Field Guide to the Vertebrate Paleontology of Late Triassic Age Rocks in the Southwestern Newark Basin (Newark Supergroup, New Jersey and Pennsylvania)

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Introduction

The Newark Supergroup of eastern North America (Fig. 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. 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, fishes, 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 (45 MY) during which these sediments were deposited, Newark fossils can be placed in an increasingly fine-scale sedimentological and paleoecological framework.

The Newark Basin (Fig. 2) is the largest of the rift sequences exposed in the United States and has been traditionally one of the richest areas for fossil collection, especially vertebrates. The purpose of this paper is to provide a guidebook to some of the more classic vertebrate localities in Triassic age rocks in the southwestern half of the Newark Basin and to highlight some of the major recent advances and outstanding problems.

This field trip was given on November 4, 1986, as part of the 46th Annual Meeting of the Society of Vertebrate Paleontology, in Philadelphia. This paper is essentially an updated, corrected, and slightly expanded version of the guidebook used for the field trip.

Institutional abbreviations: AMNH, American Museum of Natural History; ANSP, Academy of Natural Sciences of Philadelphia; PU, Princeton University collection now at YPM; YPM, Peabody Museum of Natural History, Yale University.

Geological Overview

The Newark Basin is a block-faulted, deeply eroded, half-graben (Figs. 2, 3). Along with other Newark Supergroup basins, the Newark basin developed on Paleozoic and Precambrian thrust faulted basement during the Triassic and continued subsiding well into the Early Jurassic. Most of the basin's northwest margin is bound by low-angle (20°-65°) normal, right and left oblique faults which are reactivated thrust faults developed during the Paleozoic Taconic, Acadian, and Alleghenian Orogenies (Ratcliffe, 1980; Ratcliffe & Burton, 1985); Ratcliffe et al., 1986) (Fig. 3). The Newark Basin appears to have been a relatively simple half-graben bound by these faults during most of its history (Olsen, 1985c). Most sediments dip 5° to 15° to the northwest towards the northwestern border faults. However, the hanging walls of most fault blocks are warped into a series of anticlines and synclines which die out towards the opposite sides of the blocks. Because of the large-scale block faulting which took place relatively late the basin's history and the folds, most stratigraphic intervals can be examined at the surface in three dimensions (Fig. 3).

Sedimentation seems to have begun in the Middle Carnian of the Late Triassic or perhaps as early as the Ladinian of the Middle Triassic with the deposition of the predominantly fluvial Stockton Formation. The following Lockatong and Passaic Formations were deposited in a lacustrine setting ringed by fluvial sequences. Shortly after the Triassic-Jurassic boundary (preserved in the upper Passaic Formation) massive tholeiitic basalt flows covered the basin floor in three episodes, each consisting of two or more cooling units and thin sedimentary units (Orange Mountain, Preakness, and Hook Mountain Basalts). These are separated by two sedimentary formations (Feltville and Towaco Formations) and covered by the Boonton Formation. The syn- and post-extrusive formations were formed in similar environments to the Passaic and Lockatong Formations except with a four- to six-fold increase in sedimentation rate. [The Passaic and overlying formations were included in the Bruswick Formation of Kummel (1897) and the Watchung Basalt of Darton (1890); for a review of the stratigraphic nomenclature of the Newark Basin see Olsen (1980a,b).] Sedimentation seems to have ended by the Middle Jurassic during the period of block faulting, and this was followed by

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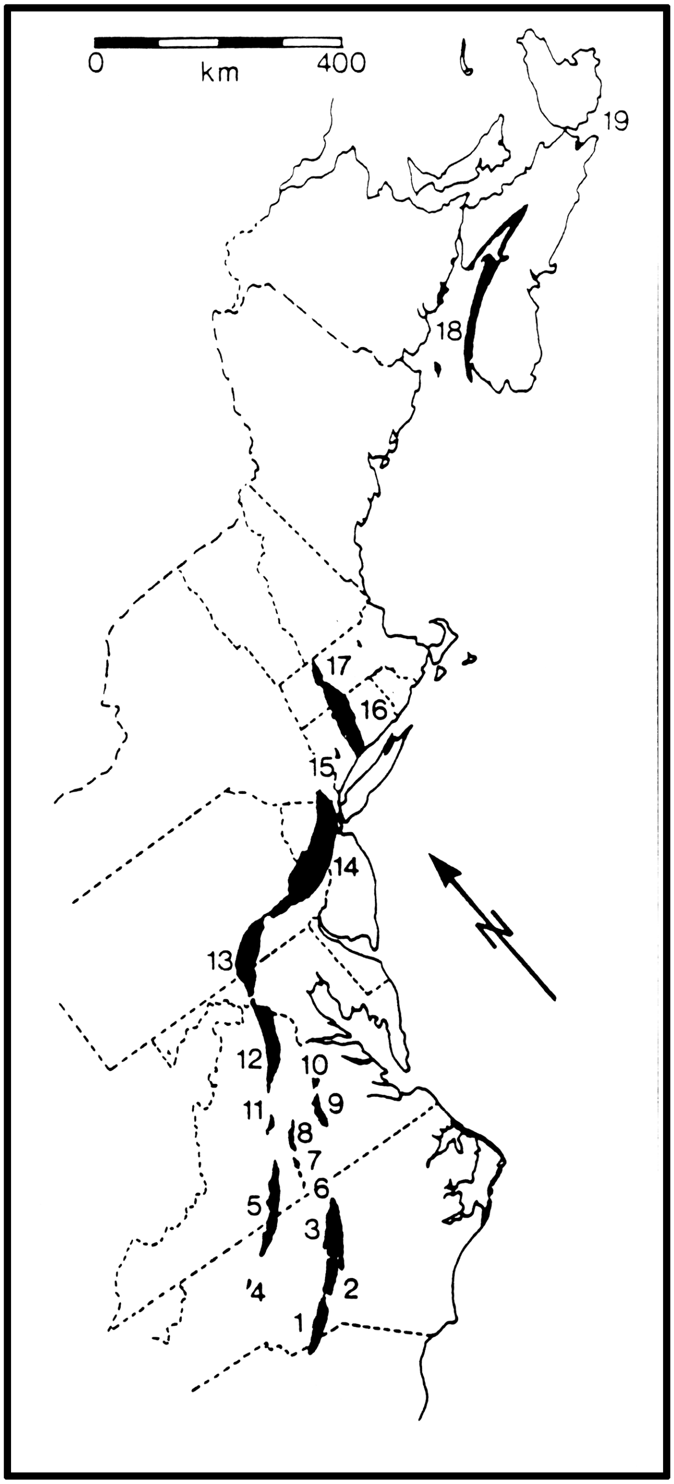


Figure 1. The Newark Supergroup of eastern North America. Exposed basins of the Newark Supergroup in black. Basin names are: **1-3**, Deep River Basin; **4**, Davie County Basin; **5**, Dan River Basin; **6-8**, Farmville and subsidiary basins; **9**, Richmond Basin; **10**, Taylorsville Basin; **11**, Scottsville Basin; **12**, Culpeper Basin; **13**, Gettysburg Basin; **14**, Newark Basin; **15**, Pomperaug Basin; **16**, Hartford Basin; **17**, Deerfield Basin; **18**, Fundy Basin; **19**, Chedabucto Basin (Orpheus Graben).

deep erosion, thermal subsidence, and coastal plain deposition along the entire Atlantic margin.

The Lockatong and Passaic Formations together make up a natural facies package united by a common theme of repetitive and permeating transgressive-regressive lake level sequences called Van Houten cycles after their discoverer (Van Houten, 1964, 1969, 1980; Olsen, 1980a,c, 1984a,b). The fundamental Van Houten cycle consists of three divisions interpreted as lake transgression, high stand, and regression and low stand facies (Fig. 4).

1. Division 1 is a calcareous claystone to siltstone with pinch and swell lamination with thin bedding, occasional desiccation cracks and burrowed horizons, stromatolites, oolites, sometimes rooted horizons. Sandstones and then conglomerates dominate this division as the basin margins are approached. This represents a lacustrine transgressive sequence with shoreline deposits.

2. Division 2 is a laminated to microlaminated calcareous claystone and siltstone, or limestone, with rare to absent desiccation cracks. Graded sandstone and coarse siltstone beds interpreted as turbidites are common towards the basin edges. This division has the highest organic content of the cycle and fish and other animal fossils are sometimes abundant; it represents the lake's high stand deposit.

3. Division 3 is a calcareous claystone and siltstone, with abundant desiccation cracks, burrowed and rooted horizons, vesicular and crumb fabrics, and reptile footprints. Sandstones and conglomerates again dominate marginal sequences. Division 3 represents the regressive and low stand deposit; the lake was at least occasionally dry with incipient soil development.

These Van Houten cycles were apparently produced by the rise and fall of very large lakes that reponded to periodic climate changes controlled by variations in the earth's orbit (Van Houten, 1969; Olsen, 1984a,b, 1986). Van Houten cycles also make up at least three orders of compound cycles. Fourier analysis of long sections of the Late Triassic Lockatong and Passaic Formations show periodicities in time of roughly 25,000, 44,000, 100,000, 133,000, and 400,000 years, calibrated by radiometric time scales and varve-calibrated sedimentation rates. These periodicities are in accord with the orbital theory of climate change.

The orbital theory of climate change states that celestrial mechanical cycles of the earth's orbit, such as the precession of the equinoxes (21,000 years), the obliquity cycle (41,000 years), and the eccentricity cycle (95,000, 123,000, and 413,000 years), produce changes in the seasonal and geographical distribution of sunlight reaching the earth which, in turn, affects climate (Berger, 1984). The theory makes specific predictions about the periodicity of climate cycles in the geological record which should be testable in the geological record. Recently, the predictions of the orbital theory have been convincingly confirmed through studies of climate-sensitive geochemical and biotic indices in deep sea sediments of Quaternary age, especially in the middle and high latitudes (Hays et al., 1976). The Lockatong periods are also in rather close agreement and are strong evidence for orbital forcing far into the past.

For convenience we will informally refer to the compound cycles in outcrops by their interpreted duration as follows: 1) cycles thought to range from 19,000 to 23,000 years but also including periods down to 14,000 years and up to about 29,000 years are the Van Houten cycles averaging 21,000 years; 2) cycles ranging from around 95,000 to 123,000 years we term 100,000-year cycles; and 3) the long cycles thought to be of about 413,000 years we call 400,000-year cycles. While this is utilitarian in conversation, it is important to remember that a range of actual periods is implied.

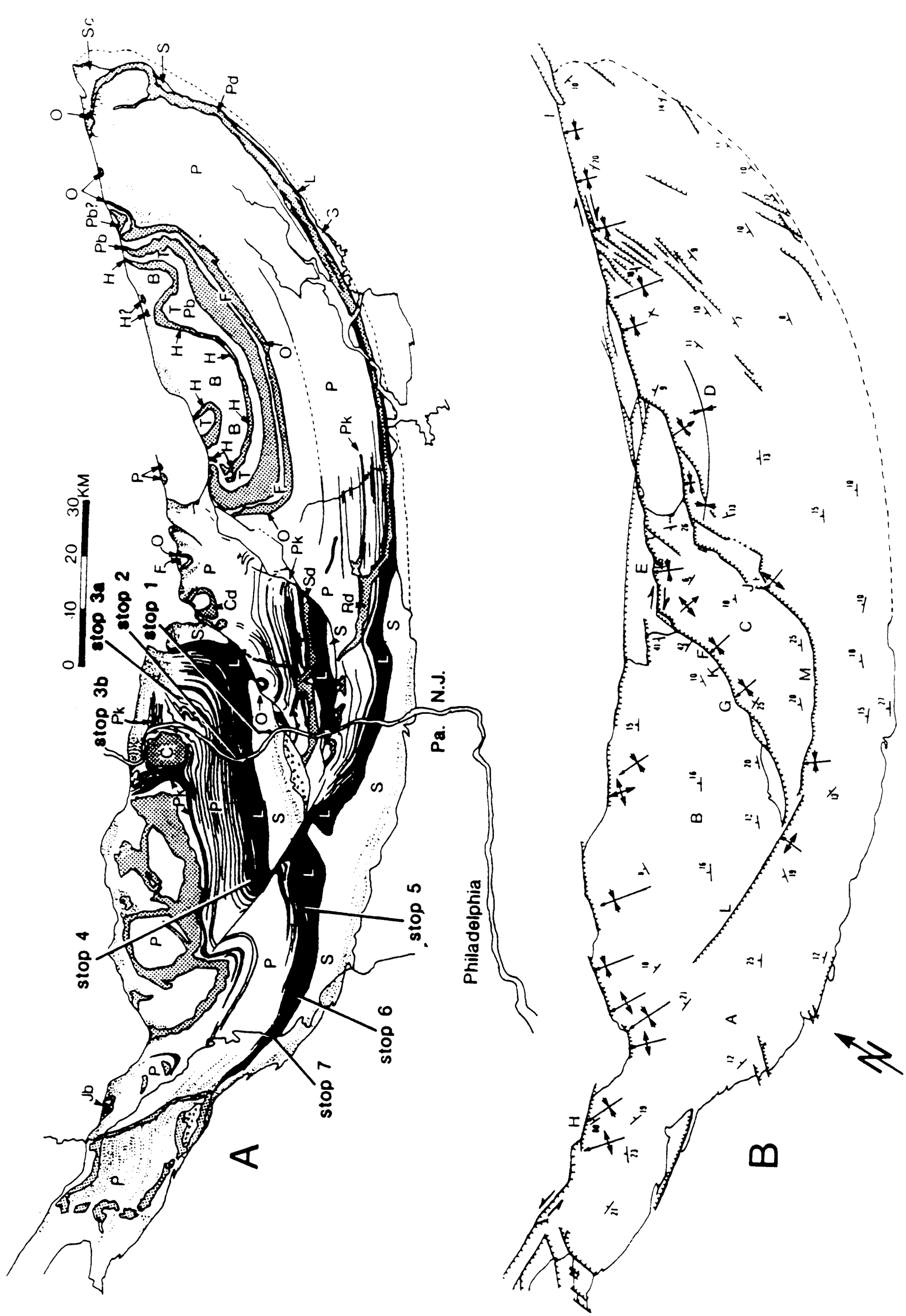
Long sequences of sedimentary cycles similar to those in the Lockatong and Passaic Formations occur through the Jurassic portions of the Newark basin and most of the rest of the Newark Supergroup, spanning a period of more than 40 million years. Van Houten cycles and the compound cycles are the main lithological theme of the Newark basin and most vertebrate localities fit within the conceptual framework provided by these cycles.

Geochronology and Correlation

Basin formation (Middle or Late Triassic, Ladinian or Carnian) and basaltic volcanism (earliest Jurassic, Hettangian) seem to have been almost synchronous throughout the eastern North America and Newark Supergroup basins and perhaps Morocco (Cornet & Olsen, 1985). Integration of evidence from paleomagnetism, radioisotopic dating, petrologic/geochemical correlation, vertebrate and palynologic biostratigraphy, and sedimentary cycles is beginning to allow very tight correlation among basins and between the Newark and other areas (Figs. 5, 6).

In their study of the paleomagnetism of the central and northeastern Newark Basin, McIntosh et al. (1985) examined the paleomagnetic stratigraphy of the upper Lockatong and lower Passaic Formations in sections to be visited on this field trip (Figs. 5, 6). Their results indicate a reversal sequence which should prove very useful in correlating among basins and testing the lateral correlation of units between fault blocks (Olsen, 1986) within basins.

More recently, William Witte (Witte & Kent, 1987) has been adding substantially to our knowledge of the Newark magnetostratigraphic record. Thus far, he has recognized a major reversed zone extending from the middle Lockatong to the middle Stockton and a normal zone below that (Figs. 5, 6).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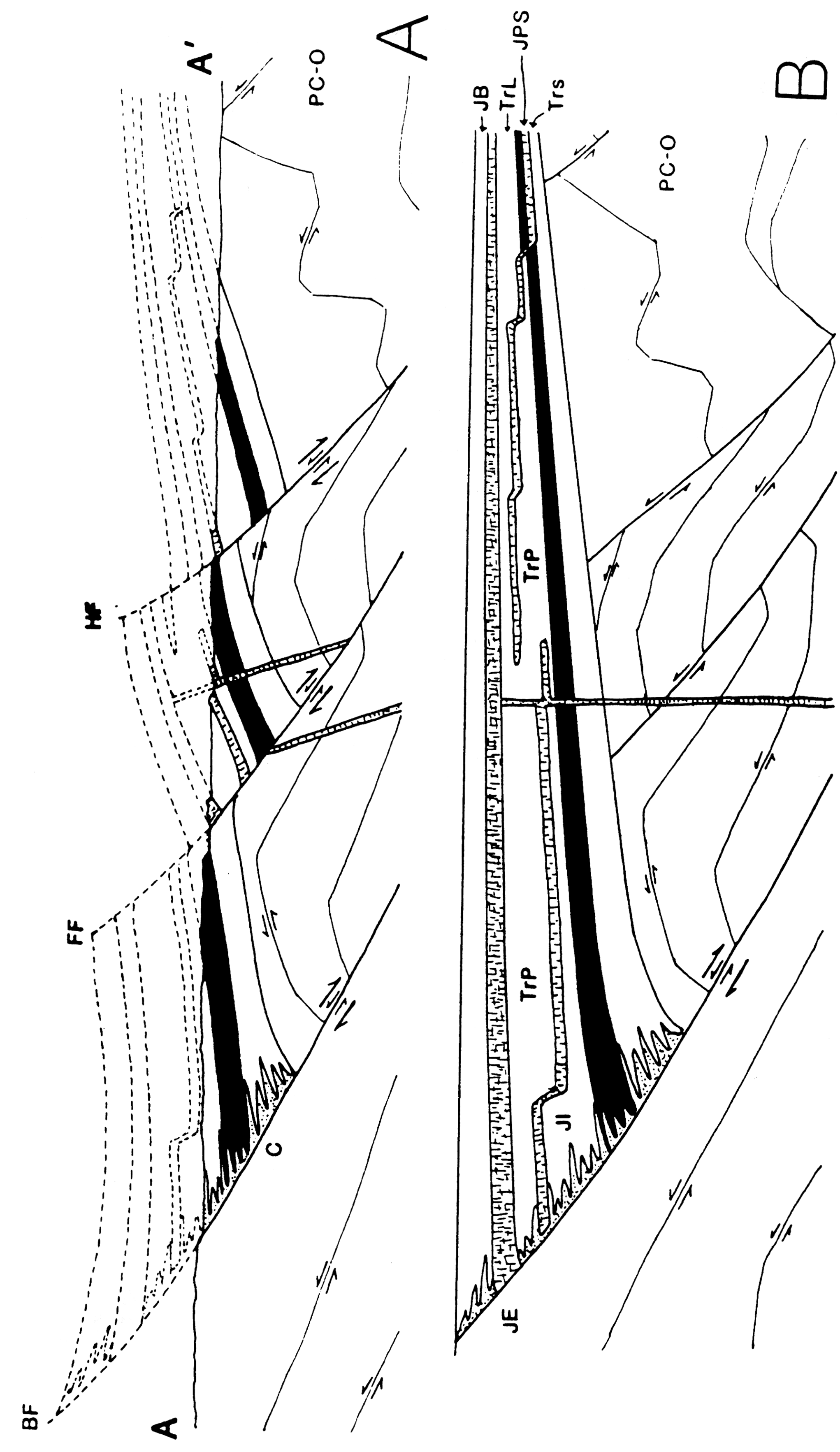
Philadelphia
Pa.
N.J.

FIELD TRIP LOG AND NOTES

Mileage	Description and Notes
0.0	The field trip begins at the Academy of Natural Sciences of Philadelphia and mileage count begins at the entrance of I-95 North off of the east end of Race Street. Head north along I-95. Highway crosses late Precambrian to early Paleozoic metamorphic basement rocks and Quaternary river terrace deposits.
23.3	Entering southern fault block of Newark Basin and basal Stockton Formation dipping to north.
26.4	Scudders Falls Bridge over Delaware River. Basal Lockatong Formation exposed on northern access road. Cross into New Jersey.
29.7	Exit from I-95 at Exit 1 for N.J. Rt. 29 (Trenton-Lambertville). Swing around right onto Rt. 29 North towards Lambertville. The geology of the portion of the field trip along the east shore of the Delaware River is shown in Van Houten (1969). An interpetive cross-section is given in Fig. 3.
31.2	Gray beds of the upper Lockatong Formation on right.
31.3	Crossing Jacob Creek. Uppermost Lockatong Formation on right.
32.8	Washington Crossing State Park: thin green-gray mudstones marking bases of vague Van Houten cycles in lower Passaic Formation in low embankment on right.
33.2	Van Houten cycles with a gray and black division 2 in back of lunch stand. These are unnamed and their correlation with beds in other fault blocks remains uncertain.
35.7	Quarry in Baldpate Mountain Diabase and metamorphosed Passaic Formation.
36.3	Crossing Buchmanville splay of Hopewell fault.
36.7	Mercer County Correctional Center Quarry in Bowman Hill Diabase.
37.8	Crossing Pidcock Creek splay of Hopewell fault and entering Stockton Formation of Sourland Mountain fault block; the stratigraphic section previously passed through is now repeated by this fault.
37.8	Poor exposures of lower Lockatong Formation in back of Lambertville Antique Flea Market.
38.6 - 38.8	Exposures of Lambertville Sill on right.
39.8	Left onto Bridge Street in Lambertville.
39.9	Right onto Main Street (Rt. 29), Lambertville; north on Rt. 29.
41.1	Intersection with U.S. Rt. 202. Good exposures of gray and red Van Houten cycles (?near Perkasie Member) in new road cuts for new Rt. 202 to east of intersection.
41.6	Crossing Dilts Corner fault, a small branch of the Flemington fault; Lockatong Formation repeated.
41.8	Quarry in Mount Gilboa Diabase, gabbro, and metamorphosed Lockatong Formation.

(Facing page) **Figure 2. A:** Lithostratigraphy and location of stops. The black areas indicate exposed Lockatong Formation or gray and black lacustrine members of the Passaic Formation; stippled areas indicate conglomerates of various formations; gray areas are igneous rocks; and patterns of "v's" indicate areas of pre-Newark rocks within the basin. Abbreviations: B, Jurassic Boonton Fm.; C, Jurassic Coffman Hill Diabase Pluton; Cd, Jurassic Cushetunk Mountain Diabase Pluton; F, Jurassic Feltville formation; H, Jurassic Hook Mountain Basalt; Jb, Jurassic Jacksonwald Basalt (= Orange Mountain Basalt); L, Triassic Lockatong Fm.; O, Jurassic Orange Mountain Basalt; P, Triassic Passaic Fm.; Pb, Jurassic Preakness Basalt; Pd, Jurassic Palisade Diabase Sill; Pk, Perkasie Member of Preakness Fm.; Rd, Jurassic Rocky Hill Diabase Sill; S, Triassic Stockton Fm.; Sc, carbonate facies of Stockton Fm.; Sd, Jurassic Sourland Mountain Diabase Sill; T, Jurassic Towaco Fm., A-A', location of cross-section (Fig. 4).

B: Structural features of the Newark Basin. Many more faults than indicated probably have a major strike-slip component. The portions of the edges of the basin not mapped as faults are mostly onlaps. Abbreviations: A, Montgomery-Chester Fault Block; B, Bucks-Hunterdon Fault Block; C, Sourland Mountain Fault Block; D, Watchung Syncline; G, Sand Brook Syncline; H, Jacksonwalk Syncline; I, Ramapo Fault; J, braided connection between Ramapo and Hopewell Faults; K, Flemington Fault; L, Chalfont Fault; M, Hopewell Fault.


A
A'
BF
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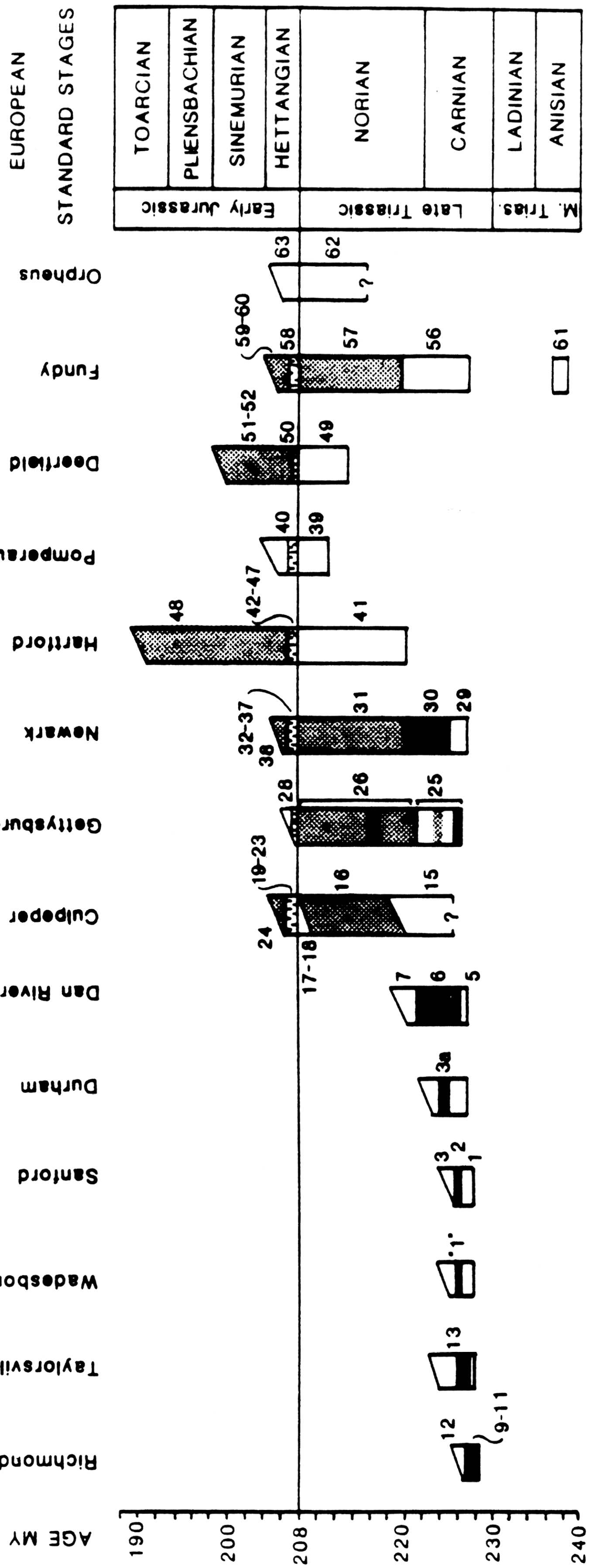

EUROPEAN STANDARD STAGES
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
NORIAN
CARNIAN
LADINIAN
ANISIAN
Early Jurassic
Late Triassic
M. Trias.
Orpheus
Fundy
Deerfield
Pomperaug
Hartford
Newark
Gettysburg
Culpeper
Dan River
Durham
Sanford
Wadesboro
Taylorsville
Richmond
AGE MY
190
200
208
220
230
240

STOP 1. Quarry in Prallsville Member of Stockton Formation (Middle Carnian Age)

Active quarry in upper part of the Prallsville Member of the Stockton Formation exposes about 60 m of section and begins about 760 m above the base of the formation (Van Houten, 1969, 1980).

Four main sediment types are obvious at these outcrops: 1) massive, well sorted medium gray to buff arkose with faint to prominent large-scale cross-bedding; 2) massive to crudely cross-bedded (2 m) arkosic conglomerate units, some of which are kaolinized and have small to large rip-up clasts; 3) well bedded red coarse siltsonte with small dune-scale cross-bedding, ripple cross-lamination, and parallel lamination; 4) blocky, massive red mudstone intensely bioturbated by *Scoyenia* and roots. These sediment types make up thick (>10 m), poorly defined upward-fining cycles possibly deposited by large, perennial, meandering rivers.

Stockton Vertebrates.

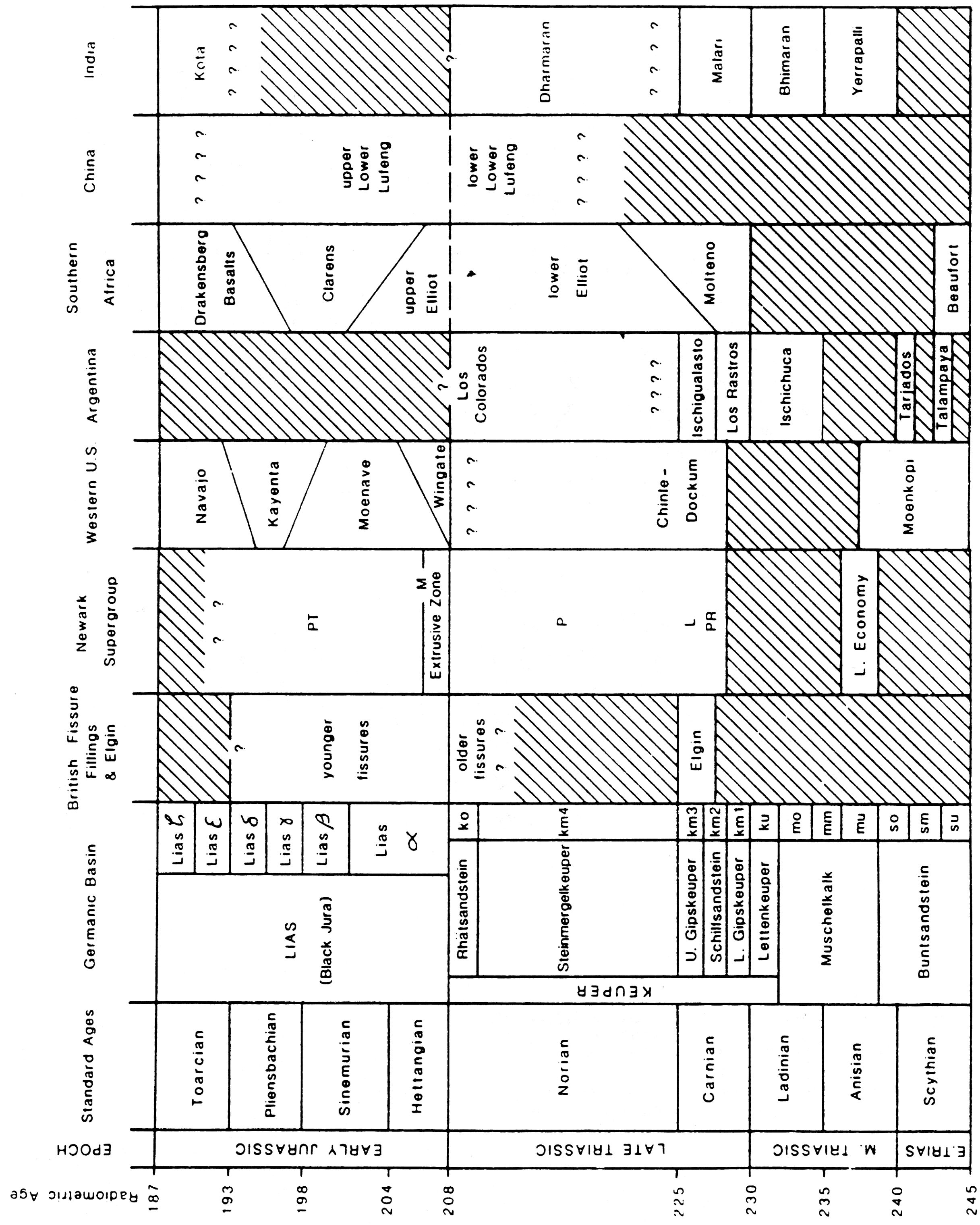
The Stockton Formation remains almost entirely unprospected for vertebrates. Nonetheless, important osseous remains have been found and these require comment. Sinclair (1917) described as *Calamops paludosus* the lower jaw of a very large labyrinthodont amphibian from the basal Stockton near Holicong, Pennsylvania (PU 12302). This jaw, still not described in detail, may belong to a large capitosaur, rather than a metoposaur as usually thought (R. W. Selden, MS.) The age of the basal Stockton is unknown and it could be as old as Middle Triassic. Early Middle Triassic capitosaurs are known from fragments from the oldest parts of the Fundy Basin sequence (D. Baird, personal communication; Olsen & Sues, 1986).

The rest of the Stockton vertebrates came from the upper beds of the formation of Late Carnian age. These include a large headless phytosaur skeleton referred to *Rutiodon manhattanensis* (Huene, 1913) from Fort Lee, New Jersey; an impression of the fragment of a metoposaur interclavicle (Baird, 1986) from Princeton, New Jersey; and phytosaur teeth from Assinetcong Crek in Flemington, New Jersey (Fig. 7).

A small assemblage of bones and footprints occurs in the upper Stockton Formation of Rockland County, New York. As this assemblage has been mentioned in print a number of times (Olsen, 1980c,d) the more important fossils are figured here pending more detailed description. The assemblage consists of indeterminate reptile bones and scutes, phytosaur teeth, and the following ichnotaxa: *Rhynchosauroides* cf. *hyperbates*, *Apatopus lineatus*, *Brachychirotherium eyermani*, ?*Atreipus* sp., and *Grallator* sp. (Figs. 7-9). This assemblage does not differ appreciably from that of the Lockatong Formation and it is probable that the fossiliferous portions of the Stockton of Rockland County may be a shoreward facies of the Lockatong.

	Return to vehicle and turn right onto Rt. 29 North.
45.7	Crossing Lockatong Creek. Extensive exposures of middle and upper Lockatong Formation and type section of Lockatong Formation are exposed upstream (McLaughlin, 1945).
46.9	Old quarry in woods on right in Raven Rock Member of Stockton Formation. Lower parts of quarry expose gray uraniferous sandstones and siltstones which were the site of a uranium prospect during the 1950s (Turner-Peterson, 1980).
47.1	stones of upper Stockton Formation on right.
47.4	Low exposures in hill on right show cyclic sequence of thin gray and thick red beds in uppermost Stockton Formation.

(Facing page) **Figure 5a.** Correlation of the Newark Supergroup.
Correlation between sections in major basins and correlation with European Standard Stages and DNAG (Decade of North American Geology) radiometric scale. Note that units are scaled by time, not thickness, and that as a consequence the extrusive zone of each basin is shown as a single unit (gray). Black zones represent units which are primarily gray and black lacustrine units while gray zones represent mostly red and gray lacustrine units.
Numbers next to each column represent the individual formations: 1) Pekin Fm.; 2) Cumnock Fm.; 3) Sanford Fm.; 3a) unnamed lacustrine rocks; 5) Pine Hall Fm.; 6) Cow Branch Fm; 7) Stoneville Fm.; 9) Lower Barren Beds; 10) Productive Coal Measures; 11)Vinita Beds; 12) Otterdale Ss.; 13) Doswell Fm.; 15) Manassas Ss.; 16) Balls Bluff Siltst.; 17) Tibbstown Fm.; 18) Catharpin Creek Fm.; 19) Mount Zion Church Basalt; 20) Midland Fm.; 21) Hickory Grove Basalt; 22) Turkey Run Fm.; 23) Sander Basalt; 24) Waterfall Fm.; 25) New Oxford Fm.; 26) Gettsyburg Sh.; 27) Hammer Creek Cgl.; 28) Aspers Basalt; 29) Stockton Fm.; 30) Lockatong Fm.; 31) Passaic Fm.; 32) Hammer Creek Cgl.; 33) Orange Mountain Basalt; 34) Feltville Fm.; 35) Preakness Basalt; 36) Towaco Fm.; 37) Hook Mountain Basalt; 38) Boonton Fm.; 39) South Britain Arkose; 40) unnamed overlying units; 41) New Haven Arkose; 42) Talcott Basalt; 43) Shuttle Meadow Fm.; 44) Holyoke Basalt; 45) East Berlin Fm.; 46) Hampden Basalt; 47) Granby Tuff; 48) Portland Fm.; 49) Surgar Loaf Arkose; 50) Deerfield Basalt; 51) Turners Falls Ss.; 52) Mount Toby Cgl.; 56) Wolfville Fm.; 57) Blomidon Fm.; 58) North Mountain Basalt; 59) Scotts Bay Fm.; 60) McCoy Brook Fm.; 61) Lower Economy Beds of Wolfville Fm.; 62) Chedabucto Fm. (= Eurydice Fm.?); 63) Argo Salt.



Radiometric Age
187
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225
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240
245
EPOCH
EARLY JURASSIC
LATE TRIASSIC
M. TRIASSIC
E.TRIAS
Standard Ages
Toarcian
Pliensbachian
Sinemurian
Hettangian
Norian
Carnian
Ladinian
Anisian
Scythian
Germanic Basin
LIAS
(Black Jura)
Lias
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Lias
Lias
Lias α
KEUPER
Rhätsandstein
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Steinmergelkeuper km4
U. Gipskeuper km3
Schilfsandstein km2
L. Gipskeuper km1
Lettenkeuper ku
Muschelkalk
mo
mm
mu
Buntsandstein
so
sm
su
British Fissure Fillings & Elgin
younger fissures
older fissures
Elgin
Newark Supergroup
PT
M
Extrusive Zone
P
L
PR
L. Economy
Western U.S.
Navajo
Kayenta
Moenave
Wingate
Chinle - Dockum
Moenkopi
Argentina
Los Colorados
Ischigualasto
Los Rastros
Ischichuca
Tarjados
Talampaya
Southern Africa
Drakensberg Basalts
Clarens
upper Elliot
lower Elliot
Molteno
Beaufort
China
upper Lower Lufeng
lower Lower Lufeng
India
Kota
Dharmaran
Malari
Bhimaran
Yerrapalli

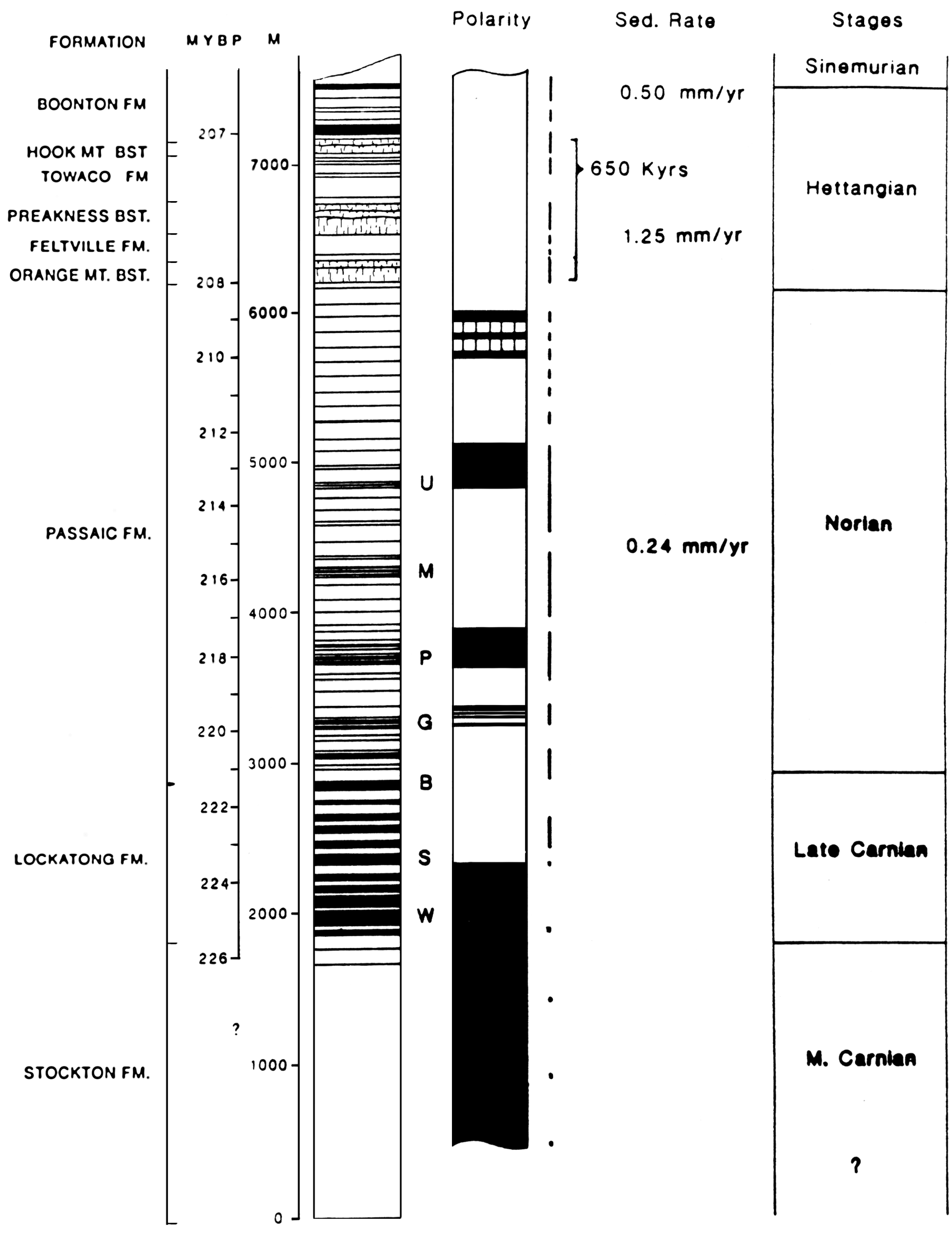


Figure 6. Magnetic stratigraphy of Newark Basin (compiled from data in McIntosh et al., 1985, and W. Witte, personal communication). Abbreviations: W) Weehawken Mbr.; S) Skunk Hollow Mbr.; B) Walls Island Mbr.; G) Graters Mbr.; P) Perkasie Mbr.; M) Metlars Brook Mbr; U) Ukranian Mbr.

(Facing page) **Figure 5b.** Correlation of early Mesozoic deposits with their standard ages (from Olsen and Sues, 1986). Explanation of abbreviations follows: su-so, mu-mo, ku, km1-km4, ko) standard abbreviations for Germanic Triassic; PT) zone corresponding to post extrusdive formations 24, 28 (in part), 38, 40 (in part), 48, 51-52, 59, 60 in Figure 5a (includes M); P, zone corresponding to pre-extrusive formations 16, 26, 31, 41, 39, 49, 57, ?62 in Figure 5a; L, L. Economy) corresponds to 61 in Figure 5a.

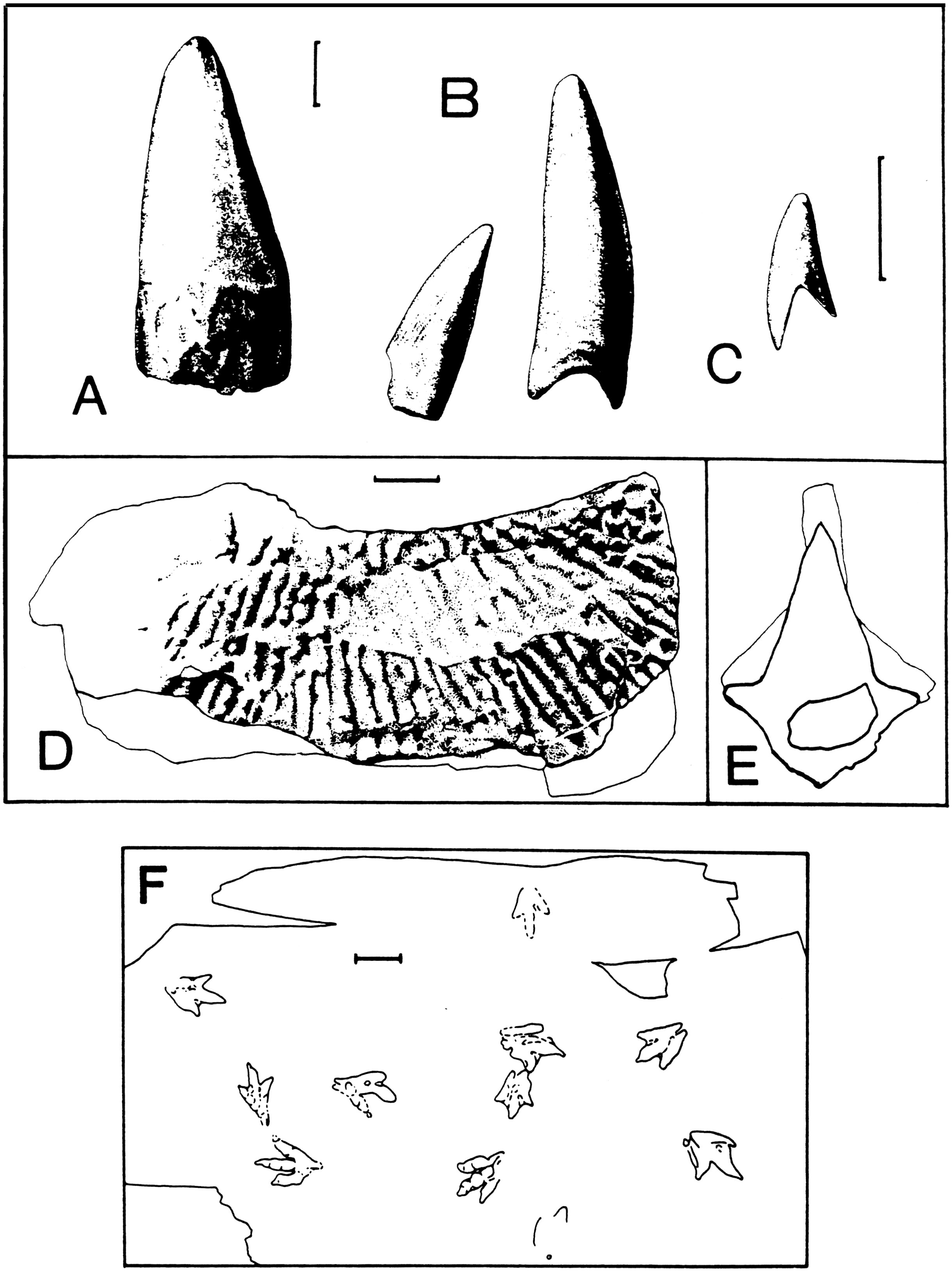


Figure 7. Vertebrates from the Stockton Formation.
A, B. Phytosaur teeth; Assicong Creek, near Flemington, New Jersey (YPM 7728 and unnumbered). Scale bar is 1 cm.
C. Phytosaur tooth; Nyack Beach State Park, Haverstraw, New York (YPM unnumbered). Scale bar is 1 cm.
D. *Metoposaurus* sp., fragmentary interclavicle (Baird, 1986); Princeton, New Jersey (PU 18364). Scale bar is 2 cm.
E. Diagramatic *Metoposaurus* interclavicle showing position of Princeton metoposaur fragment.
F. ?*Atreipus* pedal impressions; Blauvelt, New York (New York State Museum specimen). Scale bar is 10 cm.

47.8 Stumphs Tavern Road (N.J. Rt. 519 Spur). Stream along north side of road exposes gray and red beds of the ?Weehawken Member of the lower Lockatong Formation. The Weehawken and succeeding Gwynedd Member of the lower Lockatong are the most fossiliferous portions of the Lockatong. Precisely equivalent cycles are exposed in creeks which cut down cliffs on opposite side of river at Lumberville, Pennsylvania. Here a microlaminated and strongly metamorphosed limestone (by the overlying Byram Sill) of division 2 of a Van Houten cycle produces complete *Turseodus* and abundant conchostracans. Presumably equivalent beds produce copious fossils in the Princeton, Weehawken, and North Bergen areas of New Jersey to the northeast (Olsen, in press). Unfortunately, exposures of this part of the Lockatong are very poor in this part of the Newark Basin.

Note on Lockatong Formation Nomenclature

McLaughlin (1943, 1945) mapped the distribution of the red portions of the 400,000-year cycles in the Hunterdon Plateau fault block and gave most of them informal member names. These names consist of a mixture of descriptive terms (First Thin Red Member), letter designations (Member B), and place names (Smith Corner Red). The gray portions of the cycles in the Lockatong were not named with the exception of Members A and B. Because of the intense interest in many of the gray portions of these same cycles, it makes sense to apply some kind of informal, consistently applied name to each. These are shown in Table 1. McLaughlin's names are conserved where he used a place name designation. This method cuts down the potential number of named members by one-half and each member corresponds to a single 400,000-year cycle (Table 1). Most of these names have already been used informally in previous works (Olsen, 1984a, 1986). In the central Newark Basin, the Lockatong Formation is 1,100 m thick and is thus divided into eleven 400,000-year cycles, each about 100 m thick. These names will be used throughout this field guide.

Table 1.
Members of the Lockatong Formation

[Passaic Formation]	
Walls Island Member	B of McLaughlin (1943)
Tumble Falls Member	A2 of McLaughlin (1943) Double Red of McLaughlin (1943)
Smith Corner Member	lower A1 of McLaughlin (1943) Smiths Corner Red of McLaughlin (1943)
Prahls Island Member	Triple Red of McLaughlin (1943)
Tohicken member	First Thick Red of McLaughlin (1943)
Skunk Hollow Member	First Thin Red of McLaughlin (1943)
Byram Member	no equivalent
North Wales Member	no equivalent
Gwynedd Member	no equivalent
Weehawken Member	no equivalent
Hoboken Member	no equivalent
[Stockton Formation]	

48.4 Poor exposures on right of upper part of lower Lockatong Formation (upper ?Gwynedd Member).

48.5 Byram Sill on right intruding zone between lower and middle Lockatong Formation. The Byram Sill does not seem to extend down dip in this area as revealed by proprietary seismic reflection studies in Pennsylvania.

48.7 Begin 410-m-thick almost continuous section of middle Lockatong Formation.

48.9 Old quarry in upper part of North Wales and lowermost part of Byram Members. Quarry in this interval at Point Pleasant has produced a slab with large swimming trackways of *Apatopus* (D. Baird, personal communication).

49.4 Falling Rock sign. Pull over near culvert for creek exposing upper 100 m of section. Walk north along road.

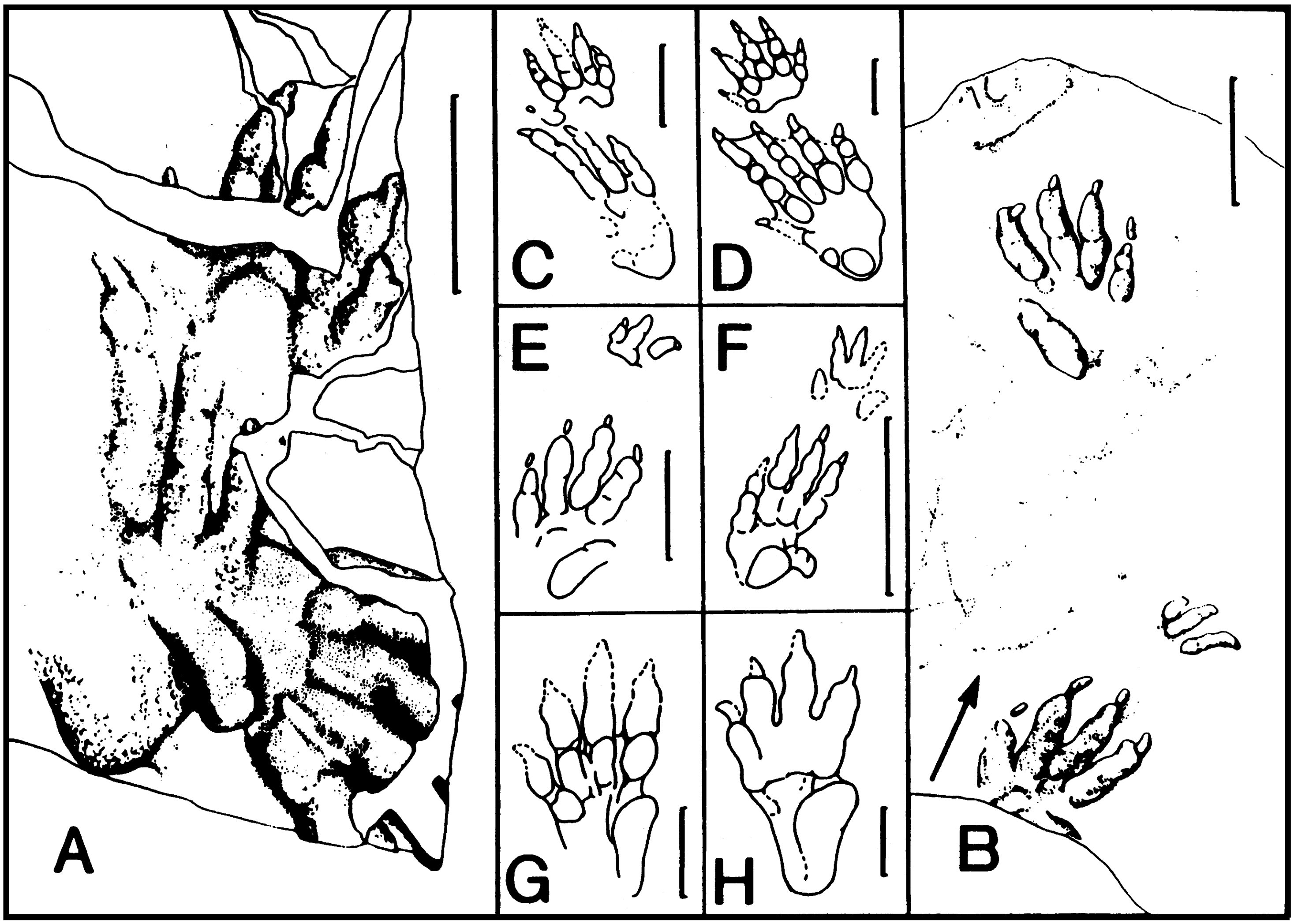


Figure 8. Footprints from the Stockton Formation of Nyack Beach State Park, Haverstraw, New York. Scale bar is 5 cm.
A, Manus-pes set of *Apatopus lineatus* overlapped by pes impression of *Brachychirotherium eyermani* (YPM 7731).
B, Trackway of ?*Chirotherium lulli* (YPM 8263).
C, Outline of *Apatopus lineatus* in (A).
D, Composite of *Apatopus lineatus* (from Baird, 1957).
E, Composite outline of ?*Chirotherium lulli* in (B).
F, Composite outline of ?*Chirotherium lulli* (from Baird, 1954).
G, Outline of *Brachychirotherium eyermani* in (A).
H, Outline of *Brachychirotherium eyermani* (from Baird, 1957).

STOP 2. Route 29 Exposures of Lockatong Formation (Late Carnian Age)

Exposed along the east side of Rt. 29 and along a small brook at its northern end are more than 400 m of middle Lockatong Formation (Figs. 10, 11). These are the exposures on which Van Houten based most of his original interpretations, and the exposures most often seen by visiting geologists. About 98% (401 m) of this section consists of fine calcareous mudstone and claystone, with the remaining 2% (9 m) consisting of very fine sandstone.

In the terminology outlined above, these exposures include North Wales, Byram, Skunk Hollow, and Tohicken Members. McLaughlin's (1944) "First Thin Red" makes up the upper part of the Skunk Hollow Member and the "First Thick Red" makes up the upper part of the Tohicken Member.

Compared to the rest of the Lockatong, fossils are very rare in this section; to our knowledge only two cycles have produced vertebrates. This is probably a function of lateral facies change, with coarser facies consistently being more fossiliferous. Unfortunately, this is the section most often examined by visiting paleontologists and it is, at least in part, responsible for the undeserved opinion that the Newark is poorly fossiliferous.

Fourier analysis of sediment fabrics in this section (Fig. 12), calibrated by varve sedimentation rates and radiometric time scales, show the main thickness and time periodicities typical of both the Lockatong and Passaic Formations in this part of the basin.

In order to facilitate comparisons with the succeeding stops and in order to illustrate the wide range of variation exhibited by these cycles, we will compare two end-members of the range of sequences of sedimentary fabrics present in this section (Fig. 13). These two end-members correspond, in part, to Van Houten's (1962, 1964, 1969) detrital and chemical short cycles.

Figure 13a (also Fig. 4) shows a single Van Houten cycle (cycle SH2, Fig. 11) in the lower part of the Skunk Hollow Member. This is the most fossiliferous cycle exposed in this outcrop. Division 1 is a thin sand overlain by thin-bedded mudstone with an upward increase in total organic carbon (T.O.C.). This represents the beginning of lake transgression over the often dry playa flat of the preceding cycle, and this is followed by deposition under increasing water depth.

The transition into division 2 is abrupt and is marked by the development of microlaminated calcareous claystone consisting of carbonate-rich and carbonate-poor couplets, an average of 0.24 mm thick. The basal few couplets of this interval contain articulated skeletons of the aquatic reptile *Tanytrachelos* and infrequent clam shrimp and articulated fossil fish (*Turseodus* and ?*Synorichthys*); abundant conchostracans occur in the middle portions of the unit. In its upper part, the microlaminae are very discontinuous, perhaps due to microbioturbation. No longer microlaminated, the succeeding portions of division 2 become less organic-rich and less calcareous upward, and there is an upward increase in pinch-and-swell lamination. Deep, widely spaced, and sinuous desiccation cracks propagate down from the top of the unit. The average T.O.C. of division 2 (83 cm thick) of this cycle is 2.5% which is a rather common value for black siltstones and limestones of the Lockatong.

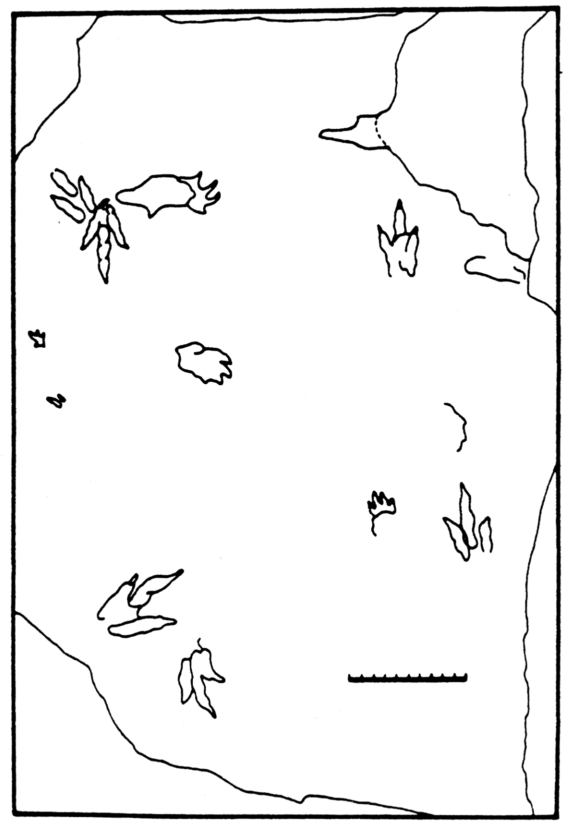


Figure 9. Slab of *Grallator* sp. and ?*Brachychirotherium* from the Staockton Formation of Haverstraw, New York (New York State Museum specimen). Scale bar is 10 cm.

The absence of syndepositional desiccation cracks, and the presence of extremely fine microlamination and articulated aquatic vertebrates, suggest that division 2 is the high stand deposit of the lake which formed this Van Houten cycle. Studies of similar microlaminated units in other parts of the Lockatong suggest deposition in water in excess of 100 m deep, below wave base, and in perennially anoxic water (Manspeizer & Olsen, 1981; Olsen, 1984a).

The presence of the articulated reptiles at the base of the microlaminated unit may represent the transgression of the chemocline of the chemically stratified lake as the lake expanded. It is common for articulated reptiles to occur right at the base of the microlaminated portions of division 2 in many other cycles of the Lockatong (Olsen, 1980c) and in other Triassic formations as well (Olsen et al., 1978). This pattern is of considerable use in prospecting for these little reptiles. The decrease in microlamination towards the top of division 2 suggests the action of microbioturbation and increased water column ventilation which Olsen (1982, 1985a) attributes to slowly decreasing water depth.

Division 3 is characterized by an overall upward increase in the frequency and density of desiccation-cracked beds and a decrease in thin bedding. This probably represents a transition into a more effectively mixed lake and ultimate desiccation due to changing climatic conditions. Reptile footprints (?*Apatopus*)

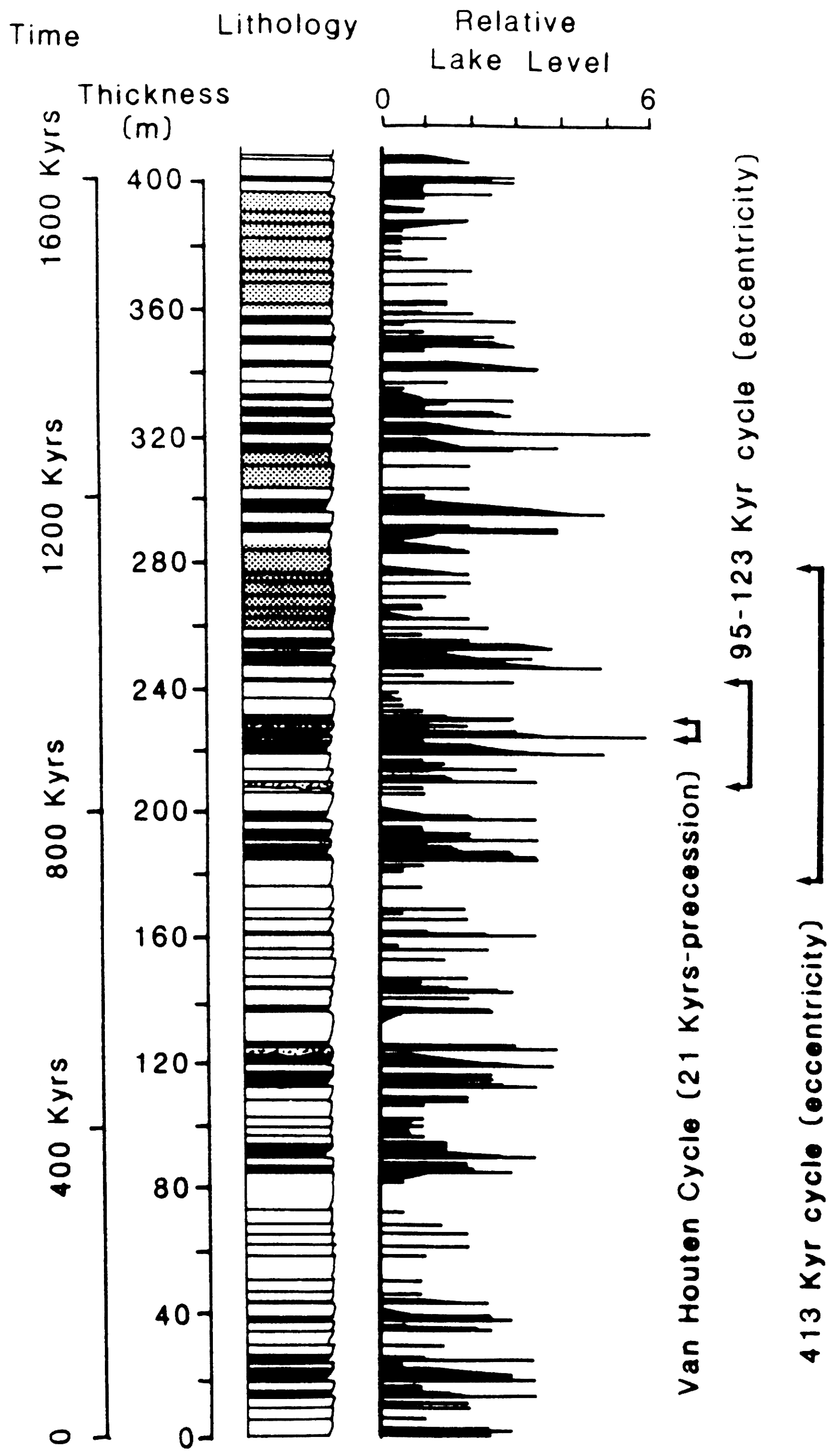


Figure 10. Measured section at Stop 2, middle Lockatong Formation showing relative lake level cycles and time scales tuned to orbital frequencies (adapted from Olsen, 1986). Section shown in detail in Figure 11a is roughly from 220 m to 320 m. White zones represent mostly gray massive mudstones; gray zones represent mostly red massive mudstones; black zones represent mostly laminated black or dark gray siltstones.

occur near the middle of the sequence (Fig. 14). Organic carbon content drops through division 3 (1.3% to .5%). This interval shows the greatest evidence of exposure in the cycle and represents the low stand of the lake. However, as evidenced by the relative infrequency of desiccation-cracked intervals and the generally wide spacing of the cracks themselves, submergence was much more frequent than emergence during the deposition.

The cycle below SH2 (SH1, Fig. 1) also contains a division 2 with a microlaminated base, fish, and clam shrimp. The total thickness of division 2 of this cycle is much thicker than in the succeeding cycle.

Division 2 in other cycles at this outcrop are not as organic-rich or as well laminated as SH1 and SH2, and the other cycles also show greater degrees of desiccation of division 3. The only fossils present tend to be rare clam shrimp and indeterminate fish bones and plant scraps.

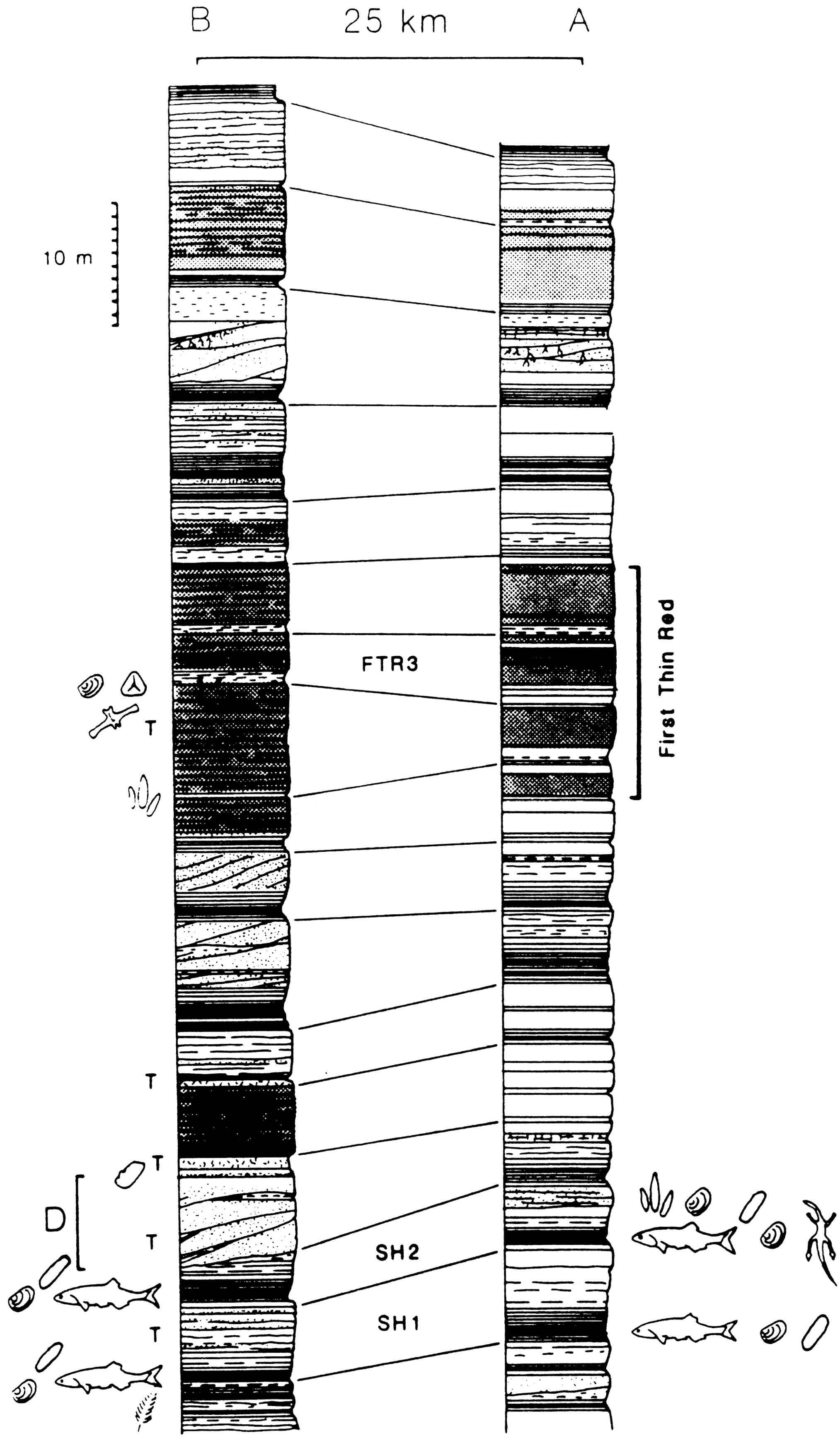
Figure 13b shows a Van Houten cycle in McLaughlin's "First Thin Red" (FTR3) about 55 m above the cycle shown in Figure 13a. This cycle contrasts dramatically with the Upper Skunk Hollow Fish Bed in consisting of 79% red massive mudstone and completely lacking a black organic-rich division 2. Division 3 of the previous cycle (also mostly red) consists of red, massive, almost homogeneous-appearing mudstone with a faint, but highly vesicular, crumb fabric. According to Smoot (1985) crumb fabric is formed by breaking up, through desiccation, of aggrading mud in a playa lake. The vesicles represent cement-filled voids formed during aggradation and cemented shortly after deposition. The vesicles do not seem to be related to an evaporitic texture.

The overlying massive mudstone of division 1 is gray and contains a better developed crumb fabric. This unit was probably deposited under much the same conditions as the unit underlying it; its iron was reduced, however, by the interstitial waters from the lake which deposited the next unit. The transition from an aggrading playa to a short-lived perennial lake is marked by an upward increase in lamination, a disappearance of the crumb fabric, and a decrease in the density of desiccation cracks.

Division 2 of this cycle consists of red and green laminated to thin-bedded claystone lacking syndepositional desiccation cracks. This is the high stand deposit of this cycle and is most comparable to the fabric seen in the lower part of division 3 of the cycle shown in Figure 13a.

Division 3 consists of massive mudstone (argillite) sequences consisting of a basal green-gray mudstone passing into a very well developed breccia fabric (Smoot, 1985) and then upwards into a well developed crumb fabric. Breccia fabrics consist of densely spaced, anastomosing cracks separating non-rotated lumps of mudstone showing some remnant internal lamination. They are very common in the Lockatong Formation and are directly comparable to fabrics produced by short periods of aggradation separated by longer periods of desiccation and non-deposition (Smooth & Katz, 1982). This is one of the fabrics that Van Houten (1969) interpreted as produced by synaeresis. The breccia fabric passes upward into a well developed vesicular crumb fabric. The transition into the overlying similar sequence is abrupt. The upper halves of these sequences are cut by dish-shaped, upward-concave clay-lined surfaces with radial slickensides. These "dish structures" were described by Van Houten (1964, 1969) and interpreted as a possible gilgai-type soil feature (Van Houten, 1980). These sorts of sequences, which here makeup division 3 of a Van Houten cycle, are very common in the fine-grained facies of the Newark Supergroup (Smoot & Olsen, in press). Clearly, this cycle represents the transgression and regression of a lake which never became as deep as the cycle shown in Figure 13a; and when lake level dropped, the lake desiccated for longer intervals. Although unfossiliferous here, cycles of this type contain clam shrimp in division 3 in coarser facies (see Stop 4). Most of the cycles in the Rt. 29 section fall somewhere between these two extremes of cycle types.

	Return to vehicle and head north on Rt. 29.
49.8	Upper part of Tohicken Member (McLaughlin's "First Thick Red") exposed on right.
50.0	Old quarry on right is in the middle part of Prahls Island Member (McLaughlin's "Triple Red"). Section in quarry has been described by Van Houten (1969, 1980).
50.35	Thick gray beds of Smith Corner Member.
50.7	Tumble Falls Road. Stream on right exposes most of Tumble Falls Member of upper Lockatong Formation. Minor transgressive interval in middle of division 3 of a gray Van Houten cycle exposed in stream at road level contains abundant and good *Rhynchosauroides* sp.
51.0	Upper red beds of Walls Island Member (member B plus High Rocks member of McLaughlin). These red beds have usually been considered the basal beds of the Passaic Formation even though they are mineralogically more similar to the Lockatong (Van Houten, 1969). They are regarded here as the uppermost beds of the Lockatong.
51.2	Exposures of gray and red Van Houten cycles of McLaughlin's member C. Section described by Van Houten (1969, 1980).


B
25 km
A
10 m
FTR3
First Thin Red
T
T
T
T
T
D
SH2
SH1

Note on the Nomenclature of Members in the Lockatong and Passaic Formations

McLaughlin (1944, 1946) split the Passaic Formation into members in a different way than he split the Lockatong: in the Passaic Formation he named the gray portions of the 400,000-year cycles, not the red. Thus the gray interval exposed at this locality is named C of the Passaic Formation (Brunswick of Kummel, 1897). In contrast, in the Lockatong he tended to name the red intervals, not the gray; thus, red interval of the Lockatong underlying member C was named the High Rocks member. Unfortunately, as work proceeds on these formations, McLaughlin's member names are becoming cumbersome, especially in the Lockatong. Pending detailed revision, we use McLaughlin's member names for the Passaic, but also include the overlying red half of each 400,000-year cycle in the named unit. For the Lockatong we will use Olsen's (1986) names. These consist of individual place names which apply to an entire 400,000-year cycle consisting of a couplet of a mostly lower gray unit plus its overlying mostly red interval.

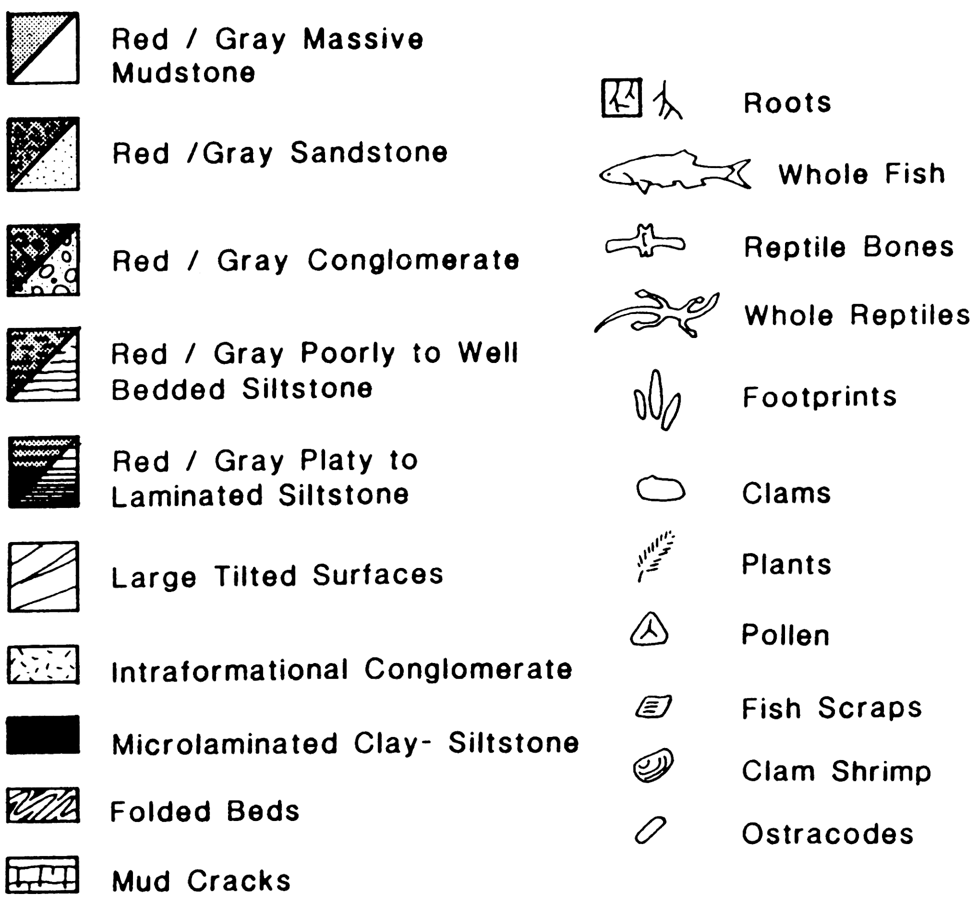


Figure 11b. Key to lithologic symbols for Figures 10, 11a, 13, 15, 17, 19, 23.

(Facing page) **Figure 11a.** Comparison of sections of middle Lockatong Formation exposures at the Rt. 29 and Haines and Kibblehouse quarry exposures. Key to lithologic symbols in Figure 11b.

51.4 Large exposures of upper parts of Member C of Passaic Formation showing continuation of pattern of Van Houten cycles expressed as variations in red mudstone fabric resembling the red mudstone cycle described in detail at Stop 2. *Rhynchosauroides* sp. occurs in some of the red laminated mudstones of division 2 of these cycles.

52.0 Crossing Warford Creek. Extensive exposures of a single Van Houten cycle in the lower part of Member D of Passaic Formation extend for over 0.5 mi. upstream (Fig. 15). The lower part of division 2 of this cycle is microlaminated and contains articulated and disarticulated *Semionotus* and *Paleolimadia*-type clam shrimp. Division 3 contains *Scoyenia*, abundant root marks, and possibly poor *Rhynchosauroides*. This same cycle crops out 6 mi. to the northeast along the east branch of Nishisackawick Creek where it still yields fish (Stop 3A).

52.6 Excellent exposures of members E and F in creek to right. In this case, McLaughlin (1944) named the gray parts of two successive 100,000-year cycles in the lower part of a 400,000-year cycle of members E and F.

55.5 Members G and H of McLaughlin are poorly exposed in hills on right. G and H are two 100,000-year cycles named in the same way as E and F; however, McLaughlin (1933) provided an alternate name, the Graters Member. McLaughlin (1943, 1944, 1946) mapped the Graters and its constituents over much of the basin.

55.9 Crossing Nishisackawick Creek.

56.1 Turn right onto Bridge Street, in Frenchtown, New Jersey.

56.15 Intersection with N.J. Rt. 12. At this point the route to Alternate Stop 3A begins; mileage resumes again at this value after return to this point.

Route to Alternate Stop 3A

56.15 Turn right onto N.J. Rt. 12 East, then immediately left onto Creek Road at Frenchtown Borough Park. Follow Creek Road to the northeast.

56.7 Cliff exposures of red beds making up upper part of Graters Member on left on west bank of stream.

57.3 Exposures of gray beds of Graters Member on right. These outcrops make up Cornet's (1977) GM-3 locality. Pollen and spores from here indicate a latest Carnian or Early Norian age (Cornet, 1977).

57.6 Extensive exposures of gray and black beds of Graters Member on left on west bank of creek.

59.7 Intersection with road on southeast. Park.

ALTERNATE STOP 3A: Lower Passaic Formation: Members E and F (Late Carnian-Early Norian Age)

Members E and F are exposed in this area, especially downstream along Nishisackawick Creek and along the little stream which begins here and heads east. We are much closer to the border fault in this area and coarser and shallower-water facies are evident. Most obvious is a dramatic increase in the prevalence of oscillatory and climbing ripple-bedded sandstone at the expense of massive mudstone, a replacement of mudstones with breccia fabrics by rooted and burrowed (by *Scoyenia*) mudstones and sandstones, and a replacement of black and dark gray laminated calcareous claystones and siltstones by purple to green siltstones. As a rule, the Passaic Formation becomes much more fossiliferous in these coarser facies. Not only is there the invariable presence of reptile footprints, but even deeper-water units tend to have more fossils, especially clam shrimp, ostracodes, fish, and plant material.

In this area, footprints are very common on claystone partings between oscillatory rippled fine sandstones. The most common form is the peculiar quadrupedal dinosaurian ichnite *Atreipus* (Olsen & Baird, 1986). This form has a *Grallator*-like pes associated with a small three-toed manus (Fig. 16). A single slab bearing a bipedal trackway of *Brachychirotherium eyermani* (PU 23641) and isolated *Rhynchosauroides brunswickii* manus impressions have also been found.

Member D is exposed not far upstream from the parking area. Like E and F, member D is coarser; however, a thick black unit is still present and although not as well laminated it still contains *Semionotus*. It is also characteristic of both the Lockatong and Passaic to contain many more bones in the coarser facies. For example, an excellent *Stegomus* skeleton was found in member D on Nishisackawick Creek to the northwest (PU 21750; Baird, 1986).

	Return via Creek Road to Rt. 12.
62.8	Intersection with Rt. 12. Turn right.
62.9	Turn right onto Race Street in Frenchtown. Mileage resumes from 58.1 mi. at this point.

Continuation of Main Route

56.2	Take left fork onto Milford Road.
56.4	Turn left onto 8th Street.
56.5	Turn right onto Hunterdon County Rt. 619 (Harrison Street) and head north.
57.9	Small quarry on right in Passaic Formation. Much burrowing by *Scoyenia* and some very poor footprints (*Brachychirotherium*) are present.
59.8	Intersection with County Rt. 519 at traffic light, Milford center. At this point route to Alternate Stop 3B begins; mileage resumes again at this value after return.

Route to Alternate Stop 3B

59.8	Turn right onto County Rt. 519 (Water Street).
60.2	Keep left at fork with York Street.
60.3	Turn right onto Preston Road and continue up hill.
60.4	Turn left onto Park Street.
60.6	Turn right onto Pine Crest development, go to end of parking lot and park. Follow path from end of parking lot into woods.

ALTERNATE STOP 3B: Smith Clark Quarry, Milford, New Jersey in Perkasie Member of Passaic Formation (Early Norian Age)

The Smith Clark Quarry was in operation in the late 19th to 20th century and was developed to quarry flagstones from sandstones of the Perkasie Member (Drake et al., 1961) of the Passaic Formation. The interval lies roughly 500 m above the footprint-bearing horizons seen at Stop 3A.

Stratigraphy of the Perkasie Member.

The Perkasie member consists of Van Houten cycles and compound cycles showing the same pattern as the Lockatong (Olsen, 1986; Olsen & Baird, 1986). It consists of two sequential 100,000-year cycles, each containing two well developed Van Houten cycles and weakly developed red and purple Van Houten cycle, succeeded upwards by red clastics (Fig. 17). McLaughlin named the lower set of gray beds member N and the upper member O. Most, if not all, of the classic material described by Eyerman (1886), Bock (1952a), and Baird (1957) apparently came from division 3 of the second gray and black Van Houten cycle of member O (Fig. 17) at this locality, not the two localities mentioned by Baird (1957).

Once thought to be the youngest strata in the basin, it is now clear that the beds of the Perkasie Member actually lie in the *lower* Passic Formation, roughly 2,800 m below the top of the formation. All of the overlying strata have been eroded in this area. Correlation of the Milford area with other fault blocks of the Newark Basin, where these younger beds are still preserved, is afforded by magnetostratigraphy, lithological matching, and a palynological correlation (Olsen, 1988).

Paleontology of the Smith Clark Quarry.

The gray footprint-producing horizons in the Smith Clark Quarry have produced the types and much associated material of *Atreipus milfordensis*, *A. sulcatus* (Baird, 1957; Olsen & Baird, 1986), *Brachychirotherium parvum* (C. H. Hitchcock, 1889), *B. eyermani* (Baird, 1957), *Apatopus lineatus* (Bock, 1952a), and *Rhynchosauroides hyperbates* (Baird, 1957), as well as examples of *Grallator* (*Anchisauripus*) *parallelus* (Baird, 1957), *Rhynchosauroides brunswickii* (Baird, 1957),

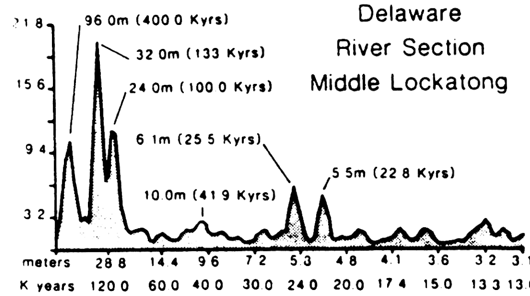


Figure 12. Fourier power spectrum of relative lake level curve in Figure 10 at Stop 2 (from Olsen, 1986).

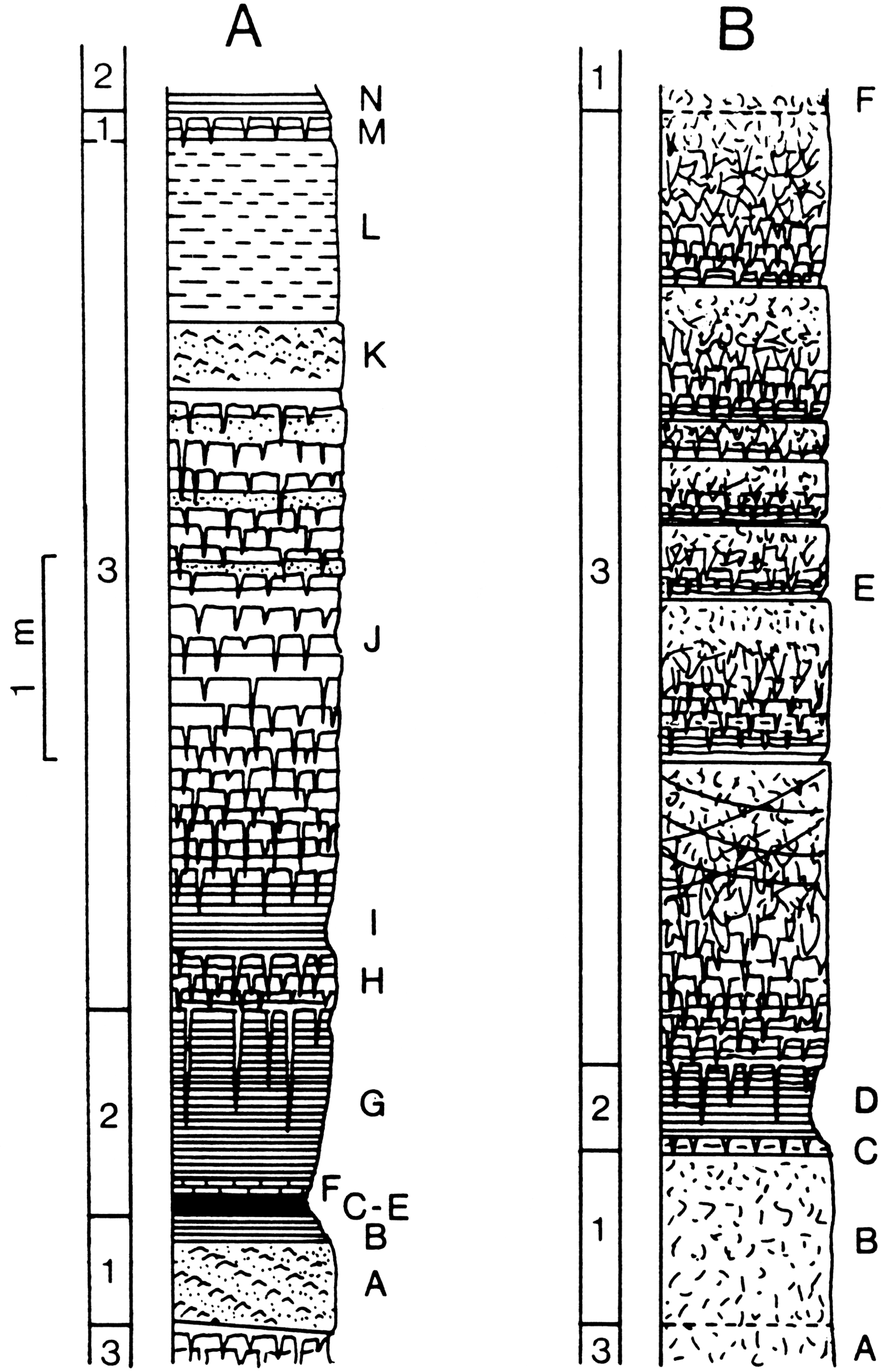


Figure 13. Two extremes in the range of cycles exposed in the Rt. 29 sectiion (Stop 2). A, Cycle SH2 of Figure 11 (see also Fig. 4). B, Cycle FTR3 of Figure 11. Key to units A-M of (A) and A-F of (B) given in Table 2. Cycle divisions shown to left of each column.

Table 2a.
Key to Figure 13a.

N	+30 cm laminated black claystone (2.9% T.O.C.).
M	10 cm gray mudstone with widely spaced desiccation cracks.
L	96 cm of massive seemingly structureless monosulfide-bearing gray mudstone follows (0.6% T.O.C.)
K	30 cm fine occillatory rippled sandstone (0.1% T.O.C.)
J	240 cm decimeter-scale beds with abundant contorted shallow to deep desiccation cracks, soft sediment deformation, reptile footprints, and rare bedding planes with clam shrimp. Thin beds of coarse silt and fine sand become common in the upper part (.5% T.O.C.).
I	30 cm of dark gray laminated mudstone with rare fish bones (0.1% T.O.C.).
H	30 cm of centimeter-scale gray mudstone beds with widely spaced deep controted desiccation cracks (1.3% T.O.C.).
G	83 cm of laminated organic-rich (5.0% T.O.C.) black limestone (77% carbonate) grading up into a less calcareous (34% carbonate) and less-organic-rich (1.6% T.O.C.) siltstone with deep, widely spaced, and sinuous desiccation cracks propagating down from above, and abundant pinch and swell lamination. Clam shrimp and ostracodes abundant at the base but absent at the top.
F	3 cm laminated blebby limestone (76% carbonate) with only occasional microlaminae (6.6% T.O.C.). Abundant ostracodes and conchostracans present.
E	8 cm microlaminated limestone with even microlamination and some pronounced stylolites passing up into limestones with very discontinuous blebby microlamina. Conchostracans, ostracodes, *Turseodus*, and coprolites present.
D	3 cm microlaminated blebby very calcareous silstone with extremely abundant clam shrimp, articulated *Turseodus*, and fish coprolites.
C	4 cm microlaminated calcareous claystone (1.4% T.O.C., 33% carbonate). Basal few couplets with articulated skeletons of *Tanytrachelos* and infrequent clam shrimp.
B	12 cm well-bedded mudstone showing an upward increase in thin bedding and total organic carbon content. Contains occasional clam shrimp and fish bones (1.0% T.O.C.).
A	39 cm gray climbing ripple-bedded fine sandstone (0.3% T.O.C.). Desiccation cracks are absent in contrast to division 3 of the preceding cycle.

Coelurosaurichnus sp. (Olsen & Baird, 1986), and an uncertain tridactyl form (Baird, 1957) (Fig. 16). Associated gray sandstones have produced an important megafossil plant assemblage (Newberry, 1888; Bock, 1969) including *Glyptolepis playsperma* and *G. keuperiana* (Cornet, 1977), *G. delawarensis* (Bock, 1969), *Pagiophyllum* spp., (?) *Cheirolepis munsteri*, *Clathropteris* sp., and *Equisetites* spp. Nearby exposures have also yielded clam shrimp in member O. The interesting, unique specimen of the plant fossil *Ginkgoites milfordensis* Bock, 1952b (ANSP uncatalogued), from the Smith Clark quarry, was destroyed on loan in 1974 (Spamer, 1988), so comparisons cannot now be satisfactorily made regarding its relationship to other fossil plants.

At a nearby outcrop along Mill Road on the north side of Hackihokake Creek to the northeast, purplish and red footprint-bearing beds of the Van Houten cycle overlying the gray beds of member O have produced *A. milfordensis*, the type of *Chirotherium lulli* (Bock, 1952a; Baird, 1954), cf. *Coelurosaurichnus* sp. (a different form than previously mentioned), and numberous small *Grallator* (PU 19910).

Vertebrate Ichnological Succession in the Newark Supergroup

The until recently poorly-known Passaic Formation footprint fauna is very rich compared with classic Jurassic assemblages of the Connecticut Valley type. Recent taxonomic revisions have whittled down the number of Early Jurassic valid genera from the 47 cited in Lull's (1953) compendium to six or eight (Fig. 18) (Olsen, 1980c,d; Olsen & Galton, 1984; Olsen & Baird, 1986; Olsen & Padian, 1986): *Grallator* spp., *Anomoepus* spp., *Batrachopus* spp., *Otozoum* sp., *Rhynchosauroides* sp. (Olsen, 1980c), *Ameghinichnus* sp. (Olsen, 1980c), and two uncertain but possibly valid forms *Hyphepus* and *Gigantipus*. Two of these, *Rhynchosauroides* and *Ameghinichnus*, were until recently (Olsen, 1980c; Olsen & Galton, 1984) unknown in Connecticut Valley-type faunules. The number of ichnospecies is completely muddled; there could be as few as 10 or many more.

In contrast, Triassic footprint assemblages from the Passaic contain at least 10 genera collected from far fewer localities: *Procolophonichnium* (Baird, 1986), *Gwyneddichnium* (Baird, 1986), *Rhynchosauroides*, *Apatopus*, *Chirotherium*, *Brachychirotherium*, *Atreipus*, *Coelurosaurichynus*, *Grallator* (Fig. 19); and equivalent beds in the Gettysburg Basin have produced *Dicynodontipes*. There are several valid species of *Rhynchosauroides*, *Brachychirotherium*, *Coelurosaurichnus*, probably *Grallator*, and *Atreipus* making up at least 15 ichnospecies.

Even at this early stage of sampling, when footprint faunules are examined from the Lockatong through Passaic, there appears to be a marked increase in taxonomic diversity through the Late Triassic. This is punctuated by a dramatic drop at, or close below, the palynologically defined Triassic-Jurassic boundary in the uppermost Passaic Formation. Newark ichnological assemblages never recover their previous levels of diversity. Global compilations of osseous taxa show the same basic pattern around the Triassic-Jurassic boundary (Olsen & Sues, 1986; Olsen et al., 1987) as one might expect of a catastrophic extinction event.

Table 2b.
Key to Figure 13b.

F	+20 cm gray massive mudstone with crumb fabric.
E	491 cm consisting of seven massive mudstone sequences, each 150 to 20 cm thick, showing the crack to crumb transition.
D	31 cm of red and green laminated to thin-bedded claystone with widely spaced desiccation cracks propagating down from the overlying unit.
C	8 cm gray claystone becoming laminated upwards. Widely spaced desiccation cracks originating at the top of the unit occur.
B	82 cm gray massive mudstone with well-developed crumb fabric with predominantly carbonate-filled vesicles.
A	+30 cm red massive mudstone with vague crumb fabric with analcime-filled vesicles.

Return to vehicle and drive back down to Water Street.

66.0 Intersection with Water Street. A roadcut in this hill to the north on the east side of road exposed most of the Perkasie Member and overlying beds. Gray and red claystones of division 2 of a Van Houten cycle about 50 m above the base of member O contain *Semionotus*, the clam shrimp *Cyzicus* sp. and cf. *Ellipsograpta*, and non-darwinulid ostracodes. These and a succeeding Van Houten cycle make up Cornet's (1977) pollen and spore localities M-4 and M-3. About 100 m above the Perkasie further up the road are outcrops of another gray member (Cornet's locality PF-3). McIntosh et al. (1985) have identified the boundary between a lower thick normally magnetized zone and an upper thick reversed zone. Here the base of the Perkasie lies about 20 m above a boundary between magnetozones. This boundary has been identified at several outcrops to the southwest in the Hunterdon fault block and in the Watchung syncline 60 km to the east (Olsen, 1988).

66.1 Turn right onto York Street. McLaughlin's members L nd M are exposed about 100 m below the Perkasie Member on the west side of York Street. Outcrops of these gray members contain clam shrimp and constitute Cornet's localities M-1 plus M-2 and M-6, respectively. Pollen and spores from these beds indicate an early Norian age (Cornet, 1977; Cornet & Olsen, 1985) for the Perkasie Member and members L and M.

Turn left onto Water Street.

66.3 Turn right into Milford Town Park. LUNCH. Exposures in hillside on opposite side of creek expose red beds in between members L-M and the Perkasie Member.

Return to York Street, turn left.

66.8 Intersection with Bridge Street, Milford, New Jersey. Turn right. Mileage resumes from 64.9 at this point.

Continuation of Main Route

65.0 Bridge over Delaware River. Cross into Pennsylvania.

65.3 Turn right on Pennsylvania Rt. 32 and continue north.

65.9 Extensive exposurs visible here on east bank of river, along River Road (as described in Manspeizer & Olsen, 1981, and Van Houten, 1969, 1980).

68.7 Cliffs of lower Passaic Formation (between Perkasie Member and members L and M). These exposures have not been prospected for fossils, as far as we know.

69.8 Junction with Pa. Rt. 611. Turn left onto Rt. 611 South.

70.2 Kintersville, Pennsylvania. Exposures of members L and M in local streams.

71.1 Type of *Rhynchosauroides [Kintneria] brunswickii* (Ryan & Willard, 1947) (PU 20467) found in cut on left side of road.

71.6 Ferndale, Pennsylvania.

73.2 Junction with Marienstien Road. About 1 mi. southeast is site of 4000-m-deep hydrocarbon test drilled in 1985. Proprietary drill hole records show that individual Van Houten cycles as well as the compound cycles present in outcrops to the southeast (such as those at Stops 2, 3A, or 3B) can be traced at least to this area and thus probably represent basin-wide events. This new borehole is close to the position of the Revere well drilled in 1891 to a depth of 843 m (McLaughlin, 1943).

Stay on Rt. 611.

75.2 Harrow, Pennsylvania. Quarry on west side of Rapp Brook exposes member O of Perkasie Member. Compared to the exposures at Milford, New Jersey, a much finer facies of the Passaic is present here with extensive development of massive mudstones. Fourier analysis of sediment fabrics shows the same hierarchical pattern of thickness periods seen in the Lockatong 1000 m lower in the Newark Basin section (Olsen, 1986).

76.3 Intersection with South Park Road. Continue on Rt. 611. To the west, along South Park Road on west side of Tohicken Creek, are exposures of Perkasie Member both along road and in spectacular spillway cut for new Lake Nockamixon.

76.4 Outcrops of member N of Perkasie Member.

78.7 Outcrops of Graters Member.

79.9 Outcrops of member D of Passaic Formation.

81.3 Entering Lockatong Formation.

85.3 Turn left at light onto entrance ramp for road to Fountainville.

85.6 Right onto Ferry Road towards Fountainville.

86.8 Entering Stockton Formation.

86.9 Fountainville, Pennsylvania. Cross small fault and reenter Lockatong Formation.

87.8 Reenter Stockton Formation.

90.0 Cross small dike.

90.5 End of Ferry Road. Turn left onto Callowhill Road.

90.8 Enter drag-folded portion of Lockatong.

92.0 Stop sign. Turn right onto Main Street, Chalfont, Pennsylvania; continue north.

92.3 Leave Lockatong Formation; enter Stockton Formation.

92.6 Enter basal Lockatong Formation, climbing up section.

94.1 Turn right onto Skunk Hollow Road.

95.1 Turn left into parking area near scale house and park.

ALWAYS ASK PERMISSION TO ENTER.

STOP 4. Haines and Kibblehouse Quarry, Middle Lockatong Formation (Late Carnian Age)

This large active quarry exposes most of Skunk Hollow Member (of which this is the type section) and lower parts of Tohicken Member of middle Lockatong Formation adding up to a total of about 120 m (Fig. 11). The section is about 25 km to the southwest of the Rt. 29 exposures of the same units (Stop 2).

McLaughlin (1946) mapped his "First Thin Red" unit through this area in the 1930s and 1940s prior to the opening of the quarry. Opened in 1965, the quarry exposes all of the "First Thin Red" and the entire pattern of Van Houten, 100,000-year, and 400,000-year cycles present along Rt. 29, making a remarkably close match at all scales. Evidently the individual cycles present along Rt. 29 extend at least 25 km to the southwest. The quarry section differs, however, in having a much larger amount of sand (33%) and in lacking the very hard analcime and carbonate-rich massive mudstones so typical of the Rt. 29 section. They are replaced with red massive mudstones with a coarser breccia fabric, rooted and burrowed fabrics, and beds of red ripple cross-laminated silt, tufa gravels, and fine sandstones with soft-sediment deformation and desiccation cracks. Some of these red units contain rare to abundant bones of *Tanytrachelos* and phytosaurs, and reptile footprints (Fig. 14). The massive gray mudstones of the basal parts of the Tohicken Member of the Rt. 29 section are replaced with flaggy oscillatory and climbing ripple-bedded sandstones with reptile footprints. The features which Van Houten used to distinguish chemical from detrital cycles are absent in the quarry section, even though the same individual cycles are still present.

Complete fish (*Turseodus*) are very common at this locality in cycles marked SH1 and SH2 in Figure 11. Clams occur in an algal tufa conglomerate above the sandstones, about 20 m above the base of the section (Fig. 11). The sandstones makeup large tilted surfaces which fine down the slope and are probably foreset beds of a small Gilbert-type delta (J. Smoot, personal communication). Fish fragments (mostly *Turseodus*) occur in the second Van Houten cycle in the lower part of the Tohicken Member.

The conditions under which it is relatively easy to find reptile bones at this exposure are rather specific. Because this is an active quarry, the best time to look at the rocks is after a strong rain; otherwise the rocks are covered with dust. If sunlight is too oblique, the bones are not visible because they are hidden by surface relief. The bones tend to cleave along with the rock on joints and the bones have no surface relief of their own. Bones tend to be most visible on a bright but overcast day when color contrasts are most obvious. On the other hand, fish are most easily seen in full sunlight, where their surface relief stands out best even when they are covered by a layer of matrix. We feel that the distribution of bones in this quarry may prove to be quite typical of the coarser-grained but still mostly lacustrine facies of the Lockatong and Stockton.

Preparation of reptile bones from matrix from the locality is very difficult, but fortunately at least the *Tanytrachelos* can be negatively prepared in HCl and then latex-cast. Once prepared in this way the bones prove to the three-dimensional and a very nice complement to more common, flattened, articulated skeletons.

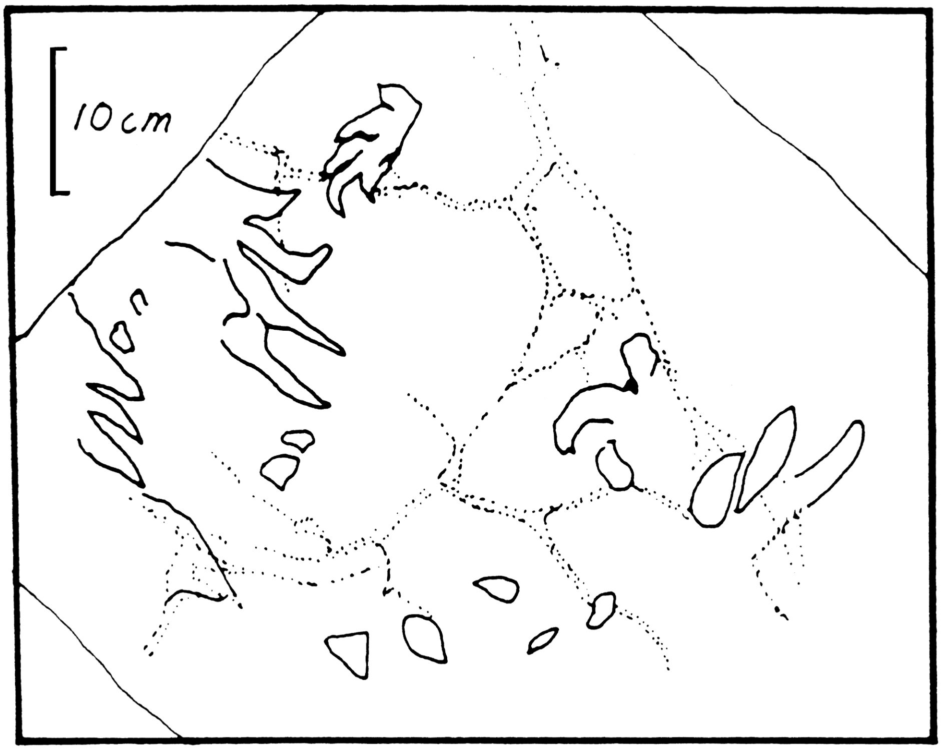


Figure 14. Poor *Apatopus* from division 3 of cycle SH2 at Stop 2 (from Manspeizer & Olsen, 1981).

Floral Remains

As a rule, plant fossils are extremely uncommon in the Lockatong Formation. However, an as yet poorly-collected florule occurs at the base of the section in this quarry. Some of the remains are pyritized and remarkably three-dimensional. So far, *Neocalamites* cf. *knowltoni*, *Equisetites* sp., *Pterophyllum* sp., *Glyptolepis* cf. *platysperma*, and *Pagiophyllum* cf. *simpsoni* have been recovered. In addition, a palynoflorule occurs in the gray siltstones just below the "First Thin Red" dominated by *Patinosporites densus* and belongs to Cornet's (1977a,b) New Oxford-Lockatong Palynoflora (Cornet & Olsen, 1985). According to Cornet (1977a) this assemblage is of Late Carnian age.

	Return to vehicle, leave quarry, and head back south on Skunk Hollow Road.
96.0	Turn left onto Pa. Rt. 152 (Main Street) towards Chalfont.
98.2	Cross Chalfont fault. Enter upper Lockatong Formation.
98.4	Turn right onto U.S. Rt. 202 South.
101.6	Turn left onto Pa. Rt. 309/U.S. Rt. 202 South.
102.6	Turn right onto U.S. Rt. 202 (Dekalb Pike).
106.0	Park near railroad overpass, cross highway to south side of road and climb up to rail lines. BEWARE OF ELECTRIC TRAINS—THEY ARE QUIET AND TRAVEL AT 50+ MI/HR.

STOP 5. Gwynedd Cut Along Reading Railroad Tracks, Lower Lockatong Formation (Late Carnian)

In the mid-19th century a tunnel was constructed for the North Pennsylvania Railroad at Gwynedd, Pennsylvania, and open cuts were constructed from there to North Wales. The tunnel was enlarged to an open cut about 1923. Presently the main cut exposes more than 200 m of the Gwynedd and North Wales Members in the lower, but not lowermost, Lockatong Formation.

Faulting is extensive at this locality and according to Watson (1958) repeats the section by about 35%. Virtually none of the faults have more than 3 m of vertical displacement and thus it is possible to measure virtually the entire section. As measured by Olsen (1984a) (Fig. 19), the section totals about 200 m plus about 20 m at the south side of the cut which could not be confidently correlated with beds to the north. Watson (1958) also measured this section, concentrating on determining the throw of the faults, and came up with a total of about 229 m.

The ususal pattern of Van Houten cycles of about 25,000 years and compound cycles of 45,000-50,000, 100,000, and 400,000 years are present (Fig. 19), based on Fourier analysis of sediment fabrics calibrated by couplets assumed to be varves and radiometric time scales (Olsen, 1984a). In this respect, this section is very similar to that along Rt. 29 in New Jersey. However,

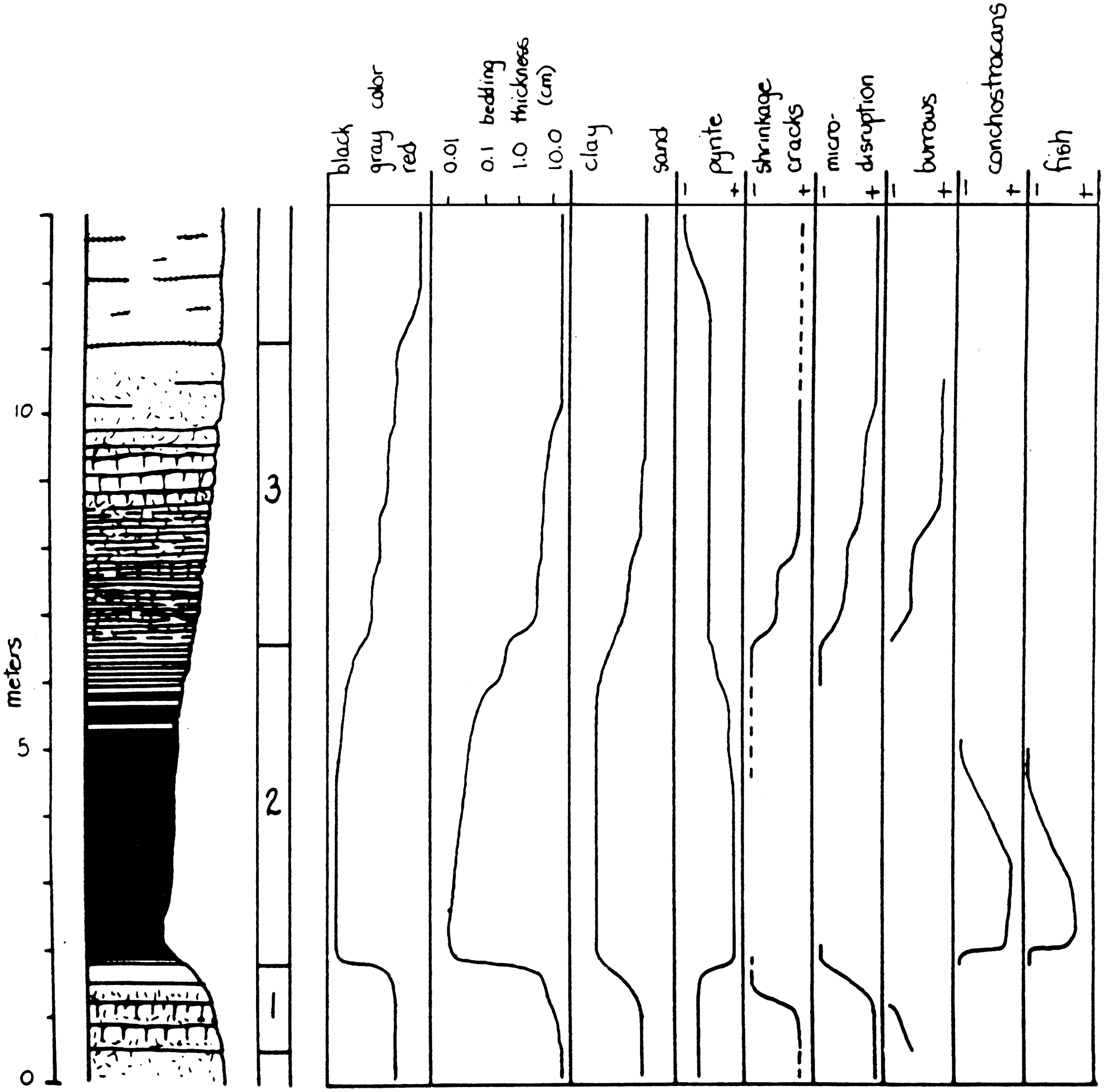
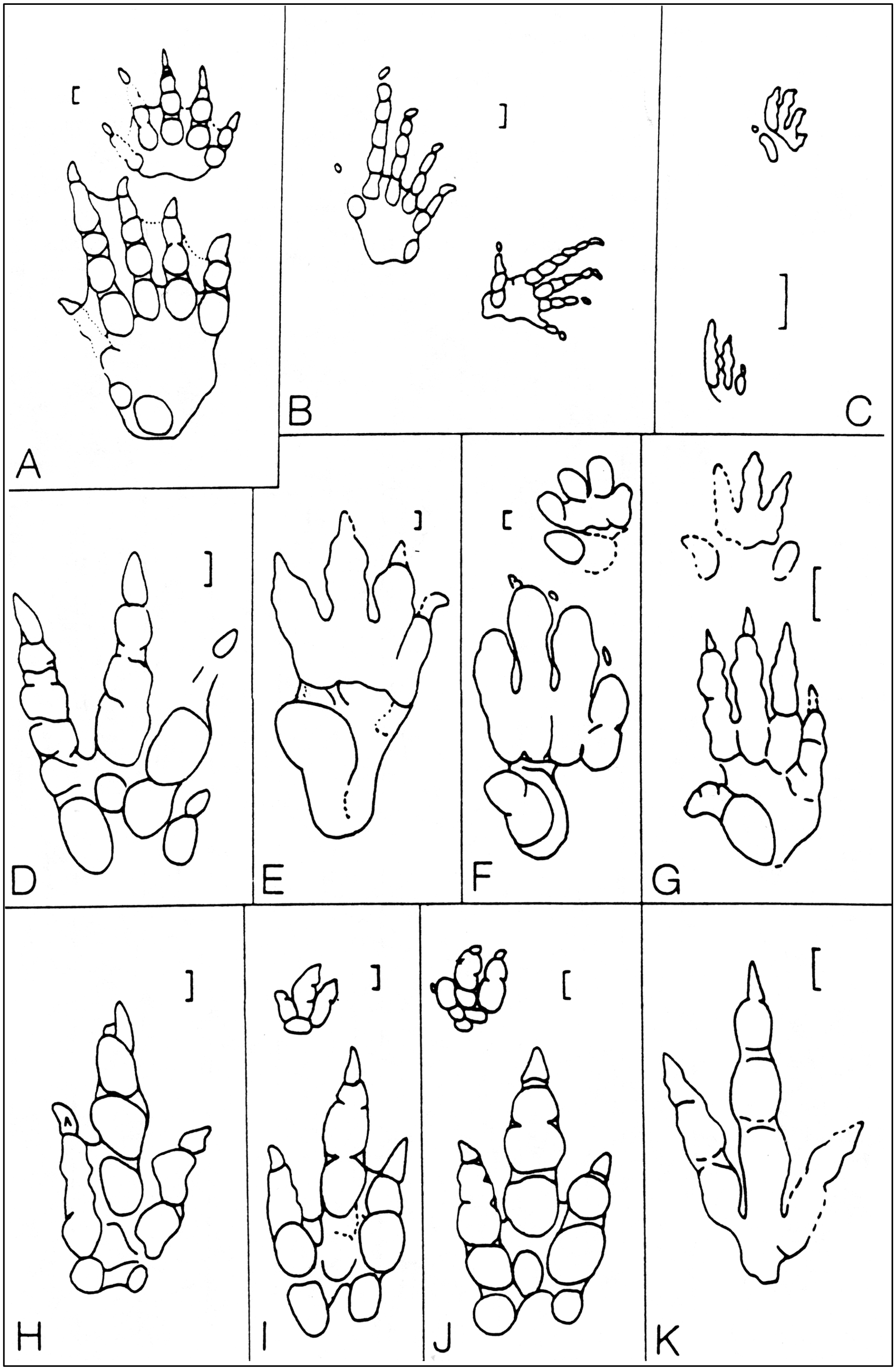


Figure 15. Single Van Houten cycle of exposed portion of Member D, Warford Brook (from Manspeizer & Olsen, 1981).


A
B
C
D
E
F
G
H
I
J
K

the section resembles the Haines and Kibbleshouse Quarry section (Stop 4) in facies; but microlaminated, fish-bearing units are much more common here than at either Stop 2 or 4. This is a function of stratigraphic position and is characteristic of the lower Lockatong (Hoboken, Weehawken, and Gwynedd Members) which has produced the bulk of Lockatong fossils.

History of Study.

Leidy (1856, 1857) was the first to describe vertebrates from Gwynedd, followed by Cope (1869), Bryant (1934), Bock (1945, 1946, 1952a, 1969), and Huene & Bock (1954). Most remains were collected from debris taken out of the cut during the original tunnel excavation and the later enlargement. Although good material can still be collected from the exposures themselves, subsequent work has largely been restricted to systematic revisions. This locality was the main source of much of the Wilhelm Bock Collection, the extant part of which is held at the Academy of Natural Sciences of Philadelphia; the locality also yielded many of Bock's type specimens. The locality name (Gwynedd) is that which Bock incorporated into many of his erected genera and species of vertebrates, vertebrate ichnofossils, invertebrates, and plants: *Gwyneddocaris*, *Gwyneddosaurus*, *Gwyneddichnium*, *Gwyneddichtis* (including *Gwyneddichtis gwyneddensis*), *Anchisauripus gwyneddensis*, *Rhabdiolepis gwyneddensis*, *Cycadospadix gwyneddensis*, and *Albertia gwyneddensis*.

Faunal Remains

Fossils are indeed abundant in the 40 or so Van Houten cycles exposed in the Gwynedd cut, and the types of a large number of Newark vertebrate taxa come from this site. These include the types of *Anchisauripus gwyneddensis* Bock, 1952a [probably *Atreipus milfordensis* (Bock, 1952a) Olsen & Baird, 1986b; see also Spamer (1988b) for notes on the type of *A. gwyneddensis*]; *Gwyneddichnium majore* Bock, 1952, *G. minore* Bock, 1952, *G. elongatum* Bock, 1952; and *Platypterna lockatong* Bock, 1952; as well as the osseous taxa *Rhabdopelix longispinis* Cope, 1869-1870, *Gwyneddosaurus erici* Bock, 1945, *Lysorocephalus eurei* Huene & Bock, 1954 (thought to be an amphibian but really a skull roof of *Turseodus*; Baird, 1965), *Gwyneddichitis major* Bock, 1959, *G. minor* Bock, 1959, *G. gwyneddensis* Bock, 1959 (the latter three may all belong in *Turseodus*), *Cionichthys* [*Redfieldius*] *obrai* (Bock, 1959), (?)*Semionotus howelli* Bock, 1959, *Osteopleurus* [*Diplurus*] *newarki* (Bryant, 1934, Schaeffer, 1952a), *Pariostegus* [*Diplurus* = *Rhabdiolepis*] *gwyneddensis* and *D. striata* (Bock, 1959) (indeterminate), and *Carinacanthus jepseni* Bryant, 1934. Phytosaur teeth, *Synorichthys* sp., conchostracans, ostracodes, and coprolites have also been found. Bock (1946) has described a supposed phyllocarid crustacean, *Gwyneddocaris parabolica* (erected as new taxa) from this locality, but the specimen has proved to be the anal plate, partial fin, and associated scales of a fish (D. Baird, personal communication; see also comments from D. Baird and H. F. Roellig quoted by Rolfe, 1969, p. R330).

Rhabdopelix*, *Gwyneddosaurus*, and *Tanytrachelos

Rhabdopelix *longispinis* Cope, 1869, and *Gwyneddosaurus erici* Bock, 1945, pose some interesting taxonomic problems. The specimens which constitute the type of *R. longispinis* were collected from the rubble removed during tunnel construction. The individual bones were apparently scattered on many small slabs and these are now lost; but judging from the crude woodcuts provided by Cope, the taxon is based on an unnatural assemblage of elements of several forms including the tanystropheid *Tanytrachelos* (Olsen, 1979), possibly the gliding lepidosaur *Icarosaurus* Colbert (1966, 1970), and fish.

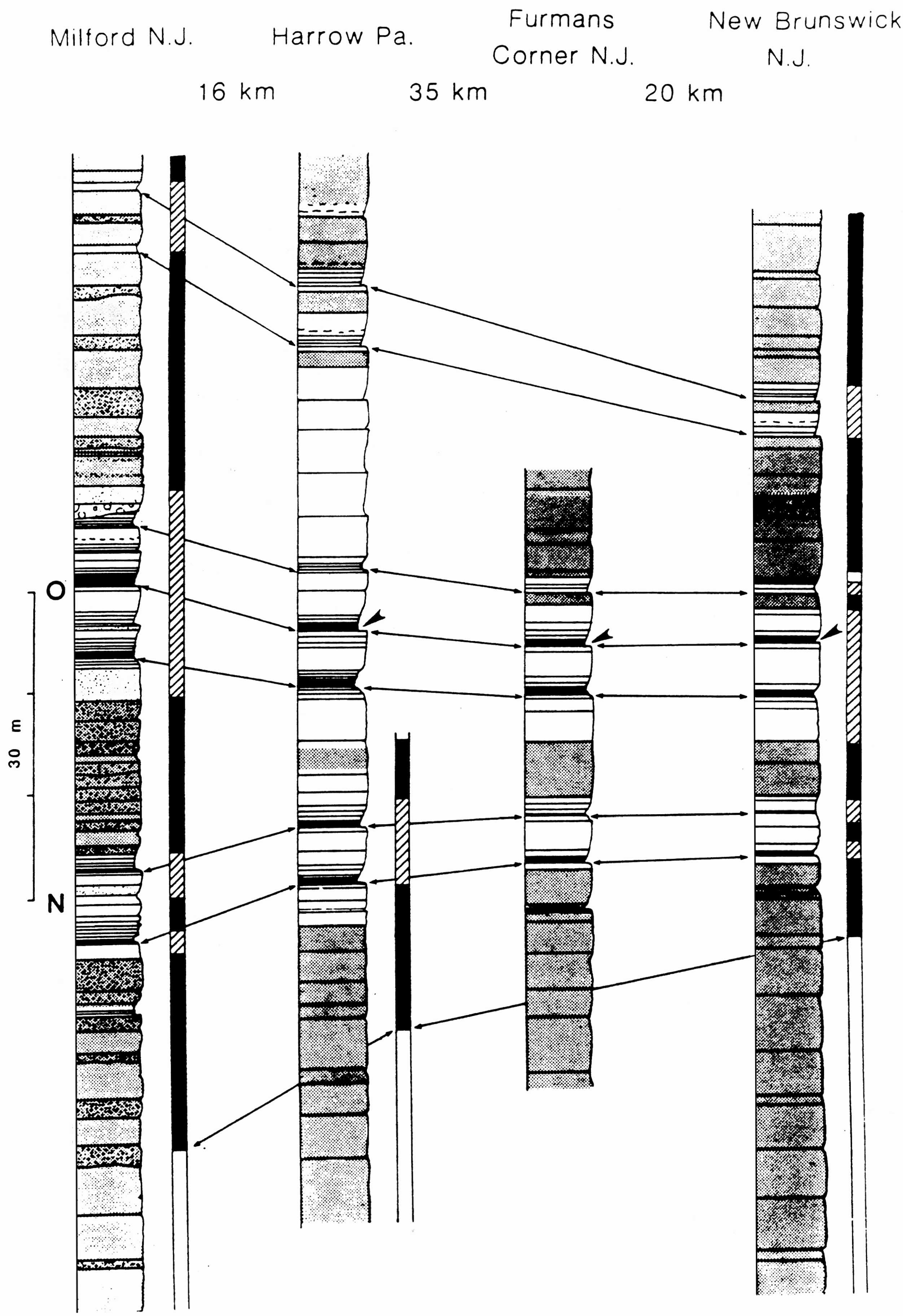
Gwyneddosaurus erici (holotype ANSP 15072) is based on a slab of microlaminated shale probably recovered from rubble removed during the enlargement of the Gwynedd cut; however, it too appears to be a composite--in fact, a gastric ejection. Although the type specimen was significantly damaged during original preparation, the ANSP collection does house Bock's photographs of the specimen prior to preparation. From the specimen in its current condition (as figured in Bock, 1945) and from the photograph, *Gwyneddosaurus* appears to be a mixture of *Tanytrachelos* and possibly some coelacanth scraps. The large, quadranglular and keeled interclavicle characteristic of *Tanytrachelos* is present as are procoelous vertebrae. At this point we have two choices. One would be to suppress *Tanytrachelos* Olsen, 1979, as a junior synonym of *Rhabdopelix* or *Gwyneddosaurus* or both. The other would be to regard the older two genera as indeterminate. Because we will never know for sure what comprised *Rhabdopelix* we should not suppress *Tanytrachelos* in its favor. At least part of *Gwyneddosaurus* more assuredly is *Tanytrachelos*, but again there is significant room for doubt--certainly at the species level it is indeterminate and we prefer to consider both *Rhabdopelix* and *Gwyneddosaurus as nomina dubia*. Therefore, we still favor retention of *Tanytrachelos* as it is founded on a nearly complete articulated specimen (Olsen, 1979).

Tanytrachelos* as the Trackmaker of *Gwyneddichnium

Bock's genus *Gwyneddichnium* from Gwynedd appears to be one of those very rare cases where it is possible to assign with a reasonable degree of confidence a footprint to a trackmaker known from osseous remains at the generic level. Both Baird (1986) and Lockley (1986) have pointed out that *Gwyneddichnium* makes a very convincing track of a tanystropheid reptile (almost certainly *Tanytrachelos*).

Tanystropheids (consisting of *Tanystropheus* and *Tanytrachelos*) have a very unusual pes. The metatarsal of digit V is shortened to a tarsal-like bone and the proximal phalanx is elongated in the form of a metatarsal (Fig. 20) (Wild, 1973; Olsen, 1979). Digit V thus points forward in the pes quite un-

(Facing page) **Figure 16.** Main footprint types present in Lockatong and Passaic Formations. Scale bar is 1 cm. **A,** *Apatopus lineatus* (from Baird, 1957); **B,** *Rhynchosauroides hyperbates*; **C,** *Rhynchosauroides brunswickii*; **D,** ?*Coelurosaurichnus* sp. (*sensu stricto type 2);* **E,** *Brachychirotherium eyermani* (from Baird, 1957); **F,** *Brachychirotherium parvum* (from Baird, 1957); **G,** *Chirotherium lulli* (from Baird, 1954); **H,** *Grallator* sp. (from Baird, 1957); **I,** *Atreipus sulcatus*; **J,** *Atreipus milfordensis* (from Olsen & Baird, in prep.); **K,** ?*Coelurosaurichnus* sp. (*sensu stricto* type 1). *Procolophonichnium* and *Gwyneddichnium* are not shown here, but see Baird (1986) and Figure 20.


Milford N.J.
Harrow Pa.
Furmans Corner N.J.
New Brunswick N.J.
16 km
35 km
20 km
O
30 m
N

like the primitive lepidosaur condition. Both characters are synapomorphies uniting the two genera and autapomorphies of tanystropheids (Olsen, 1979). Only pterosaurs and some turtles show a similar condition and that is surely convergence.

In *Tanytrachelos*, however, digit III of the pes is the longest, in contrast to *Tanystropheus* which has the primitive reptilian condition in which the longest digit is IV. This shortening is apparently accomplished by reduction of the number of phalanges in digit IV. The phalangeal formula for the pes in *Tanytrachelos* is therefore 2 3 4 4 4. Digit II is also the longest in the manus of tanystropheids but in *Tanytrachelos* there is no reduction in phalangeal number (phalangeal formula of 2 3 4 5 4) while in *Tanystropheus* there is reduction (phalangeal formula of 2 3 4 4 4).

Gwyneddichnium majore (holotype ANSP 15212, paratype 15213) is a quadrupedal, digitigrade ichnite with a 5-toed manus and pes in which digit III is the longest. Critically, in the pes, digit V is relatively long, projects forward, and is only slightly more divergent than digit I, if at all. The reconstructed phalangeal formula is 2 3 4 4 ?3 (Fig. 20) assuming a normal reptilian metatarsus, or 2 3 4 4 4 assuming an elongate metatarsal-like phalanx of V. If the latter is accepted, *Gwyneddichnium* can be argued to share a critical synapomorphy in particular with *Tanytrachelos* in the shortened digit IV. In addition, articulated pedal and manual specimens of *Tanytrachelos* match in all phalangeal proportions and size the manual and pedal *Gwyneddichnium* imprints. The smallest *Tanystropheus* is several times the length of the largest *Tanytrachelos* (Wild, 1973). We therefore conclude that the maker of *Gwyneddichnium majore* was *Tanytrachelos*. We agree with Bock (1952a) that his ichnotaxon was probably made by *Gwyneddosaurus*, although the latter specimen has no feet! We do not suggest that the name *Tanytrachelos* be applied to these ichnofossils, which no matter how convincingly interpreted must retain their own name.

In the reconstruction of *Tanytrachelos* provided by Olsen (1980c,d) *Tanytrachelos* is shown in walking pose with the hind foot overstepping the fore because the hind legs are so long. Confirmation of this is seen in *Gwyneddichnium* as well (Fig. 20).

If *Gwyneddichnium majore* is correctly assigned to *Tanytrachelos*, then we learn several new things about the latter. First, *Tanytrachelos* was capable of walking in at least very shallow water (cm), if not out of the water. There really is nothing about the skeleton to suggest it might not have been fully aquatic. Second, it was dentigrade. There is nothing about either the osseous structure of manus or pes to suggest this. Third, it did not drag its tail, although the tail could have been buoyed up by a centimeter or so of water. Fourth, we know its pes had rather coarse scales or tubercles on a poorly padded foot.

We now know more about *Tanytrachelos* than about most extinct animals. Its skeletal structure is unusually clear for such a small animal, based on numerous articulated flattened individuals and many three-dimensional bones from Stop 4. We can tell males from females because of the paired "baculi" at the base of the pelvis in about 50% of the specimens (Olsen, 1979). We know it had smooth skin on the legs and body (skin is preserved in some specimens from the Danville-Dan River Basin) but rough skin on the soles, and we know how and where it walked. But we still do not know its color.

The nature of *Gwyneddichnium minore* (holotype ANSP 15216, paratype 15217) is not so clear. There are no pes impressions in the available material and the manus has digit IV projecting less anteriorly than II, while the opposite is true of *G. majore*. The manus skeleton of *Tanytrachelos* can fit in *G. minore* by counterclockwise rotation of the metatarsus cross-axis of the hand. Indeed, this ichnotaxon does fit within the rather wide range of variability seen in the abundant undoubted *Gwyneddichnium* trackways from Arcola, Pennsylvania (see below). Nonetheless, it is still possible that *G. minore* consists of bipedal

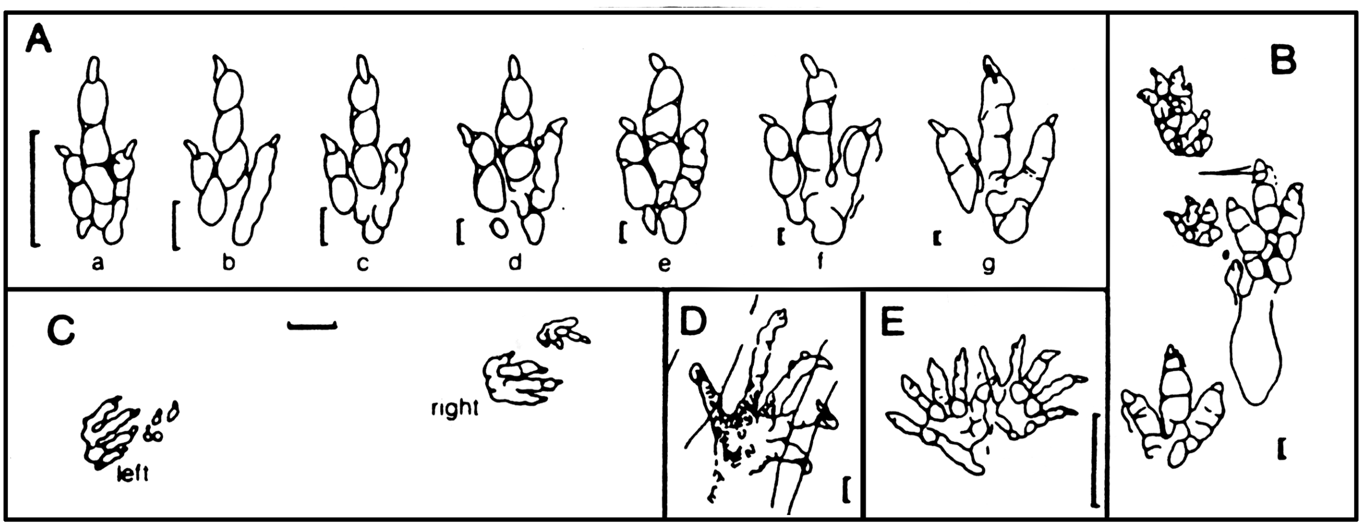


Figure 18. Newark Supergroup Jurassic footprint taxa (from Olsen, 1980c), Towaco Formation of Newark Basin. Scale bar is 1 cm. **A,** Size series of *Grallator* spp. ranging from *G.* (*Grallator*) sp. through (e) *G.* (*Anchisauripus*) sp. and (g) *G.* (*Eubrontes*) sp. **B,** *Anomoepus* manus-pes sets. **C,** *Batrachopus* cf. *deweyi*. **D,** Manus of *Rhynchosauroides* sp. **E,** Manus-pes sets of *Ameghinichnus sp.*

(Facing page) **Figure 17.** Lateral correlation of Perkasie Member of Passaic Formation across Newark Basin and correlative magnetostratigraphy (magnetic polarity data from McIntosh et al., 1985). Vertical, white, black, and diagonally ruled bars represent normal, reversed, and uncertain polarity zones, respectively. Large chevrons denote unusually radioactive zones. Key to lithological symbols in Figure 11b.

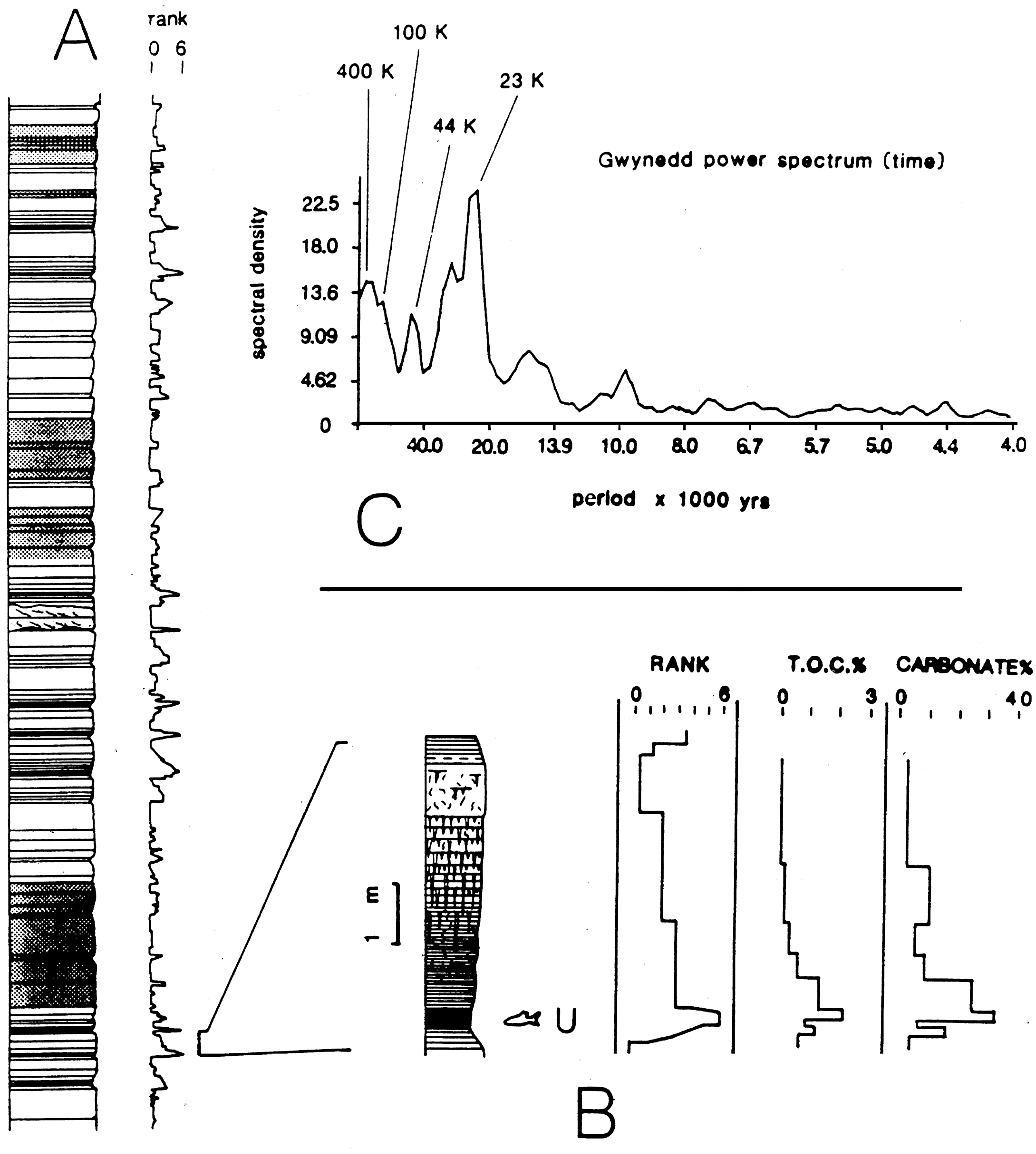


Figure 19. Gwynedd section (Stop 5); symbols as in Figure 11. **A**, Measured section with relative lake level (Olsen, 1986). **B**, Single Van Houten cycle; T.O.C. stands for Total Organic Carbon in wt. %; U indicates radioactive unit. **C**, Power spectrum in time for entire Gwynedd section showing main periods of cycles; assumed sedimentation rate 0.24 mm/yr.

trackways of a minute chirothere, as originally suggested by Olsen (1980d). If *G. minore* in reality consists of pedal impressions, it may be a new ichnogenus and certainly not a tanystropheid.

Gwyneddichnium elongatum (holotype ANSP 15214; paratypes 15215, 16006) is even more obscure, consisting of an indistinct isolated pes impression in which the digits cannot be counted with confidence--it is best regarded as indeterminate.

?Salamander Tracks?

On ANSP 15213, the paratype of *Gwyneddichnium majore*, are a series of small tracks referred to *Kintneria* sp. by Bock (1952a, 1964) (these tracks have a separate catalogue number, ANSP 16003). Another slab, ANSP 15220, is covered with similar small tracks. At first, it seemed likely that these tracks could be referred to *Rhynchosauroides* as had the type material of *Kintneria* (Baird, 1964). However, unlike typical *Rhynchosauroides*, these do not have a recurved digit V on the manus. In fact, there are no impressions with five digits and there is no clear indication whether these are in fact manus impressions. (It is not uncommon, however, for undoubted *Rhychosauroides* trackways to consist only of manus impressions.) Some impressions on ANSP 15220 are quite clear and resemble not *Rhynchosauroides* but rather the salamander tracks figured by Peabody (1959). Unfortunately, both slabs have too many overlapping impressions for trackways to be worked out.

Floral Remains

Small poorly preserved scraps of plants occasionally occur at this locality. An unfortunately large number of taxa have been founded on mostly indeterminate remains from Gwynedd by Bock (1969), including the types of *Brachyphyllum conites*, *Thujatostrobus triassicus*, *Gloetrichata formosa*, *Stolophorites lineatus*, *Cycadenia elongata*, *Cycadospadix gwyneddensis*, *Zamiostrobus minor*, *Z. rhomboides*, *Carpolithus carposerratus*, *C. amygdalus*, *Albertia gwyneddensis*, *Araucarites cylindroides*, and *Pagiophyllum crassifolium*. Most of these are conifer shoots, cone scales, or invertebrate ichnofossils. One of Bock's (1961) forms, *Diploporundus rugosus* from Gwynedd, is definitely the arthropodan ichnite *Scoyenia*; namely Wanner's (1889) *Ramulus rugosus* was based on *Scoyenia* from his *Atreipus* locality. Bryant (1934) cites "*Podozamites*" and Bock (1952) also lists *Pterophyllum powelli* (? = *Zamites powelli*) without locality, and "*Neocalamites* from Gwynedd". Unfortunately, all of the Gwynedd plant types of Bock are not available to researchers and might be lost (Spamer, 1988). Bock's (1969, fig. 62A) specimen of "*Dendrophycus triassicus*" (Newberry, 1888) from Gwynedd (which he included in a section on the Thallophyta) is a pseudofossil (ANSP 66002, Invertebrate Paleontology, formerly ANSP Paleobotany 4314).

Pollen and spores also occur within portions of Van Houten cycles at Gwynedd. The palynomorph assemblage is dominated by *Patinosporites densus* and non-striate bisaccates and is similar to that which occurs at Stop 4; it is likewise of Late Carnian age. Bruce Cornet has kindly supplied a list of taxa (Table

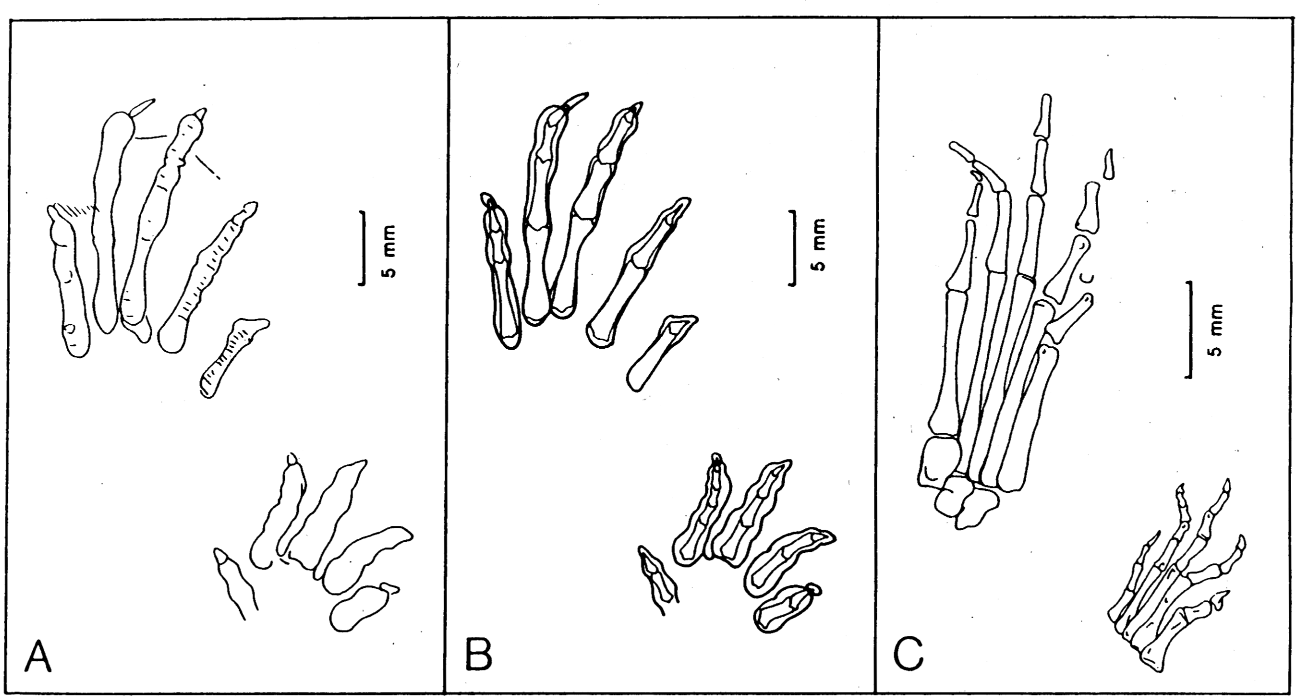


Figure 20. Comparison of *Gwyneddichnium majore* and manus and pes of *Tanytrachelos ahynis*. **A,** Composite of left manus-pes set of *Gwyneddichnium majore* based on the type material. **B,** Diagramatic composite outline of manus-pes set of *Gwyneddichnium majore* with reconstructed manus and pes skeleton. **C,** Left manus and pes of *Tanytrachelos ahynis*, based on YPM 8600.

3) he has identified from a sample at about 33 m above the base of the measured section in Figure 19.

The Bock Specimens from Gwynedd

Some confusion exists in the literature as to the status and correct catalogue numbers of the type material of Bock. The Bock Collection held at the Academy of Natural Sciences of Philadelphia has lately been curated and uncatalogued items given catalogue numbers. The following notes emend Bock's published data and provide new information for uncatalogued specimens (E. Spamer, personal communication; all catalogue numbers are ANSP numbers and all specimens listed here, as identified by Bock, are from the Gwynedd cut).

Fish: *Semionotus howelli* Bock, 1959 (holotype 15663), *Rhabdiolepis striata* Bock, 1959 (holotype 15652, paratype 15653, and 16046-16051), *Redfieldius obrai* Bock, 1959 (holotype 15649), *Gwyneddichtis major* Bock, 1959 (holotype 15655; paratypes 15656, 16200; and 16201-16212), *G. minor* Bock, 1959 (holotype 15647), *G. gwyneddensis* Bock, 1959 (holotype 15650, figured by Bock in pl. 13, fig. 1; counterpart to holotype 17067, figured by Bock in pl. 14, fig. 1; paratype 15651; and 16030-16037, 17068-17072).

Vertebrate Ichnofossils: *Platypterna lockatong* Bock, 1952a (holotype 15224 [noted by Gillette, 1978, as missing; relocated 1987]), *Gwyneddichnium majore* Bock, 1952a (holotype 15212, paratype 15213, and 16131-16150, 16058, 16214-16223), *G. minore* Bock, 1952a (holotype 15216, paratype 15217, and 16052-16070, 16137, 16086-16093, 16107-16108), *G. elongatum* Bock, 1952a (holotype 15214, paratype 15215, and 16006), *Kintneria* sp. (Bock, 1952a) (16003, not 15242 as published by Bock; on same slab with 15213), *Clespisaurus* sp. (Bock, 1952a; 16001, not 15231 [*errore*]), and undetermined footprints (16004, 16005, 16007).

Coprolites: 16023; 16024 (mixed with *Cyzicus*).

Invertebrates (ANSP Invertebrate Paleontology): *Cyzicus ovatus* (Lea, 1856) (64896, erroneously marked as a paratype); ostracodes (66000).

Table 3.

Palynomorphs from Stop 5, Gwynedd railroad cut in lower Lockatong Formation. List based on study contributed by B. Cornet done in 1978. Right hand column gives percentages of total.

Patinsporites densus	27.5
Camerosporites pseudoverrucatus	10.0
C. verrucosus	3.0
Vallasorites ignacii	9.5
Vallasporites sp.	4.0
Pityosporites spp.	5.0
Alisporites cf. *parvus*	7.5
A. australis	2.0
A. ovatus	1.5
A. cf. *parvus*	7.5
A. opii	0.5
Alisporites spp.	3.5
Platysaccus spp.	2.0
?*Paracirculina* sp.	+
Corollina meyeriana	1.0
Sulcatisporites spp.	1.0
Colpectopollis cf. *ellipsoid*	4.0
Colpectopollis sp.	2.0
Klausipollenites sp.	2.0
Eucommiidites troedsonii	2.0
Pseudoenzonalasporites summus	1.0
Cycadopites spp.	3.5
Genus A of Dunay (1972)	1.5
Triadospora cf. *obscura*	1.0
T. stabilis	+
Distaverrusporites sp.	0.5

Return to vehicle and head south on Rt. 202.

106.9 Entering Stockton Formation.

108.6 Crossing over Northeast Extension of Pennsylvania Turnpike, with cuts exposing upper Stockton and lower Lockatong. Colbert's (1943) "Blue Bell phytosaur" was found north of here in quarry in lower Lockatong.

110.3 Turn right onto Germantown Pike (old Pa. Rt. 422).

112.9 Entering Lockatong Formation.

113.2 Potshop Road. To east along this road is the Gill quarry at Fairview Village. This quarry has excellent outcrops of lower Lockatong which are very fossiliferous although poorly prospected. The usual Lockatong forms have been found including *Turseodus*, *Osteopleurus newarki*, and *Tanytrachelos*. This is Bock's (1959) Fairview Village locality.

113.8 Trooper Road; turn left.

114.2 Entering Stockton Formation.

115.3 Turn right onto Pa. Rt. 363 (Ridge Pike).

115.8 Turn left onto Park Avenue.

116.0 Outcrops of basal Lockatong Formation on north side of Mine Run on right.

116.5 Enter Stockton Formation.

118.3 Turn right onto Egypt Road.

119.0 Cross Perkiomen Creek.

119.1 Turn right onto Lower Indian Head Road, enter Lockatong Formation.

119.9 Outcrops on east side of Perkiomen Creek are of red and gray beds of Hoboken Member of lower Lockatong. To north is Skippack Creek with excellent exposures of lower Lockatong Formation upstream.

120.1 Park. Walk on left to North Reber Road 0.2 mile and turn right onto old railroad bed. Proceed down tracks to large outcrops on west side of tracks.

STOP 6A. Reading Railroad Outcrops of Lower Lockatong Formation at Arcola, Pennsylvania (Late Carnian Age)

Outcrops of about 40 m of lower Lockatong Formation occur in cut along west side of abandoned railroad bed. Lower part of section consists of upper parts of Weehawken Member and lower parts of Gwynedd Member. Lower gray sandstones of upper Weehawken Member contain phytosaur bones and teeth (seen in rubble on east side of tracks). Middle cycles contain abundant scraps of *Turseodus* and *Osteopleurus* as well as abundant darwinulid ostracodes and clam shrimp (*Cyzicus*). Red flaggy siltstones exposed below uppermost cycle (just to south of fault 2) contain *Rhynchosauroides* spp. and other ichnofossils. Uppermost Van Houten cycle exposed here contain abundant complete *Osteopleurus*, occasional *Turseodus* and cf. *Pariostegus* (large coelacanth), darwinulid ostracodes, and *Cyzicus*. This cycle is Bock's (1959) Yerkes locality.

Rhynchosauroides hyperbates from Schuylkill Expressway

A long series of road cuts (now partly covered) for the Schuylkill Expressway (new Rt. 422) exposed roughly 200 m of lower Lockatong Formation including the interval exposed here along the Reading Railroad trackbed (Olsen & Baird, 1986a). About 100 m of section were repeated by faults within the outcrops. At the northernmost cut an enormous (900 m^2) area of footprint-bearing beds was exposed during construction (1983-1984). This interval occurs in division 1 of the cycle just below the Osteopleurus-bearing cycle in the uppermost beds at the railroad cut.

Rare, poor dinosaur tracks (?*Atreipus*?) occur in the lower parts of division 1. About 1 to 3 cm below the top of division 1 is a very laterally persistent parting surface, traceable over the entire exposure, which is so unusual that it deserves special description. The bed forming the track-bearing surface is about 1 to 2 cm thick. It is finely laminated at the base and ripple laminated at the top; the ripple troughs are filled with fine siltstone so that the upper surface shows no ripples. The lower surface has natural casts of poor cf. *Gwyneddichnium* sp. There are no internal parting planes but there are small calcareous nodules within the oscillation-ripple bedded portion of the bed. This unit is broken by narrow but deep (+ 30 cm) mud cracks propagated down through at least the upper 5 cm of division 1. The main track-bearing surface is covered by irregular patches of very fine, short (1 to 4 mm) wavy lines which could be the impression of a filamentous algal scum. Large (4 to 20 cm) cylindrical siltstone tubes puncture the surface at irregular intervals. Because these tubes branch downward in the underlying units, we assume that they represent the bases of small trees. Detailed impressions of conifer fronds (cf. *Pagiophyllum simpsoni*) drape around a number of these tubes where they intersect the main footprint surface, proving that the trees lived at the time the footprints were made. Conifer shoots occur sporadically over the rest of the surface. We infer that the trees puncturing the footprint surface produced the foliage present on the surface, although this cannot be proved.

The most common ichnite on the main surface appears to be *Rhynchosauroides hyperbates* Baird, 1957, originally known from the Perkasie Member of the Passaic Formation. Many of the individual manus-pes sets have scaly plantar surfaces completely preserved in exquisite detail (Fig. 21). Sinuous trackways of this form crisscross the surface, and some trackways come full circle. Because all the material is the same size, it is possible that all of the these trackways were made by the same individual wandering (stalking?) back and forth. Some of the trackways have body and limb impressions where the trackmaker rested; others show a transition from walking to swimming, strongly suggesting that the footprint surface was under a few centimeters of water at the time of impression.

Figure 21. Manus impression of *Rhynchosauroides hyperbates* from lower Lockatong Formation of Arcola, Pennsylvania (Stop 6).

Only four trackways belonging to other ichnotaxa crossed the exposed part of the surface. One faint trackway appears to be referable to *Brachychirotherium* cf. *B. eyermani* (YPM 9963) and another is clearly *Apatopus lineatus*, both known elsewhere from the Perkasie Member and Stockton Formation of the Newark Basin (Olsen, Salvia & Selden, in prep.) and the Gettysburg Formation of the Gettysburg Basin. The third trackway is referable to *Atreipus milfordensis* (Fig. 22) (Olsen & Baird, 1986b). The most western tracks of the series are much deeper and sloppier than the more eastern ones, so the track surface was not of uniform competence. No other dinosaurian tracks could be found on this surface. The last trackway(s?) consists of faint manus impressions possibly of *Rhynchosauroides* or *Gwyneddichnium*.

About 0.5 to 1.5 cm below division 2 is another widespread parting plane with abundant footprints. This surface is covered with a very large range of sizes of often beautifully detailied trackways of *Gwyneddichnium* sp. (incorrectly identified as *Rhynchosauroides* cf. *R. brunswickii* in Olsen & Baird, 1986b, from the lower part of division 1). Fronds of *Pagiophyllum simpsoni* are also present.

No fossils were found in the green claystone of division 2 of this cycle, but small, poor ?*Rhynchosauroides* occur sporadically in division 3. Division 1 of the next cycle has produced a good manus-pes set of *Brachychirotherium parvum*, otherwise known from the Passaic Formation (Baird, 1957; Olsen & Baird, 1986). The succeeding division 2 is the same *Osteopleurus*-bearing unit present along the railroad cut. Other cycles exposed lower in these highway cuts contain the same taxa present in the railroad cut, including a partial phytosaur skull.

The context of the main track-bearing surface within the cyclic section suggests that the reptiles walked in very shallow water upon a drowned soil that still supported living trees. This surface was already draped with several centimeters of lacustrine mud deposited by a recent transgression of what was shortly to become an offshore area of a perennial lake.

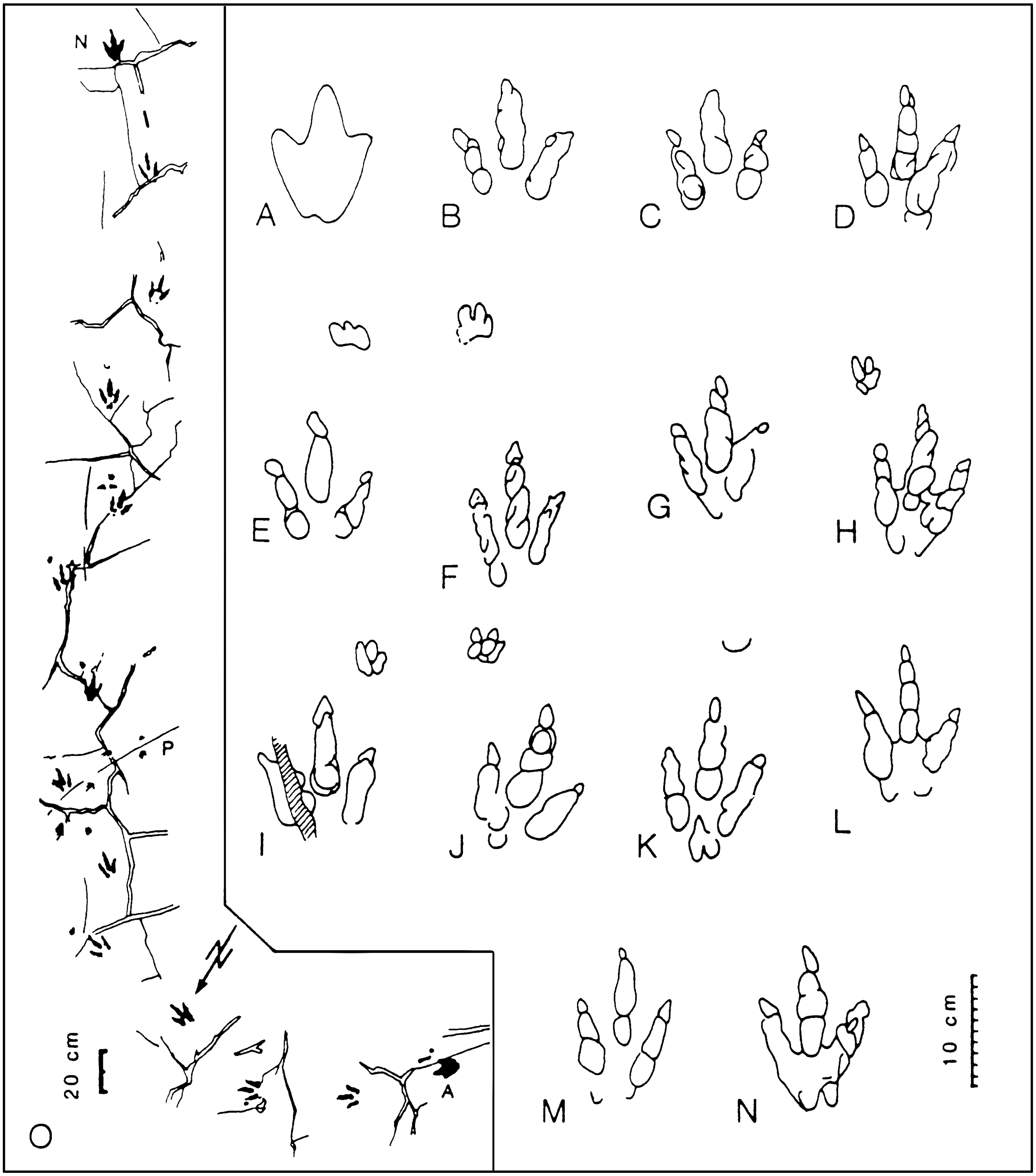


Figure 22. *Atreipus milfordensis* from the lower Lockatong Formation of Arcola, Pennsylvania (Stop 6). A-N, Successive pes and manus-pes impressions all drawn as if right impressions, from trackway shown in O. A is a right pes impression, B is a left pes impression, etc. O, trackway showing position of tracks (A-N). P in O shows trackway of *Rhynchosauroides hyperbates*. J, YPM 9961. From Olsen & Baird (1986).

	Return to vehicle and head south along Lower Indian Head Road.
120.3	Turn right on Upper Indian Head Road.
120.7	Road paralleling Schuylkill Expressway on left; park.
	Walk along path to north into abandoned and graded quarry.

STOP 6B. Quarry at Oaks, Pennsylvania; Lower Lockatong Formation (Late Carnian)

The quarry was excavated for road metal and fill during construction of Schuylkill Express, but is now abandoned. Low outcrops expose upper Hoboken and lower Weehawken Members. Exposures were partly duplicated in expressway road cuts and are much fresher than along the railroad tracks. Sandstones between lower cycles in Weehawken Member contain abundant phytosaur bones, teeth, and fragments. Comments about conditions of bone collection mentioned at Stop 4 apply here as well. Fish remains are abundant in black shales in all the cycles in the Weehawken Member exposed at this outcrop. All the bones—both fish and reptile—weather a bright blue and thus show up especially well.

	Return to vehicle and head west on Egypt Road.
120.8	Pass under Schuylkill Expressway.
121.1	Turn right onto Black Rock Road.
122.8	Cross Pennsylvania Rt. 29.
123.0	Enter Passaic Formation. Turn left onto Pa. Rt. 113 South.
124.9	Turn left, staying on Rt. 113 South; reenter Stockton Formation. Straight ahead about 1 mi. are Conrail tracks (old Penn Central Railroad). Extensive exposures of Lockatong and Passaic Formations occur intermittently on east side of tracks from there to Pottstown.
125.1	Cross Schuylkill River.
126.2	Small stream with exposures of clam-bearing beds in lower Lockatong Formation.
126.3	Crossing above Black Rock Tunnel.
126.6	Stay stright on High Street.
126.8	Park. Walk eastward down the street to Conrail tracks.

STOP 7. Black Rock Tunnel, Phoenixville, Pennsylvania; Lower Lockatong Formation (Late Carnian)

Cuts along Conrail tracks on east side of Phoenixville and walls of the Black Rock Tunnel expose much of the uppermost Stockton and lower Lockatong Formations. Walk south along the tracks to near mouth of French Creek; turn around, walk north, up section, along tracks.

The first outcrops in back of the Phoenix Steel Co. plant consist of dune-scale, cross-bedded, buff arkose passing upward into red and brown sandstone with ripple-scale cross-bedding. The overlying bed of red and gray siltstone is well exposed to the west in a cut of the railroad spur which passes overhead. Exposures just north of access road expose basal cycles of Lockatong Formation (Hoboken Member). The uppermost exposed cycle has a black calcareous division 2 packed with darwinulid ostracodes and *Cyzicus*. Phytosaur teeth, coprolites, and *Turseodus* fragments are common in this unit. Faults probably mark both the north and south sides of this outcrop. Further to the north are large but seasonally overgrown outcrops of an undetermined part of the lower Lockatong (?Weehawken Member).

Just before the south portal of Black Rock Tunnel is another fault block exposing an undetermined part of the Lockatong. Pollen and spores recovered from green-gray siltstones at this outcrop, like others in the lower Lockatong, indicate a Late Carnian age (B. Cornet, personal communication).

At the time of its construction, the Black Rock Tunnel was the longest such excavation in North America. During its construction and subsequent enlargement, a large number of fossils, mostly invertebrates and vertebrates, were discovered. Most of these were recovered by Charles M. Wheatley and described by Edward D. Cope, Isaac Lea, Joseph Leidy, and T. R. Jones. As a consequence many important Newark vertebrate types originated here.

Wheatley (1861) described the section exposed in the Black Rock Tunnel and reported the stratigraphic positions for as many of the fossils as possible. Wheatley's description plus an excellent cross-section in the tunnel was also published by Jones (1862). Unlike most tunnels, this one is not cased and the walls still expose the Lockatong. Consequently, Joseph Smoot (U.S. Geological Survey, Reston, Virginia) and I were able to remeasure the tunnel section in 1985 (Fig. 23). Wheatley's section of 1861 and our section are for the most part closely comparable except for some black shales in the upper part of the section which went unrecognized by Wheatley.

As usual, this section of the Lockatong consists of Van Houten cycles, most of which contain abundant but disarticulated vertebrates. The overall facies resembles that at Stops 6A and 6B and some of the same cycles may be represented here. Sandstones are a common component of divisions 1 and 3 of the cycles and microlaminated beds are absent, being replaced by laminated ostracode-rich calcareous claystones and siltstones. Clams are fairly common, even in some black siltstones, and roots and burrows occur in all but the most organic-rich units.

The first vertebrates described from Phoenixville consisted of fish, phytosaurs, and footprints. Isaac Lea (1856a,b, 1857) described but did not figure the type of *Turseodus acutus* (a lower jaw; Schaeffer, 1952b), a small footprint he called *Chelichnus wymanianus* [*nomen nudum*; see note by Spamer, 1989] (*Rhynchosauroides*; Fig. 32), and *Centemodon sulcatus* (phytosaur tooth). In 1859 Joseph Leidy added *Eurydorus serridens* to the list of Phoenixville fossils.

Rutiodon and *Belodon*

In 1866 Cope reviewed the herptiles found at Phoenixville and made some amazingly perspicacious observations which should have cleared up taxonomic problems handed down to this day. Cope pointed out that *Rutiodon carolinensis* (Emmons, 1856), the most common Newark Supergroup phytosaur, is probably synonymous with *Belodon plieningeri* from the Stubensandstein of Germany. Based on the figures of Von Meyer (1861, 1863), this indeed seems to be the case, and *Rutiodon* Emmons, 1856, should almost certainly be regarded as a junior synonym of *Belodon* Von Meyer, 1842. *Mystriosuchus planirostris* E. Fraas, 1896, is very different from *B. plieningeri* and the latter should not be included in the former genus

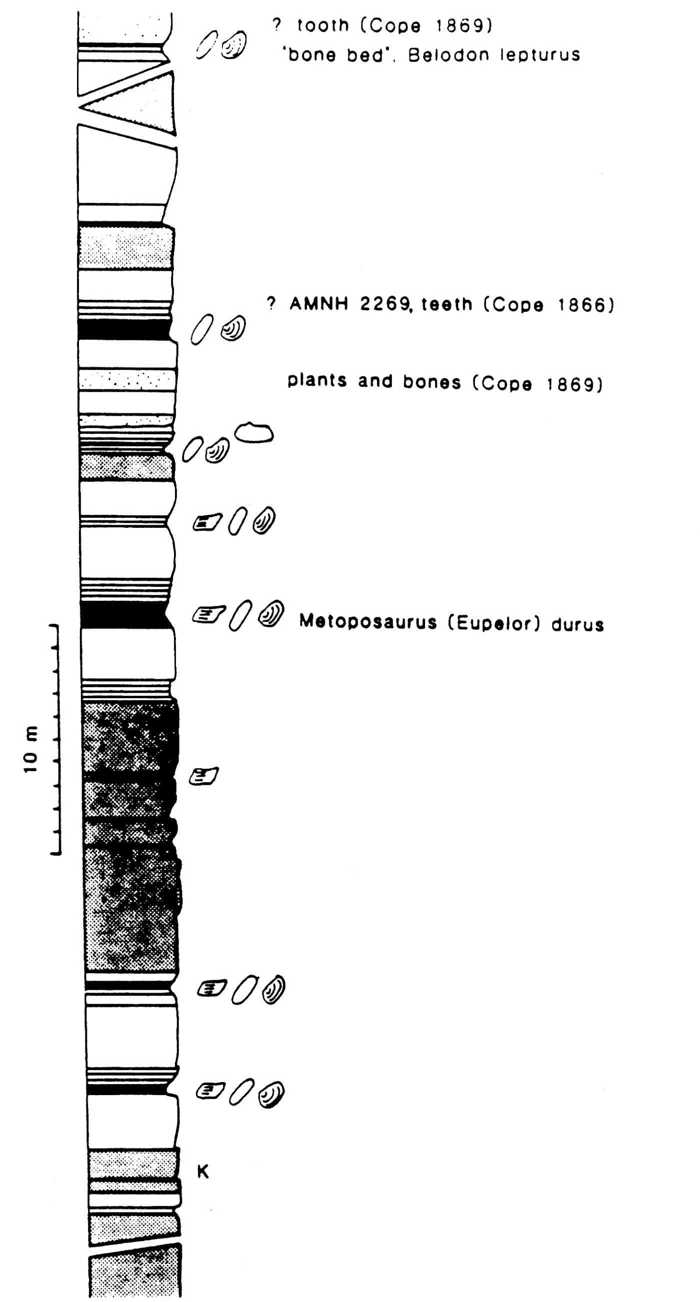


Figure 23. Measured section in Black Rock Tunnel, Phoenixville, Pennsylvania, showing positions of major described vertebrate remains. Section measured by J. Smoot and P. Olsen. Symbols as in Figure 11 except that black zones denote only black laminated siltstones, not microlaminated units.

(*contra* Gregory, 1962). Cope also noted that the anterior teeth of *B. plieningeri* are fluted like those of *Rutiodon carolinensis* and the posterior teeth are squatter, laterally compressed, and serrated like Leidy's *Eurydorus serridens*, the latter also being synonymous with *B. plieningeri.* Unfortunately, Cope's synonymy was never formalized and we still call most of our American phytosaurs *Rutiodon*.

The "bone bed" shown in Wheatley's section ultimately produced the partial phytosaur skeleton Cope (1870, 1871) described as *Belodon lepturus* (Fig. 23). This form is indistinguishable from *Rutiodon* [*Belodon*] *carolinensis* as noted by Huene (1921).

In addition to these remains, there are two partial phytosaur skulls and numerous teeth, from a buff sandstone (Fig. 31) mentioned by Wheatley (1861), that are still undescribed in the AMNH Wheatley collection.

Eupelor durus

Cope in his 1866 paper also described a cranium of a labyrinthodont amphibian which he compared closely to *Mastodonsaurus diagnosticus* (which we now recognize as the type species of *Metoposaurus*). This he identified as coming from bed number 15 of Wheatley's section, in which beds are unfortunately not numbered (Fig. 23). As pointed out by Baird (1986), Cope's anatomical analysis was absolutely correct. The specimen consits of two pieces of a large skull table representing the area from the orbits to the pineal eye. the species was named *Mastodonsaurus durus* in 1866 but in 1868 Cope placed it in a new genus, *Eupelor*. The specimen is probably *Metoposaurus* but unfortunately is indeterminate to genus. All of the metoposaur specimens described by Colbert & Imbrie (1956) as from Phoenixville are actually from the New Oxford Formation of the Gettysburg Basin, but were mislabeled (Baird, 1986).

Invertebrates

Clams were among the first specimens to be described from Phoenixville (Conrad, 1858) and the diversity of mollusks from this locality is larger than at any other Newark Basin locality (Fig. 24). Clams are especially common in one bed in the tunnel (Fig. 23) which also crops out along Rt. 132 (see mileage 127.2, above). Ostracodes are extremely common as are clam shrimp (Rogers, 1854; Leidy, 1859; Wheatley, 1861; Jones, 1862, 1890, 1891; Bock, 1946; Raymond, 1946); type specimens of a number of crustacean species come from this locality. The taxonomies of these fossils are unfortunately completely confused and badly in need of revision.

Wheatley (1861) mentions the presence of a portion of a limulid carapace. This is very interesting because limulid tracks are known from a number of Newark localities, including here (Fig. 23) under the name of *Kouphichnium* (Caster, 1939), but body fossils have remained elusive. We are confident that intensive search in this coarser facies of the Lockatong will add greatly to our knowledge of Newark invertebrates.

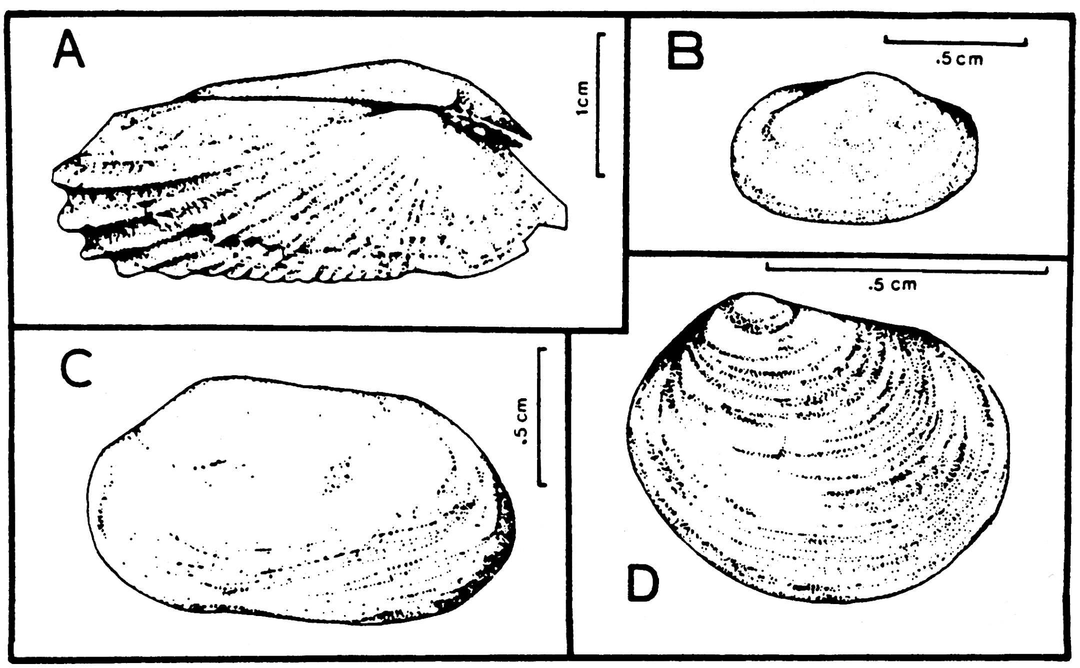


Figure 24. Invertebrates from Stop 7 (Black Rock Tunnel, Phoenixville, Pennsylvania). A-C, Clams (?unionids). D, The clam shrimp *Cyzicus*.

Return to vehicle and turn right.

126.9 Turn left onto Main Street.

127.0 Enter Stockton Formation.

127.2 Turn left onto Bridge Street.

127.6 Cross Schuylkill River. Enter Mont Clare, Pennsylvania.

127.7 Road on left follows west side of canal and leads to large outcrops of lower Lockatong on east bank of Schuylkill River. These outcrops, almost 2 km long, are virtually unstudied although scraps of phytosaurs from this locality are present in the AMNH Wheatley Collection) and scraps of *Semionotus* and *Turseodus* occur in the black calcareous siltstones. Unionid clams described by Lewis (1884) were evidently incorrectly attributed to the Mont Clare outcrops by Richards (1944); they almost certainly come from the upper Stockton Formation at the south portal for the old Pennsylvania Railroad tunnel on the *west* side of Phoenixville (see Axsmith & Kroehler, 1989).

128.1 Turn right onto Egypt Road.

131.4 Enter Schuylkill Expressway (I-76) eastbound and head back to Philadelphia. (Entrance is near the Lockatong-Stockton contact.)

END OF FIELD TRIP LOG.

Acknowledgements

Our warmest thanks go to Donald Baird, Bruce Cornet, and William Witte who generously shared with us much unpublished information which greatly added to the usefulness of this paper. Earle Spamer is gratefully acknowledged for adding helpful sections on the status of specimens mentioned in the text from the Wilhelm Bock collection. We especially thank the owners and operators of the Haines and Kibblehouse Quarry in Chalfont, Pennsylvania, for permission to study, collect specimens, and run field trips. Finally, we thank the reviewers for catching the all too common mistakes and omissions in the manuscript.

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