp.	Waterfall (C)	5 – 6	Olsen et al., 1982
Semionotus sp.	Feltville (N)	5 – 6	Olsen et al., 1982
Semionotus sp.	Towaco (N)	3 – 6	Olsen et al., 1982
Semionotus sp.	Shuttle Meadow (H)	4 – 6	Olsen et al., 1982
Semionotus sp.	East Berlin (H)	2 – 6	Olsen et al., 1982
Semionotus sp.	Portland (H)	3 – 6	Olsen et al., 1982
Semionotus sp.	Shuttle Meadow (P)	6	Olsen et al., 1982
Semionotus sp.	McCoy Brook (F)	3 – 6	Olsen et al., 1982
Semionotus sp.	Scotts Bay (F)	4 – 6	Olsen et al., 1982
?Pholidophoridiformes			
'*Acentrophorus' chicopensis*	L. – M. Portland (H)	6	Olsen et al., 1982
Coelacanthidae (coelacanths)			
Diplurus longicaudatus	Boonton (N)	6	Schaeffer, 1948
Diplurus longicaudatus	Shuttle Meadow (H)	4 – 6	Schaeffer, 1948
Diplurus longicaudatus	East Berlin (H)	6	Schaeffer, 1948
Diplurus longicaudatus	Waterfall (C)	6	Olsen et al., 1982
Diplurus longicaudatus	Midland (C)	6	Olsen et al., 1982
Synapsida (mammal-like reptiles)			
Trithelodontidae			
Pachygenelus sp.	L. McCoy Brook (F)	1	Olsen et al., 1987
**Ameghinichnus* sp.	U. Towaco (N)	3	Olsen and Galton, 1984
Sauria (saurian reptiles)			
Sphendontidae (tuatara and relatives)			
cf. *Sigmala* sp.	L. McCoy Brook (F)	1	Olsen et al., 1987
cf. *Palycymalia*	L. McCoy Brook (F)	1	Olsen et al., 1987
**Rhynchosauroides* sp.	U. Towaco (N)	3	Olsen, 1980c
Sphenosuchidae (crocodylomorphs)			
new genus	L. McCoy Brook (F)	1	Olsen et al., 1987
?Sphenosuchidae			
**Otozoum moodii*	Portland (H)	2	Lull, 1953

AGE Taxon	Formation	Environment	Reference
**Otozoum moodii*	Turners Falls (H)	3	Lull, 1953
**Otozoum moodii*	McCoy Brook (H)	2–3	Olsen et al., 1987
Protosuchidae (early true crocodiles)			
Stegomosuchus longipes	M. Portland (H)	2	Emerson and Loomis, 1904
?new genus	L. McCoy Brook (F)	1	Olsen et al., 1987
**Batrachopus deweyii*	U. Passaic (N)	2	Olsen and Baird, 1986b
**Batrachopus deweyii*	Feltville (N)	3	Olsen, 1980b
**Batrachopus deweyii*	Towaco (N)	3	Olsen and Padian, 1986
**Batrachopus deweyii*	Boonton (N)	3	Olsen and Padian, 1986
**Batrachopus deweyii*	Shuttle Meadow (H)	3	Olsen and Padian, 1986
**Batrachopus deweyii*	East Berlin (H)	3	Olsen and Padian, 1986
**Batrachopus deweyii*	Portland (H)	2–3	Olsen and Padian, 1986
**Batrachopus deweyii*	Turners Falls (Df)	3	Olsen and Padian, 1986
**Batrachopus* sp.	(Culpeper) (C)	3	Olsen and Padian, 1986
**Batrachopus* spp.	Turners Falls (Df)	3	Olsen and Padian, 1986
**Batrachopus* spp.	Portland (H)	2–3	Olsen and Padian, 1986
**Batrachopus* spp.	McCoy Brook (F)	1–3	Olsen, 1981
Anchisauridae (prosauropod dinosaurs)			
Ammosaurus major	M–U Portland (H)	2	Marsh, 1889
Anchisaurus polyzelus	U. Portland (H)	2	Marsh, 1896
Theropoda (carnivorous lizard-hipped dinosaurs)			
Podokesaurus holyokensis	?M. Portland (H)	2	Lull, 1953
limb bones	M. Portland (H)	2	Colbert and Baird, 1958
tooth	Shuttle Meadow (H)	6	McDonald, pers. commun., 1987
tooth	Waterfall (C)	6	Hentz, 1984
**Grallator (Grallator)* spp.	U. Passaic (N)	2	Olsen and Baird, 1986b
**Grallator (Grallator)* spp.	Feltville (N)	3	Olsen, 1980c
**Grallator (Grallator)* spp.	Towaco (N)	3	Olsen, 1980c
**Grallator (Grallator)* spp.	Midland (C)	3	Lull, 1953
**Grallator (Grallator)* spp.	Hickory Run??? (C)	3	Lull, 1953
**Grallator (Grallator)* spp.	Waterfall (C)	3	Lull, 1953
**Grallator (Grallator)* spp.	Shuttle Meadow (H)	3	Lull, 1953
**Grallator (Grallator)* spp.	East Berlin (H)	2–3	Thorpe, 1929
**Grallator (Grallator)* spp.	Portland (H)	2–3	Lull, 1953
**Grallator (Grallator)* spp.	Turners Falls (Df)	3	Lull, 1953
**Grallator (Grallator)* spp.	McCoy Brook (F)	2–3	Olsen et al., 1987
**Grallator (Anchisauripus)* spp.	U. Passaic (N)	2	Olsen and Baird, 1986
**Grallator (Anchisauripus)* spp.	Feltville (N)	3	Olsen, 1980c
**Grallator (Anchisauripus)* spp.	Towaco (N)	3	Olsen, 1980c
**Grallator (Anchisauripus)* spp.	Midland (C)	3	Lull, 1953
**Grallator (Anchisauripus)* spp.	Hickory Run??? (C)	3	Lull, 1953
**Grallator (Anchisauripus)* spp.	Waterfall (C)	3	Lull, 1953
**Grallator (Anchisauripus)* spp.	Shuttle Meadow (H)	3	Lull, 1953
**Grallator (Anchisauripus)* spp.	East Berlin (H)	2–3	Thorpe, 1929
**Grallator (Anchisauripus)* spp.	Portland (H)	2–3	Lull, 1953
**Grallator (Anchisauripus)* spp.	Turners Falls (Df)	3	Lull, 1953
**Grallator (Anchisauripus)* spp.	McCoy Brook (F)	1–3	Olsen et al., 1987
**Grallator (Anchisauripus)* spp.	Scotts Bay (F)	2	Olsen, 1981
**Grallator (Eubrontes)* spp.	U. Passaic (N)	2	Olsen and Baird, 1986
**Grallator (Eubrontes)* spp.	Feltville (N)	3	Olsen, 1980c
**Grallator (Eubrontes)* spp.	Towaco (N)	3	Olsen, 1980c
**Grallator (Eubrontes)* spp.	Midland (C)	3	Lull, 1953

AGE Taxon	Formation	Environment	Reference
**Grallator (Eubrontes)* spp.	Hickory Run??? (C)	3	Lull, 1953
**Grallator (Eubrontes)* spp.	Waterfall (C)	3	Lull, 1953
**Grallator (Eubrontes)* spp.	Shuttle Meadow (H)	3	Lull, 1953
**Grallator (Eubrontes)* spp.	East Berlin (H)	2 – 3	Thorpe, 1929
**Grallator (Eubrontes)* spp.	Portland (H)	2 – 3	Lull, 1953
**Grallator (Eubrontes)* spp.	Turners Falls (Df)	3	Lull, 1953
**Grallator (Eubrontes)* spp.	McCoy Brook (F)	2, 3	Olsen et al., 1987
**Grallator (Eubrontes)* spp.	Scots Bay (F)	2	Olsen, 1981
'Fabrosauridae' (poorly defined primitive bird-hipped dinosaurs)			
Scutellosaurus sp.	L. McCoy Brook (F)	1	Olsen et al., 1987
new genus (teeth and bones)	L. McCoy Brook (F)	1	Olsen et al., 1987
?dorsal vertebra	Towaco (N)	6	this paper
**Anomoepus scambus*	Feltville (N)	3	this paper
**Anomoepus scambus*	Towaco (N)	3	this paper
**Anomoepus scambus*	Midland (C)	3	this paper
**Anomoepus scambus*	Shuttle Meadow (H)	3	this paper
**Anomoepus scambus*	East Berlin (H)	3	this paper
**Anomoepus scambus*	Portland (H)	2 – 3	this paper
**Anomoepus scambus*	Turners Falls (Df)	3	Lull, 1953
**Anomoepus scambus*	McCoy Brook (F)	2 – 3	this paper