VIEW OF PASSAIC FALLS by W. H. Bartlett, 1840

FOSSIL GREAT LAKES OF THE NEWARK SUPERGROUP IN NEW JERSEY

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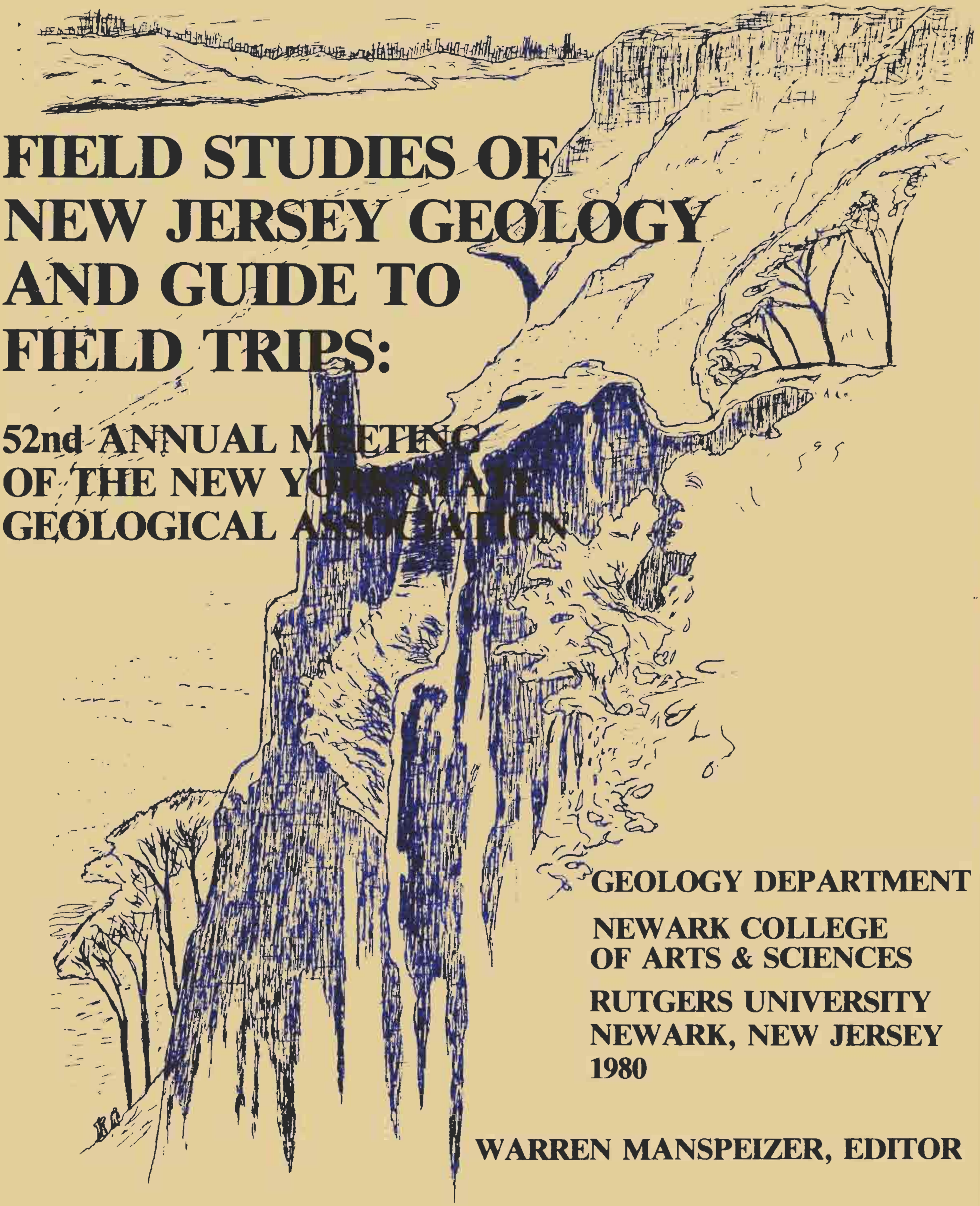

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FOSSIL GREAT LAKES OF THE NEWARK SUPERGROUP IN NEW JERSEY

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Introduction

Because Newark Basin lacustrine rocks are (1) often composed of sedimentary cycles, (2) traceable over very large areas, and (3) unusually rich in fossil remains, they are among the most interesting and challenging of Newark Supergroup deposits. While lacustrine sequences are found in all sedimentary divisions of the Newark Basin, those of the Lockatong, Feltville, and Towaco formations are known in greatest detail and are therefore the focus of this field trip. I concentrate on the interpretation of the lake sediments, paying special attention to some fundamental problems in their interpretation. In addition, I touch on some relevant paleozoology.

Lockatong Formation, Detrital cycles - General Comments

The Lockatong Formation (see Olsen, this fieldbook) is composed almost entirely of well-defined sedimentary cycles (Van Houten, 1969; and this fieldbook). Of the two short cycles described by Van Houten, chemical and detrital, only the latter will be discussed here; they resemble not only cycles found higher in the Newark Basin section, but also lacustrine sequences of other Newark Supergroup basins.

As originally noted by Van Houten, Lockatong detrital cycles clearly reflect the expansion and contraction of lakes. Recent study of these cycles (Figure 1) shows that each can be split into three lithologically identified divisions (from the bottom up): 1, a thin (ca 0.5 m) platy to massive gray siltstone representing a fluvial and mudflat to lacustrine (transgressive) facies; 2, a microlaminated to coarsely laminated black to green-gray fine, often calcareous siltstone (0.1-1.0 m) formed during maximum lake transgression; and 3, a generally thickly bedded or massive gray or gray-red siltstone or sandstone (0.5-4.0 m) usually showing a disrupted fabric and current bedding and sometimes bearing reptile footprints and root horizons (regressive facies).

If individual detrital cycles can be traced over the extent of the Lockatong Formation, the area of division 2 of each cycle is a measure of the average minimum size of the lake during maximum transgression; this is about 7000 km^2. Of course the actual size of the lakes were significantly larger than this. If, as may have been the case, the Newark, Gettysburg, and Culpeper basins were connected by open water at times, the lake would have been about the same dimensions as Lake Tanganyika or Lake Baikal; that is, about 32,500 km. While the lake may have been this large, actual tracing of individual cycles is reasonably complete only for the northern Newark Basin (see stops 2 - 4).

Vertical sections through Lockatong cycles show consistent lateral trends in lithology and paleontology (Table 1). If the assumption of basin-wide extension of individual cycles is correct, these trends reflect lateral changes through large lakes, rather than changes from one small lake to the next. Detrital cycles traced away from the geographic and depositional center of the Newark Basin show changes in faunal and floral assemblages due to deposition in progressively shallower water. These changes influence the entire cycle, although they are most obvious in division 2 (see Table 1). In addition to lateral change in facies, there is a correlated change in cycle thickness (see Fig. 2). For instance, along the Delaware River (at the geographic and depositional center of the basin), the mean thickness of detrital cycles is 5.2 m (Van Houten, 1969) while in the northern Newark Basin this thins to 1.5 m.

The microlaminated sediments of division 2 are made up of couplets of laminae, one of which is more calcareous than the other (in their unmetamorphosed state) (Fig. 3). Similar sediments are produced in a variety of modern lakes; in most of the studied cases the couplets are the result of seasonal variation in sedimentation and are thus varves (Nipkow, 1920, 1927; Kelts and Hsu, 1978; Tolonen, 1980; Edmonson, 1975; Sturm and Matter, 1978; Ludlam, 1969, 1973; but see Neev

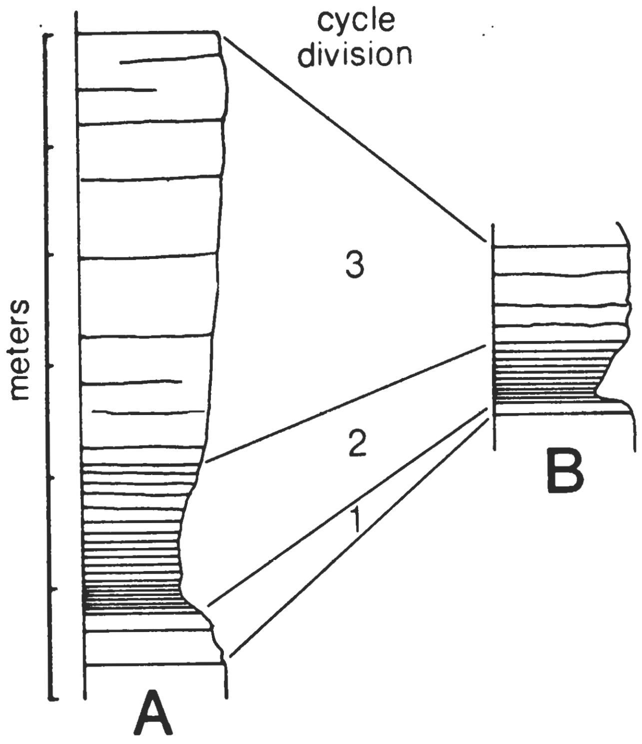

Fig. 1 Diagram of generalized Lockatong detrital cycles: A, cycle from the center of the Newark Basin; B, cycle from the northeastern edge of the Newark Basin. Based on sections exposed near Gwynedd, Pennsylvania (A) and Weehawken (B). For description see text.

and Emery, 1967). By analogy with these modern sediments, I regard the Lockatong sediment couplets as varves. Assuming that the rate of deposition is approximately the same for each division, we can estimate the duration of each cycle by extrapolating the average varve count per unit thickness to the non-varved portion of the cycle. While varve counts are still preliminary, my own work agrees with that of Van Houten (1969) in suggesting approximately 20,000 years per cycle for the central Newark Basin. In marginal areas, such as Weehawken (see stops 1 - 4), varve counts indicate much shorter durations for each cycle, on the order of 5000 to 10,000 years, which presumably indicates significant bypassing or erosion.

The Stratified Lake Model

The shallow water facies of division 2 are arranged around the deeper water facies (Figure 2, Table 1). The latter, which shows no bioturbation, is strongly suggestive of deposits formed today in lakes where the oxidation of accumulating organic matter produces an anoxic bottom layer of water (less than 2% saturation). This type of lake is termed "stratified"; the upper oxygen-rich water layer is called the "epilimnion" while the bottom, oxygen deficient, layer is referred to as the "hypolimnion" (Hutchinson, 1957). Those lakes which never experience the mixing of the epilimnion and hypolimnion (ie. destratification or turnover) are termed "meromictic" and those which mix rarely or at irregular intervals are called "oligomictic" (Hutchinson, 1957). Most temperate lakes mix once ("monomictic") or twice ("dimictic") each year.

Seasonal variations in sedimentation are preserved as varves in modern meromictic and oligomictic lakes because the hypolimnion has no little oxygen and so much toxic matter (such as H_2S) that burrowing organisms cannot survive (Moore and Scrutton, 1965; Davies and Ludlam, 1973; Kelts and Hsu, 1978). These same limiting conditions allow whole organisms which drift into the hypolimnion to be preserved without disturbance by scavenging animals (Schäfer, 1972).

In contrast to meromictic and oligomictic lakes, modern lakes with even very limited seasonal mixing or relatively slight amounts of hypolimnetic oxygen (2% of saturation or more) usually support dense colonies of burrowing animals which churn the sediments (Brinkhurst, 1974; Hiltunen, 1969; Cair, and Hiltunen,1965; Inlands Fisheries Branch, 1970; Davis, 1974; Kleckner, 1967). Thus among modern lakes, microlaminated sediments are produced almost exclusively by those which are oligomictic or meromictic.

Exceptions to this generality, however, are common enough to show that the presence of microlaminated sediments alone cannot be used to identify ancient deposits produced in stratified lakes. Lakes with extremely low levels of organic production, such as some alpine or glacial lakes, sometimes have microlaminated sediments (Sturm and Matter, 1978), presumably because there is too little organic matter in the sediments to support populations of sediment-burrowing organisms. On the other hand, there are lakes with very high organic production and are constantly mixed (holomictic), but which nonetheless produce microlaminated sediments (Tolonen, 1980). This may be because the rate of depletion of oxygen (by the oxidation of organic substances) on the lake bottom is greater than the rate of supply from the overlying waters, thus excluding a bottom fauna. In any case, in these lakes there are too few burrowing organisms to destroy the forming microlaminae. It is clear also that the conditions permitting the preservation of microlaminated sediments are varied; no single set of conditions is responsible for all modern examples.

The tolerances of the resident organisms to "adverse" conditions are also crucial in determining which lakes produce microlaminated sediments. We cannot assume that the sensitivity of sediment burrowing organisms has been the same since the Mesozoic; perhaps there has been a trend through the Phanerozoic towards the ability to survive in low oxygen and high hydrogen sulfide concentrations. If this were the case,

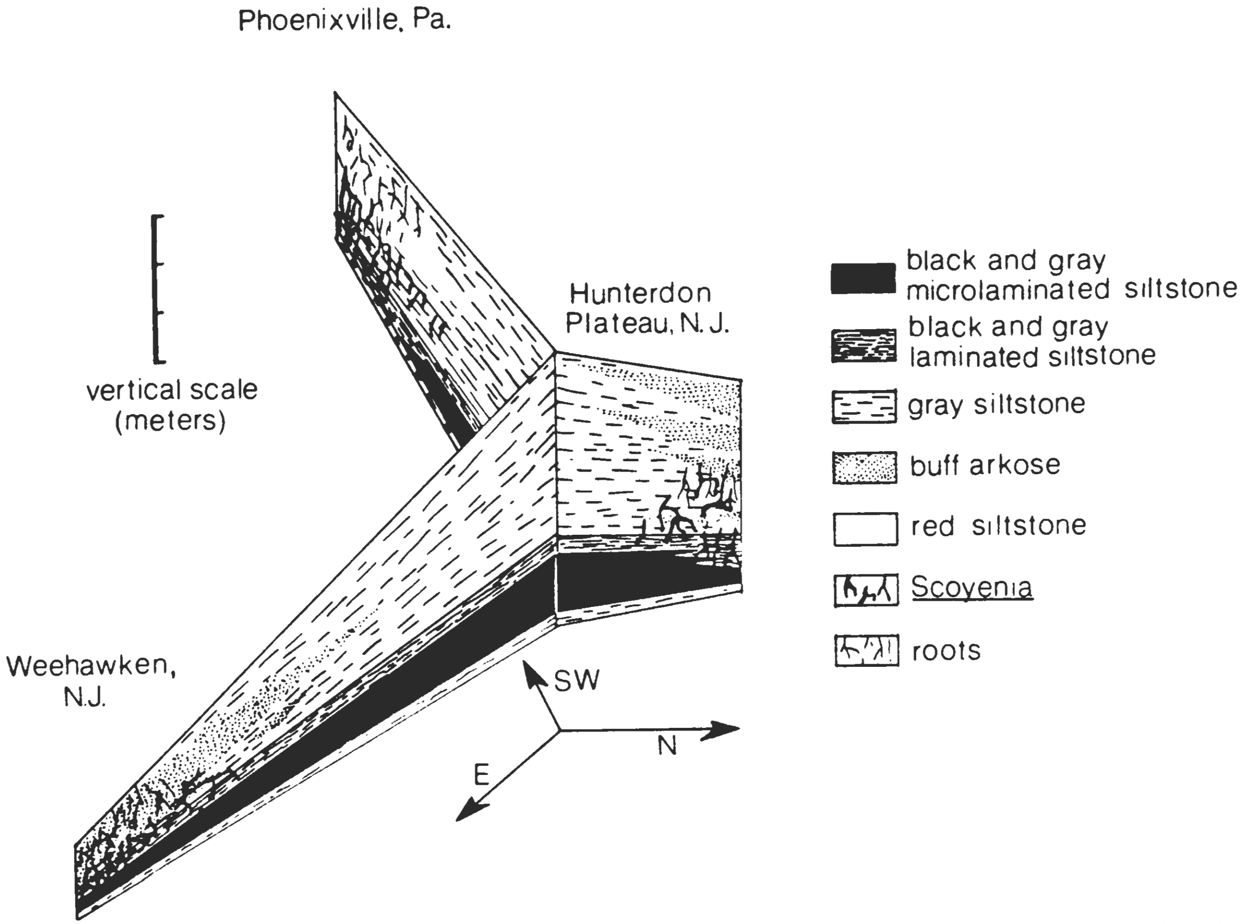

Fig. 2. Generalized facies relationships of Lockatong detrital cycles (horizontal distances not to scale); Phoenixville is 50 km from the southern portion of the Hunterdon Plateau (Stockton, New Jersey), which in turn, is 27 km from the northern corner of the plateau and 105 km from Weehawken, New Jersey.

and ancient organisms were less tolerant of anoxic conditions, a greater variety of ancient lakes could have produced microlaminated sediments.

Lockatong Invertebrates and Their Use as Depositional Indicators

The most abundant large (+2 mm) Lockatong invertebrates are bivalved crustaceans of the order Conchostraca (often called clam shrimp) (Figure 4) (Pennak, 1953). Conchostracans occur throughout division 2 from the deepest water facies to the shallowest and are often present in microlaminated beds lacking any other invertebrates. Today, conchostracans are almost entirely restricted to small, temporary bodies of water from which fish are absent (Hutchinson, 1967; Tasch, 1969; Tasch and Zimmerman, 1961; Packard, 1883); thus, the presence of conchostracans in ancient deposits has been interpreted as indicating similar temporary waters (Tasch and Zimmerman, 1961, 1961a; Tasch, 1961; 1964, 1969; Kobayashi, 1954). However, the Lockatong distribution of conchostracans is entirely at odds with their current distribution; conchostracans found in division 2 of Lockatong detrital cycles lived in very large lakes supporting large populations of fish and small aquatic reptiles. Similar situations occur in Palaeozoic and Mesozoic rocks throughout the world and include the Upper Pennsylvanian Linton Shale (D. Baird, pers. comm.), the Permian *Mesosaurus*-bearing beds of South America and southern Africa (D. Baird, pers. comm.), the Jurassic Jehol beds of China (Kobayashi, 1954), and the Cretaceous Sungari Series of Manchuria (Kobayashi and Huzita, 1942; Takai, 1942). In marked contrast, there are no conchostracans from the entire Cenozoic record (Tasch, 1969; Kobayashi, 1954). Clearly, either the habits of conchostracans or the factors which limit their distribution have changed since the Cretaceous. This points up the dangers of constant extrapolation from the recent; it makes the past look like a repeat of the present, hiding real changes which may have occurred. In this case the sedimentological context of Lockatong conchostracans demonstrates that their present environment is not the key to their past.

The lateral transition from microlaminated to coarsely laminated sediments in division 2 is correlated with the appearence of numerous podocopid ostracods similar to *Darwinula* (Figure 4). Today these crustaceans burrow in the sediments of a wide variety of fresh water environments from puddles to great lakes (Ed-

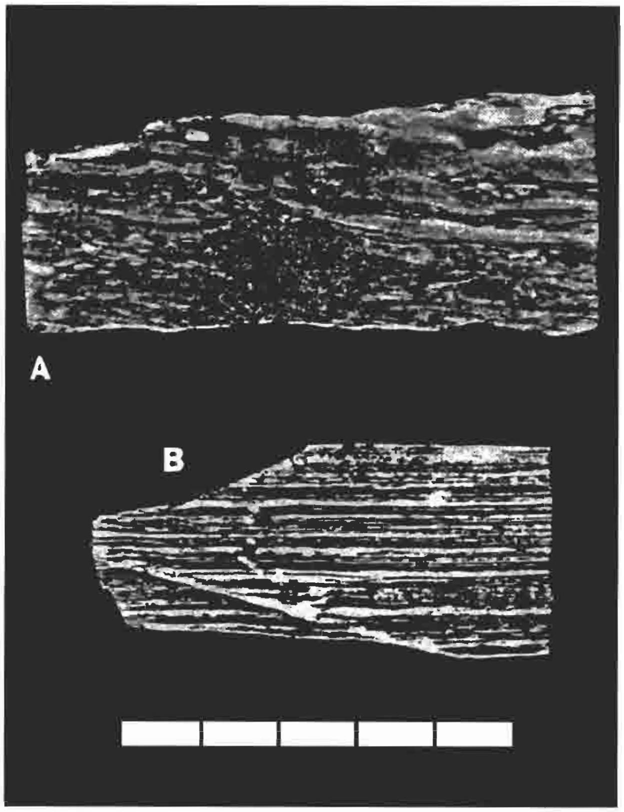

Fig. 3. Contrasting samples of division 2 of detrital cycles: A, microlaminated siltstone (hornfels) from the *Diplurus* -bearing portion of cycle 5 at Weehawken, New Jersey; B, intensively bioturbated siltstone from unidentified cycle at Phoenixville, New Jersey — this specimen contains many unionid clams (See C of Figure 4)

monson, 1959), but always in water with some oxygen. Thus, I infer that the appearance of abundant ostracods in division 2 indicates the presence of at least seasonally oxygenated water.

Farther from the depositional center of the cycles, distinctive large burrows (Figure 4) appear in the sediments of division 2. These burrows, called *Scoyenia* (White, 1929; Bain and Harvey, 1977) are from 0.3-1.3 cm in diameter, are marked by small 1-3 mm) longitudinally oriented ridges on the outside, and have a meniscus-type of infilling. In the Durham sub-basin of the Deep River Basin, they have been found in association with numerous crayfish (Bain and Harvey, 1977) and it is plausible that *Scoyenia* burrows are, in fact, crayfish burrows. Unlike the superficially similar marine *Ophiomorpha*, however, the maker of *Scoyenia* has never been found in its burrow and thus other kinds of arthropods cannot be ruled out.

Finally, restricted to the margin of the Lockatong in division 2 of detrital cycles and in the conterminous Stockton Formation (see Olsen, this fieldbook), clams appear (Figure 4). Today, clams are most commonly found in sediments below well-oxygenated waters (Edmonson, 1959).

Lockatong Fish

The preservation of Lockatong vertebrates varies vertically as well as horizontally in single cycles (Table 1). Generally, the presence of articulated fish is correlated with a distinct microlamination of the sediments. The beds transitional between divisions 1 and 2 are laminated but not distinctly varved and tend to contain isolated bones of fish and small reptiles. The lowest portions of division 2 are usually the best laminated and have the highest proportion of complete fish and reptiles (see Stop 2). The upper portion of division 2 becomes less distinctly laminated, up and as the laminated structure is lost, so are the articulated fish. The upper portions of division 2 often contain only fragmentary fishes or isolated bones; the sediments are poorly laminated and often contain abundant ostracods.

The lateral transitions from the deep to the shallow water facies of division 2 are similar to the vertical changes, in terms of fish preservation, again tracking the degree of lamination of the sediments (Table 1). The microlaminations of the low portions of division 2 persist the greatest distance laterally, perhaps reflecting the downward working of bioturbation agents after the lake bottom again became inhabitable.

Six genera of fish are known from the whole of the Lockatong Formation (Figure 5). Most abundant, both as fragmentary remains and whole fish, is the palaeoniscoid *Turseodus*. Next most common are small individuals of the coelacanth *Diplurus*. The holostean *Semionotus* and the subholostean *Synorichthys* are less common, on the whole, but are the dominant forms locally (Stops 2-4). The subholostean *Cionichthys* appears very rarely and the hybodont shark *Carinacanthus jepseni* is known from only one specimen (Olsen, McCune, and Thomson, In Press).

Along the marginal edge of the deep water facies of division 2 (such as at Weehawken) individual cycles are dominated by very large numbers of a few kinds of fish. In most cases only one genus is common in a particular unit (Stop 2), the others either being absent or very rare. Replacement of the dominant genus can occur between cycles in a vertical sequence or within division 2 of a single cycle. Along the Hudson River, in the northern Newark Basin, the number of different genera present in a single bed is usually not greater than three and so far has not exceeded four for an entire cycle. In contrast, the few, well collected sections in the central Newark Basin show a much more even distribution of genera; for example, all six Lockatong genera have been found in the same 10 cm portion of one cycle even

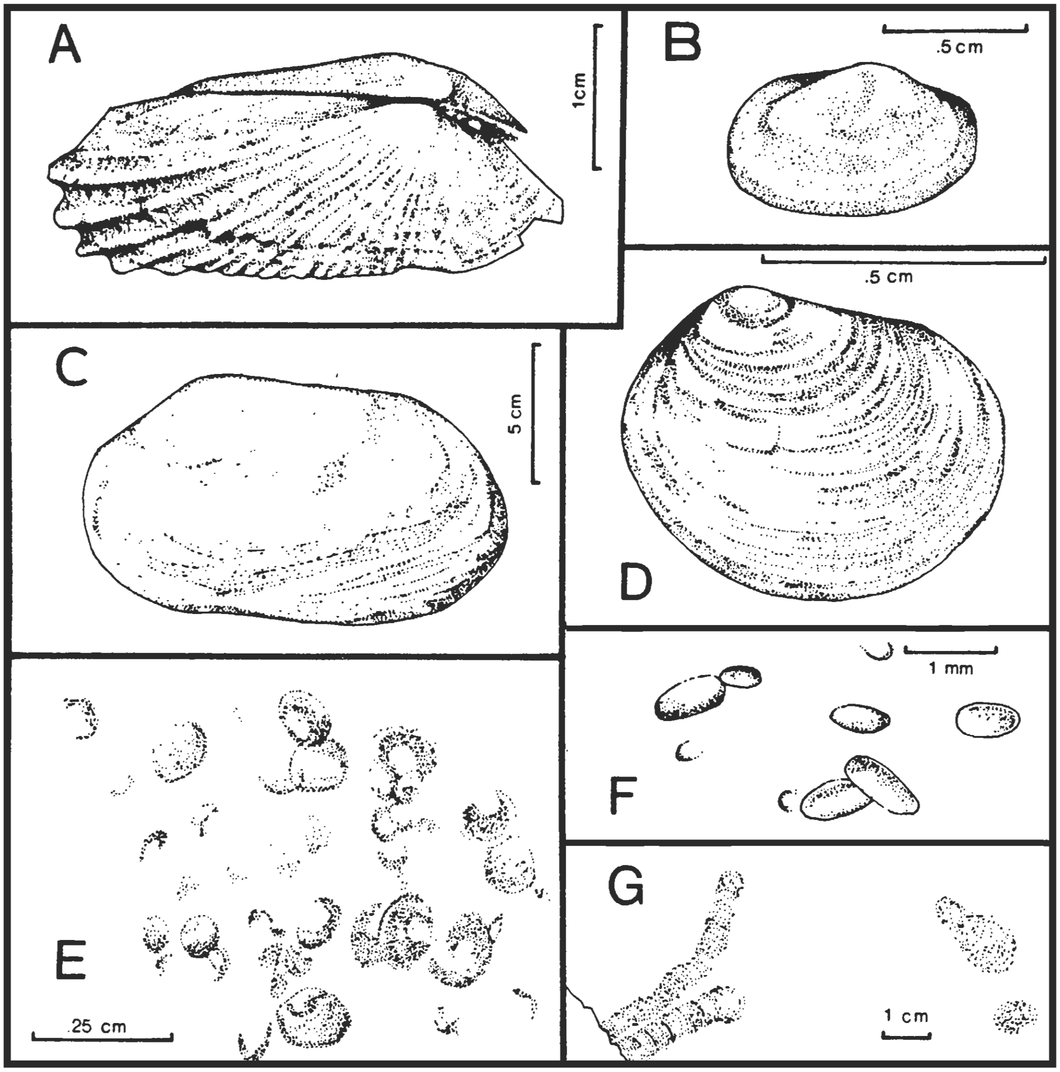

Fig. 4. Lockatong Formation invertebrates: A, B, and C, unidentified probable unionid clams from Phoenixville, Pennsylvania (AMNH Cope Collection); D, large individual clam shrimp valve *(Cyzicus* sp.) from Phoenixville, Pennsylvania (uncatalogued YPM (IP) Wherry collection); E, small clam shrimp from cycle 6, Gratacap's locality, Weehawken, New Jersey (YPM (IP) 28802; F, *Darwinula* - type ostracods, from upper part of division 2 of cycle 5, at the "Yale quarry", Weehawken, New Jersey (Field Number W5-1036); G, *Scoyenia* from cycle a at Palisades Interstate Park above Ross Dock, Fort Lee, New Jersey (YPM (IP) 28810).

though a total of less than 200 fish have been collected from the unit.

How does this rather incomplete picture of Lockatong generic diversity compare with that of modern lakes? At this point it becomes clear that very little is actually known about fish diversity in modern lakes - most of what is published is based on commercial fishery data which must be viewed with caution. The best data are available for Lake Victoria in Africa and this is presented in Figure 6.

By analogy with Lake Victoria (Figure 6) we would expect the largest number of fish genera in the Lockatong lake shallows and the lowest number in the lake center. In terms of fossilization, we might expect the central lake sediments to be numerically dominated by central lake fish, supplemented with drifters from the shallows. If Lockatong genera were similarly distributed, we would expect the fish living in the shallows to be represented in the sediments as isolated scraps, perhaps not even identifiable to genus, while the central lake fish would be much better preserved. The largest number of well preserved fish should come from the portion of the lake with the lowest number of genera. Thus, on the basis of the numbers of individuals per genus in Lake Victoria, we should expect the number of genera represented in the deep water facies of division 2 to be small.

The number of genera present and the relative abundances of the different genera determine the composition of a particular sample. In Lake Victoria, while 15 genera are present in water 0-9 m in depth, a sample of

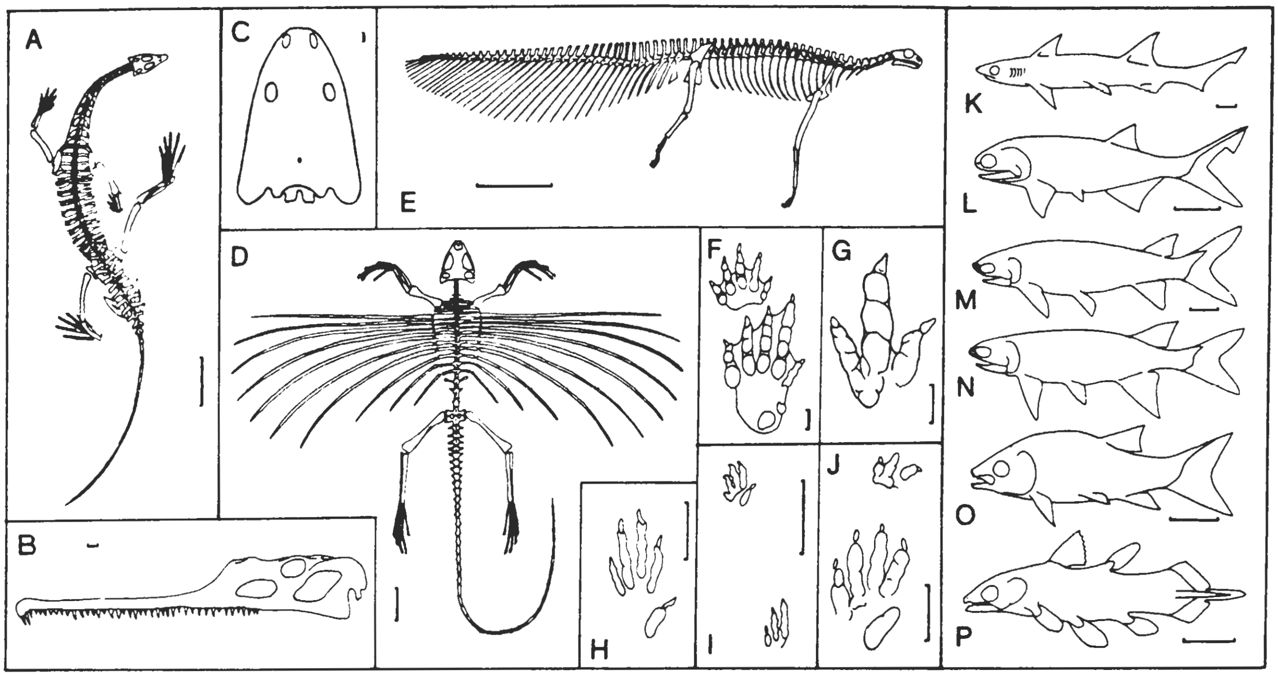

Fig. 5. Lockatong Formation vertebrates and reptile footprints from the upper Stockton, Formation (for repository abbreviations see Olsen, this Fieldbook) (From Olsen, In prep.); A, *Tanytrachelos* cf. *ahynis,* reconstruction; B, Rutiodon carolinensis, reconstruction; C, *Eupelor durus,* reconstruction; D, *Icarosaurus siefkeri,* reconstruction; E, "deep tailed swimmer", tentative reconstruction; F, *Apatopus lineatus,* composite right manus and pes; G, *Grallator* sp., left pes; H, *Gwyneddichnium minore,* right pes; I, *Rhynchosauroides brunswicki,* right manus and pes; J, *Chirotherium* cf. *eyermani,* right manus and pes; K, *Carinacanthus jepseni,* reconstruction; L, *Turseodus* sp., reconstruction; M, *Synorichthys* sp. reconstruction; N *Cionichthys* sp., reconstruction; O, semionotid of the "*Semionotus brauni* group", reconstruction; P, *Diplurus newarki,* reconstruction. Scale 2 cm.

1000 indentifiable fish from that area could be expected to yield only about 6 genera (using Hurlbert's 1971 refinement of Sanders' 1968 rarefaction technique -Peet, 1974 and Tipper, 1979),because some genera are much more abundant than others. In the middle of Lake Victoria, while the relative abundances of the genera are more equally distributed, the total number of genera is much reduced, so that the number of genera in a given sample would still be small. For a sample of 1000 fish from the deepest waters of Lake Victoria it is expected that about 4 genera would be recovered. Considering the limited sample size of well-preserved fish from the Lockatong and the lack of a well-preserved shallow water fish assemblage, the presence of only six genera is not very different from what might be expected of a modern lake.

This discussion is intended to indicate the problems inherent in comparing generic diversity of recent and fossil lakes, not to imply that the generic diversity of the Lockatong was similar to that of Lake Victoria. A sample of six genera appears reasonable for at least one great lake considering sampling bias, but it is also reasonable for a pond. This analysis of generic diversity is also clouded by the difficulty of applying comparative techniques developed for organisms living at one time to fossil organisms which lived over thousands of years in a changing environment. At this point, what little is known about modern lake diversity can serve as a null hypothesis, indicating in this case that simple comparisons of generic diversity between ancient and modern lakes is not, as yet, very informative.

Specific diversity is even more difficult to deal with than generic. Work on the number of species present in the existing sample of Lockatong fishes is just beginning (A. R. McCune, pers. comm.). While at this point we cannot pretend to know how many species of each genus are present, it is clear that some genera show more variability in morphology than others. The Lockatong fish genera may be ranked in terms of decreasing morphological diversity which may, in turn, reflect specific diversity as follows: *Turseodus, Diplurus, Semionotus, Synorichthys, Cionichthys,* and *Carinacanthus.* This morphological diversity is presently under investigation by A. R. McCune (Yale Biology) using a variety of computer assisted numerical techniques. Pending the results of the analysis, we suggest qualitatively that a sample of one genus contains more than one species if the range of variability in that sample exceeds the range of a single population of a congener preserved in a mass kill (known from other Newark deposits or other parts of the world). Thus, we expect the genus *Turseodus* to contain more species than the other Lockatong genera. As

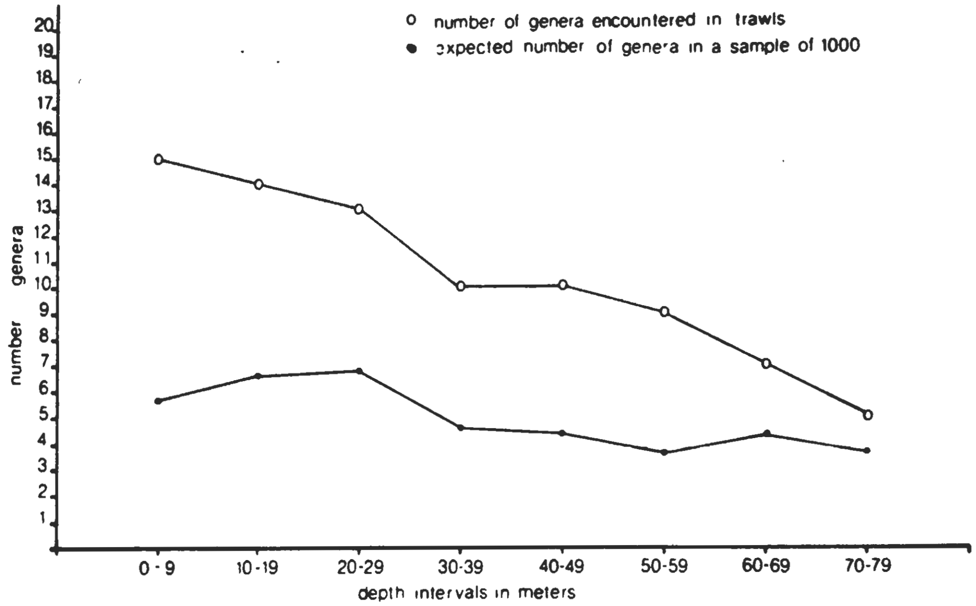

Fig. 6. Relative abundances of fish genera in Lake Victoria, East Africa.

For the purposes of this analysis I have followed the practice of Kudhongania et al. and group all non-*Tilapia* ciclid genera in *Haplochromis* since this is similar to what is easily recognized in paleontological context. While there are at least 22 genera in Lake Victoria only 15 occur outside of rivers and streams which enter the lake or occur in abundances great enough to be encountered in the experimental trawling operations.

Data are from Kudhongania (1972) and Kudhongania, et al. (1971) and were originally in the form of desmersal fish biomass estimates (which are essentially area weighted extrapolations of the trawling results). I divided the biomass estimate for each genus at a depth interval by the mean weight of an individual of that genus (derived from Beauchamp, R.S.A. and others, 1950) to obtain the approximate number of individuals.

Hurlbert's (1971) refinement of Sander's (1968) rarefaction technique was used to obtain the expected results for a sample of 1000 individuals.

will be discussed in succeeding pages, the morphological variability of Lockatong genera is small compared to certain younger Newark Basin forms.

Little Aquatic Reptiles

Two genera of aquatic reptiles are surprisingly abundant in cycles of the lower Lockatong. One, *Tanytrachelos* (Olsen, 1979) is a little (20-40 cm), long-necked, slender, lizard-like animal (Figure 5) whose nearest relative appears to be the much larger (1-6 m), monstrously long-necked *Tanystropheus* from the Old World Middle Triassic. Among reptiles *Tanytrachelos* is unusual because of the ease with which the skeletons may be sexed. One sex (male) has a pair of sickle-shaped bones which appear to be the reptilian analog of a mammalian baculum; the other sex lacks them. The "sex ratio" is about 50/50 in a large collection (ca. 150 specimens) of *Tanytrachelos* from its type locality in the Cow Branch Formation of the Dan River Group in North Carolina (Olsen, 1979).

The other genus (Figure 5), which has come to be known as the "deep tailed swimmer", has as yet no formal name (Colbert and Olsen, In Prep.). This small (ca. 20 cm) animal is characterized by a deep, ventrally directed tail fin supported by extraordinarily long hemal spines. In addition, its front legs are longer than its hind legs and its lower jaw is beak-like and toothless anteriorly. At this point, the relationships of this strange animal remain an enigma.

These little reptiles are not distributed through Lockatong detrital cycles at random. They are almost exclusively found, both as articulated skeletons and isolated bones in the lower parts of division 2, often in the lowest beds containing whole fish (see Stops 1 and 2).

Feltville Formation, Washington Valley Member - General Comments

About 3150 m above the early Late Triassic Lockatong Formation, is the first laterally extensive perennial lake sequence in the Early Jurassic (Hettangian) of the Newark Basin. This part of the lower Feltville Formation contains a limestone-bearing sequence which bears a gross resemblance in vertical sequence to a single Lockatong detrital cycle (Figure 7). I have been informally calling this portion of the Feltville the "Washington Valley member" and it can be split into three basic divisions at most exposures as follows (from the bottom up): 1, a 0 to 3 m gray to red siltstone and fine sandstone showing current bedding, root zones, abundant reptile footprints, and carbonized

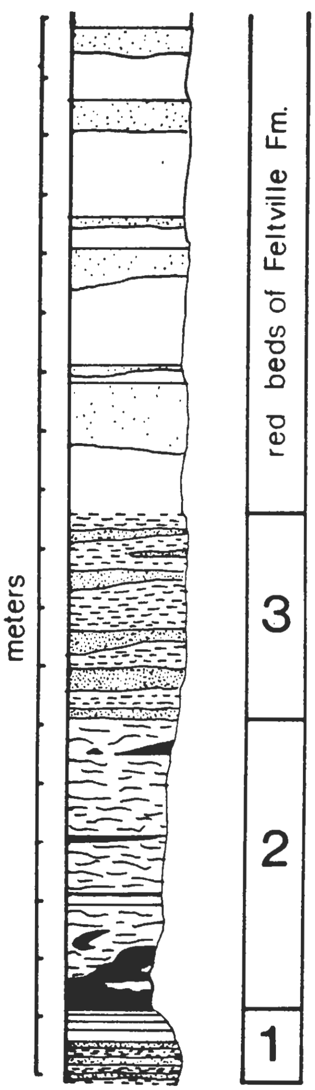

Fig. 7. Generalized section of "Washington Valley member" of Feltville Formation. Note resemblance to Towaco cycles (Figure 13) and Lockatong detrital cycles (Figure 3).

megafossil plants (transgressive facies); 2, a 0.5 to 5 m black, gray, or red and green-gray microlaminated to massive limestone and calcareous siltstone with abundant fossil fish and graded to massive siltstone (deep water facies); and a 1 to 3 m gray or red siltstone similar to division 1 but with fewer footprints (regressive facies). Division 1 grades down into and division 3 grades up into red and buff clastics. As there is only one unit like the Washington Valley member in the Feltville Formation, the sequence cannot be called cyclic. Nonetheless, the vertical sequence of beds and their fossil content show that, like Lockatong cycles, the Washington Valley member was deposited by the expansion and contraction of a large lake.

It is more difficult to assess the original area covered by the lake which deposited division 2 of the Washington Valley member than it is to assess the Lockatong lake area. Like all Newark Basin Jurassic beds, the Feltville Formation is preserved only in a few synclines along the major faults which cut the Newark Basin and form its western boundary (see Olsen, this fieldbook). So far the Washington Valley member has been positively identified in only the southern half of the Watchung Syncline and in the New Germantown Syncline. Exposures are too poorly known in the Sand Brook and Jacksonwald Synclines and in the northern half of the Watchung Syncline to determine the presence or absence of the Washington Valley member in these areas. Given the present state of knowledge, the minimum area covered by the lake which deposited division 2 is --- km^2 although the lake was probably much larger.

Lateral facies relationships in the Washington Valley member are very different from Lockatong detrital cycles despite the similarity in vertical section. On a small scale, the Washington Valley member shows lateral variation in thickness and lithology (Figure 8) far outside the range of Lockatong cycles. Thickness changes markedly along strike as does color. Within 300 m in the Watchung Reservation (type area for the Feltville Formation) the color of the limestone of division 3 changes from gray and black to white and green-gray and the color of fish bone changes from black to amber. Siltstones associated with all three divisions change from gray to red in the same area, but all the beds still retain palynomorphs and black coalified plant remains. The thickness of the red siltstone between the Washington Valley member and the underlying Orange Mountain Basalt varies markedly along strike as well; at some localities division 2 rests directly on the basalt (Figure 8). I believe these lateral changes reflect an irregular depositional surface.

On a larger scale, the Washington Valley member thickens towards the New Germantown Syncline, as does the whole of the Feltville (Figure 9). This thickening is in the same direction as the mean paleocurrent vector for the formation which is southwest (pers. obs. and Manspeizer, pers. comm.). Presumably, this indicates that the depositional center of the Feltville, unlike that of the Lockatong, was located near the present western edge of the Newark Basin.

The relationship between the calcareous and noncalcareous portions of division 2 is complex, especially in the Watchung Syncline exposures. While there is almost always a basal laminated limestone bed (Figure 10) the higher limestone units are very discontinuous, interrupted by massive to crudely bedded gray siltstone. These limestone units usually have scoured nongradational tops. It appears that some episodes of limestone deposition were separated by intervals of submarine scour which removed much of the originally

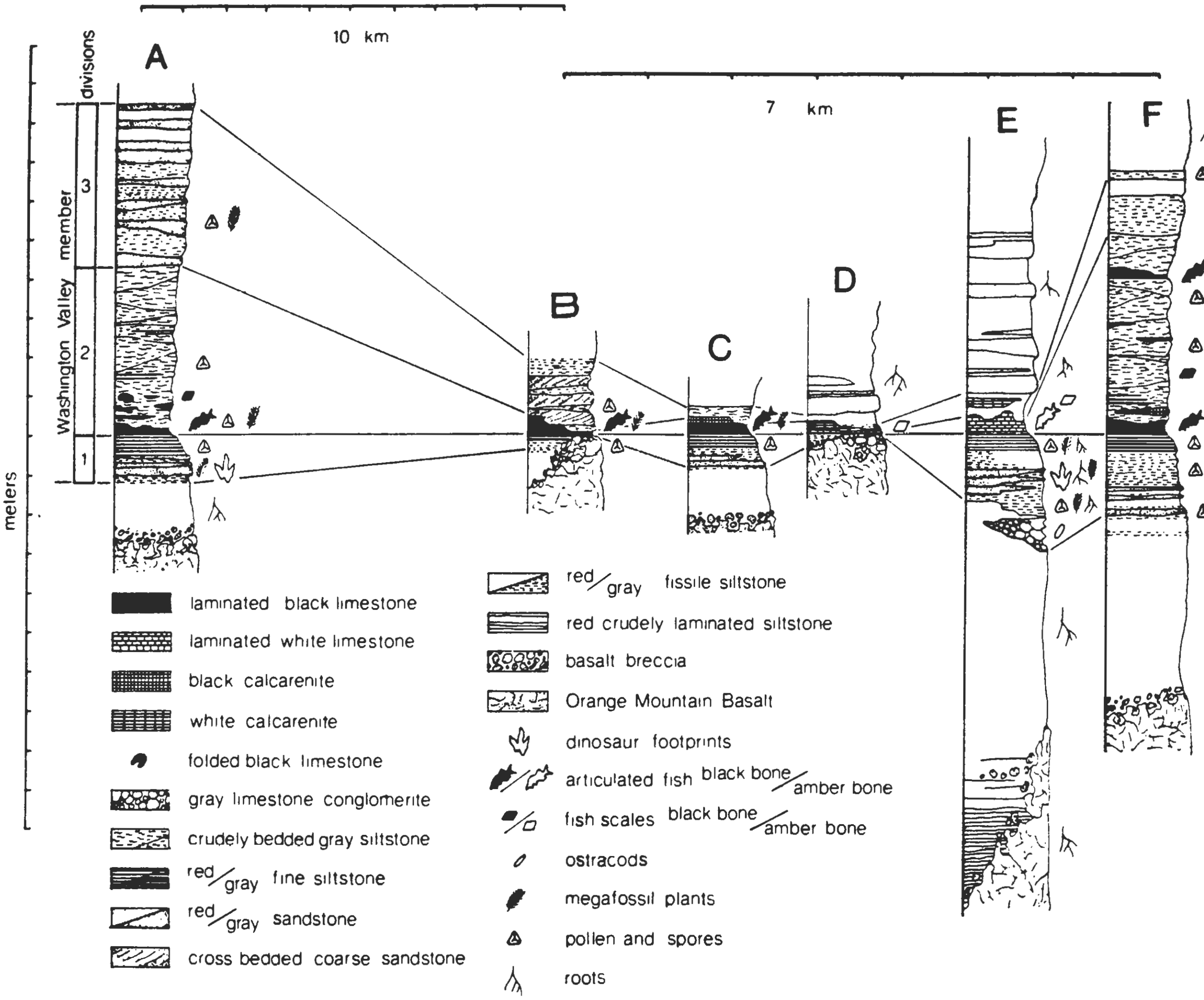

Fig. 8. Small scale lateral change in Washington Valley member: A, outcrop along East Branch about 145 m northwest of Vosseller Road near intersection with Roberts Road, Somerset County, New Jersey; B, banks of small stream running parallel to and on the southeast side of Valley Road, 1.6 km north of Watchung, New Jersey rotary (Somerset County). Elsinore Drive crosses this stream 80-100 m down stream from locality; C, bluffs and pool exposures along Green Brook about 400m northeast of intersection of Plainfield Avenue, Valley Road, and Bonnie Burn Road and about 618m down brook from overpass of Plainfield Avenue over brook (outcrops at boundary of Union and Somerset Counties); D, outcrops along Green Brook north of (c) above and about 200m, south of the Plainfield Avenue bridge over Green Brook; E, two combined sections, 400m apart, one on the south, one on the north side of Blue Brook about 1.9km and 2.3 km respectively, upstream from the crossing of Sky Top Drive over Blue Brook, Watchung Reservation, Union County, New Jersey — type section of the Feltville Formation; F, outcrops in bluff of small tributary of Blue Brook, 260m south of Lake Surprise, Watchung Reservation, Union County, New Jersey.

deposited limestone. Support for this hypothesis comes from the presence of beds of calcarenite made up of redeposited limestone (Figure 10) and the presence of occasional rolled beds of limestone isolated in gray siltstone (Figure 10).

Thus, a relatively deep water (plus several tens of meters) environment is suggested by most features of division 2 throughout most of its exposed area. On the other hand, at least the upper part of division 2 in the white limestone and red siltstone exposures in the Watchung Reservation (E of Figure 8) shows some features suggestive of shallow water deposition and shallow water reworking of carbonates (Manspeizer, this Fieldbook).

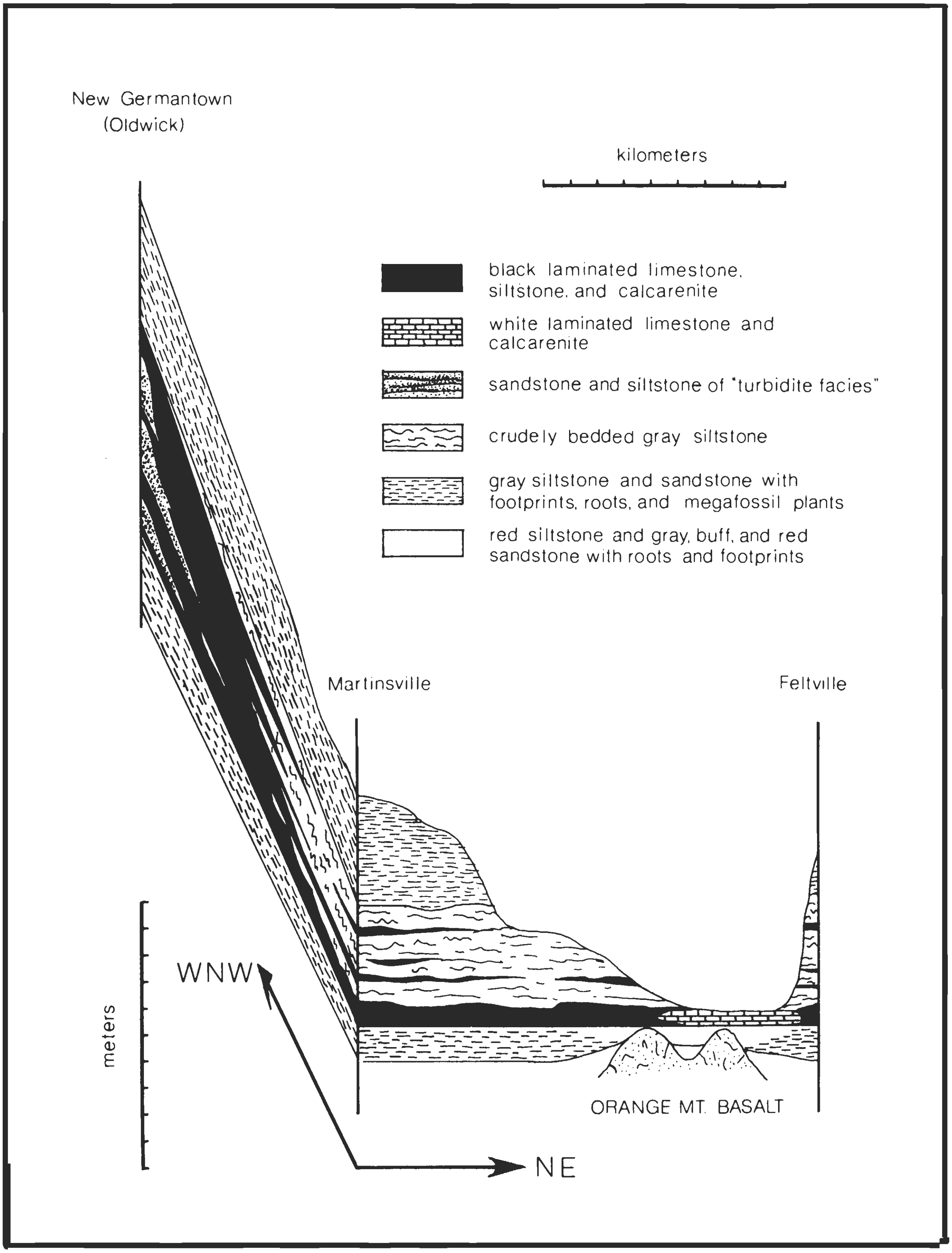

Fig. 9. Lateral facies relationship in Washington Valley member.

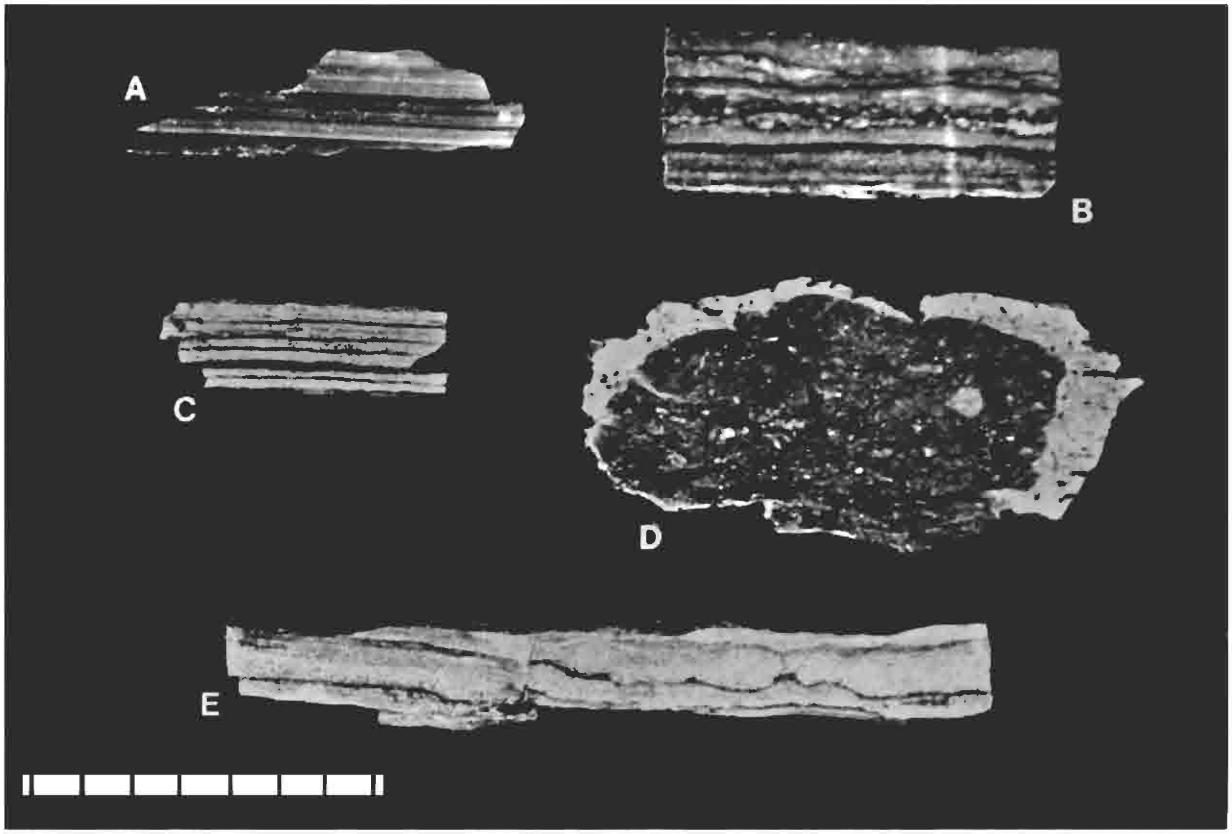

Fig. 10 Hand samples of portions of division 2 of the Washington Valley member: A, laminated gray siltstone from upper part of division 2 from a small tributary of Rockaway Brook in the New Germantown Syncline—dark laminae differ from light by increased content of Kerogen, primarily pollen and spores; B, light gray laminated calcarenite from upper part of division 2 from southern exposures in the Watchung reservation; C, laminated (and in part microlaminated black limestone, from bluff along the East Branch of Middle Brook, Martinsville, New Jersey — couplets consist of kerogen rich claystone siltstone lamina and a kerogen containing limestone lamina; D, coarse gray silty calcarenite, from bluff along the East Branch of Middle Brook, Martinsville, New Jersey; E, thin sandy turbidites, from a small tributary of Brook in the New Germantown Sycline — graded beds consist of fine sand grading up into gray silt and then fine dark gray kerogen - rich siltstone.

All samples are polished and wetted with glycerol. Scale in cms.

In contrast to the Watchung Syncline exposures, those of the Oldwick Syncline contain little massive siltstone. Instead, the siltstones are well bedded, often sandy, sometimes conglomeritic, and are usually made up of beds 1 to 5 cm thick showing a distinct graded pattern (Figure 10) characteristic of turbidites. (A turbidite is a sedimentary unit showing a characterisitic upwards fining in grain size associated with a series of structures indicating deposition by intrusions of dense sediment-laden water which flow beneath less dense water along the basin floor — turbidity currents.) While turbidites are usually considered characteristic of marine environments (Bouma, 1962, 1964), there are no *a priori* reasons why they should not occur in all bodies of water. In fact, turbidity currents do play major roles in lacustrine sedimentation; for instance, they account for as much as half of the accumulated sediments in meromictic Green Lake, Fayetteville, New York (Ludlam, 1974). Houbolt and Jonker (1968) show that Lake Geneva (Switzerland) also has thick accumulations of turbidites and these are very similar to the New Germantown Syncline examples.

Those features of the deep water facies of division 2 of Lockatong detrital cycles which are consistent with the stratified lake model of deposition are also present in the laminated portions division 2 of the Washington Valley Member. There are, however, major differences in facies patterns between the Lockatong cycles and the Washington Valley member which are at least partially due to the different cross-sectional shape of the lake. For instance, division 2 of the Washington Valley member lacks macroscopic benthic organisms throughout its preserved area. Also, the microlaminated, whole-fish-bearing portions of division 2 extend to the western edge of the Newark Basin, whereas in Lockatong lakes, microlaminated beds get no closer to the basin's western edge than a few kilometers. This and the presence of interbedded conglomerates in division 2 show that the western edge of

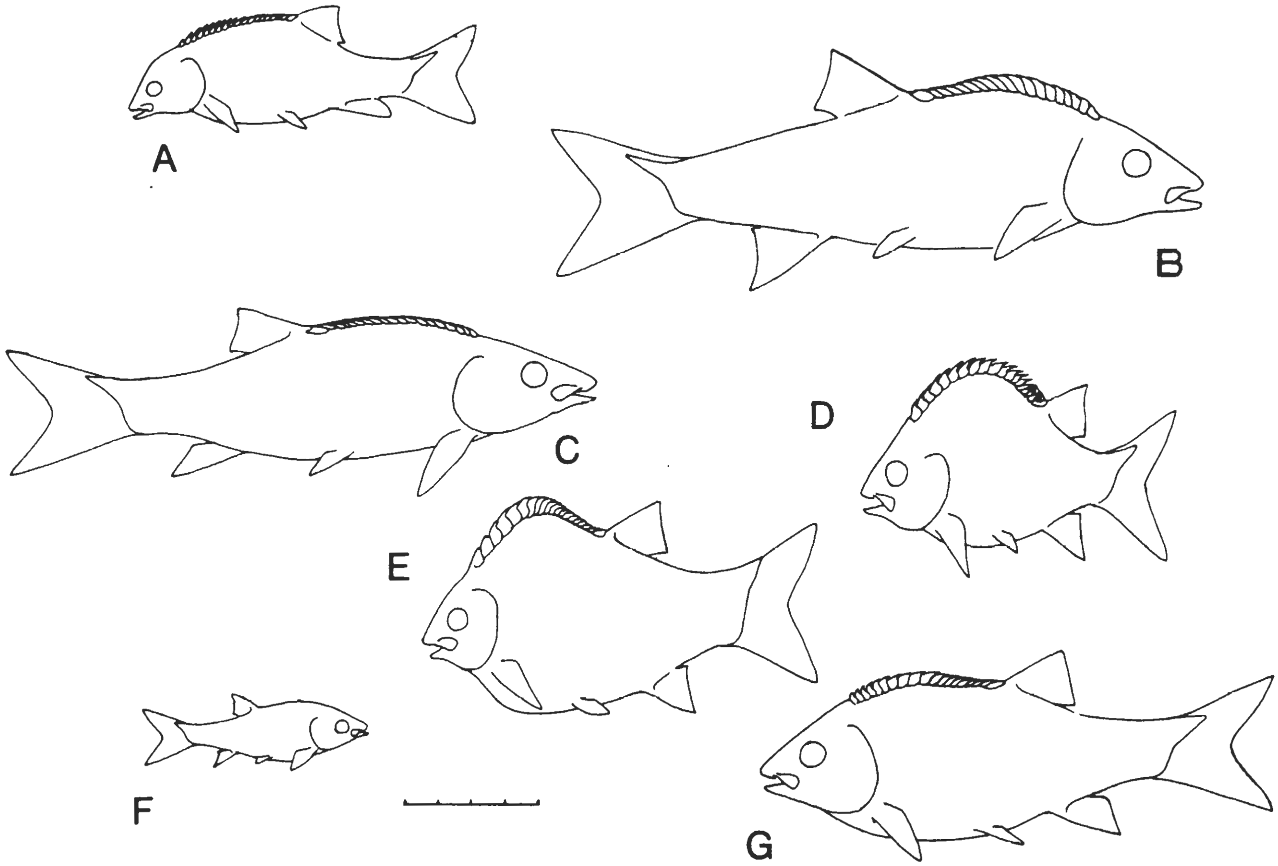

Fig. 11 Outline shapes of semionotid fish from the Washington Valley member of the Feltville Formation; A, AMNH 672 from Old Field's Copper Mine, Watchung, New Jersey (Figured in Newberry, 1888); B, YPM 6452 from bluff along East Branch of Middle Brook, Martinsville, New Jersey; C, YPM 6455, from same locality as B; D, YPM (uncatalogued specimen) from small tributary of Rockaway Brook, in the New Germantown Syncline, Oldwick, New Jersey; E, YPM 6809, from same locality as B; F, YPM 6450, from same locality as B; G, YPM 7763, from same locality as B.

These are attempted reconstructions of the individuals listed above: They are designed to give a general feeling for morphological variability among Feltville Semionotids rather than details of any one specimen. Scale in cms.

the Washington Valley lake basin was steep.

Feltville Formation Fish

While invertebrates are very rare in the Washington Valley member, fossil fish are abundant in the laminated limestone and thin turbidites. The kinds of fish and their patterns of diversity are very different from the Lockatong; *Semionotus* is everywhere overwhelmingly abundant. The only other genus present is the subholostean *Ptycholepis* and this is represented by only a few characteristic skull bones and scales. This apparent low generic diversity is offset by very high levels of morphological diversity among semionotids (Figure 11). This variability far exceeds that of the entire Lockatong sample of semionotids (+ 1500 specimens) despite the much smaller size of the Washington Valley sample. Using the rule of thumb outlined for Lockatong fish, it appears that this amount of morphological diversity reflects the presence of an unusually high number of semionotid species. The relatively small number of whole Washington Valley member fish precludes, at this point, a minimal species count, although such an effort is planned (A. R. McCune, pers. comm.).

Interbasin Correlation by Semionotids

The most distinctive semionotids present in the Washington Valley member of the Feltville Formation belong to what I have called the "*Semionotus tenuiceps*-group" (Figure 12). They are characterized by large and often elaborate scales in front of the dorsal fin. Similar fish are known from only two other formations in the Newark Supergroup: the Towaco Formation of the Newark Basin (see Olsen this fieldbook) and the Turners Falls Sandstone of the Deerfield Basin. Despite the proximity of the Deerfield and Hartford basins, no fish of the "*S. tenuiceps* group" have been found in the latter. Likewise, the subholostean *Redfieldius*, semionotids of the "*S. micropterus* group", and *Diplurus* cf. *longicaudatus* which are present in both the Shuttle Meadow and East Berlin formations of the Hartford Basin are absent from the Feltville Formation and

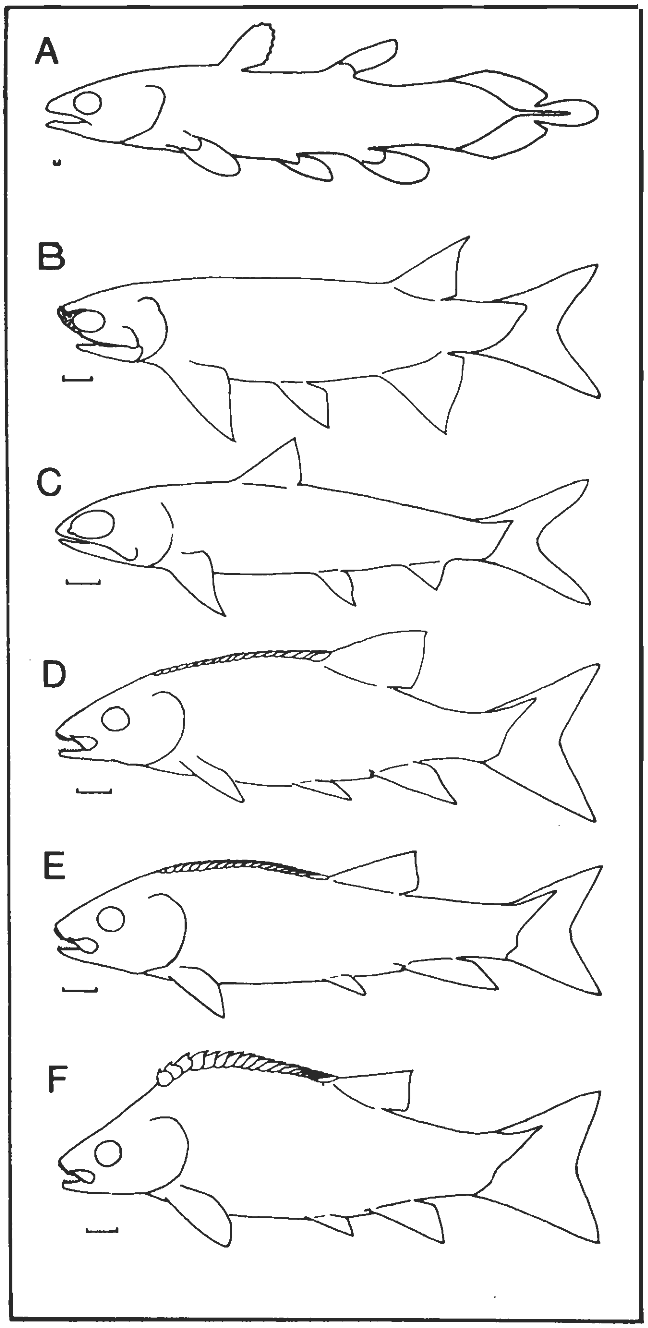

Fig. 12 Reconstructions of fishes of the Newark Jurassic: A, *Diplurus longicaudatus;* B, *Redfieldius* sp.; C, *Ptycholepis marshi;* D, member of the *"Semionotus elegans* group"; E, member of the *"Semionotus micropterus* group"; F, member of the *"Semionotus tenuiceps* group".
Adapted from Olsen (In Prep). Scale 1 cm.

Turner Falls Sandstone. Therefore, the fish evidence does not support correlation of the three lava flow formations and interbedded sediments of the Newark and Hartford Basins as has been suggested. The presence of *Redfieldius* higher in the Newark Basin section (Boonton Formation) suggests that the Feltville Formation (and the Towaco Formation and Turners Falls Sandstone as well) are older than the Shuttle Meadow Formation (Olsen, McCune and Thomson, In Press).

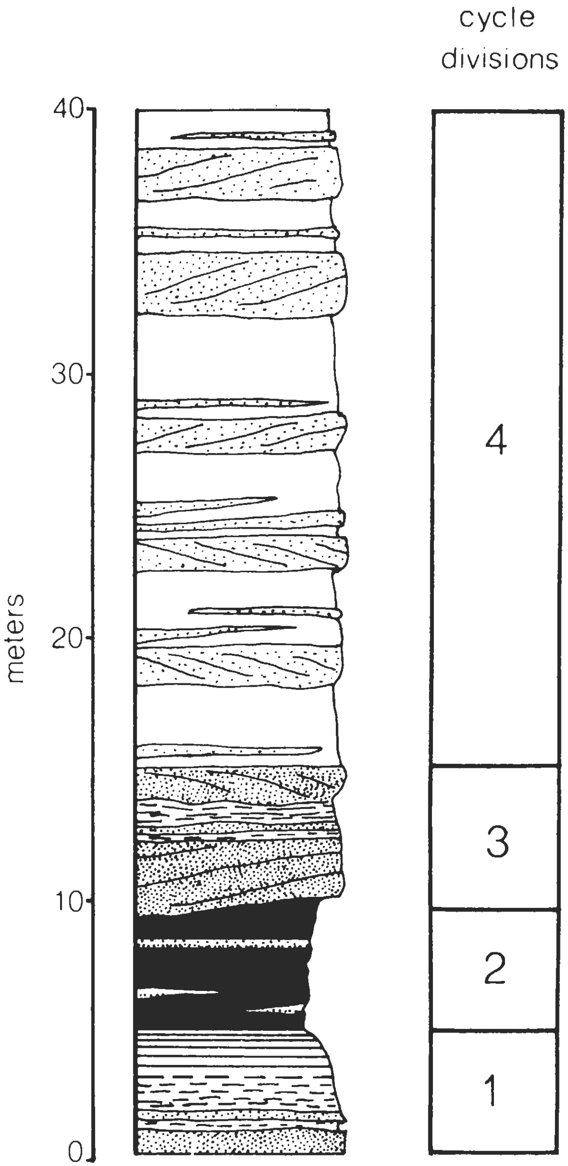

Fig. 13 Generalized Towaco Formation cycles. Description in text.

Towaco Formation Cycles - General Remarks

The Towaco Formation, like the Lockatong, consists predominantly of sedimentary cycles (Figure 13) produced by the expansion and contraction of large lakes. In contrast to the Lockatong, Towaco cycles have a mean thickness of 30 m and contain thick sequences of red clastics. In gross form, Towaco cycles look like stretched out Lockatong detrital cycles with a concommitant reduction in the density of various features of bioturbation and diagenesis and an increase in the preservation of primary sedimentary structures. Towaco cycles also resemble the Washington Valley member if the overlying red beds of the Feltville Formation are added. The cycles of the Towaco Formation can be broken, for convenience, into four basic divisions as follows (from the bottom up): 1, a 1 to 5 m gray siltstone and sandstone (or conglomerate) often with root horizons, reptile footprints, and large to small scale

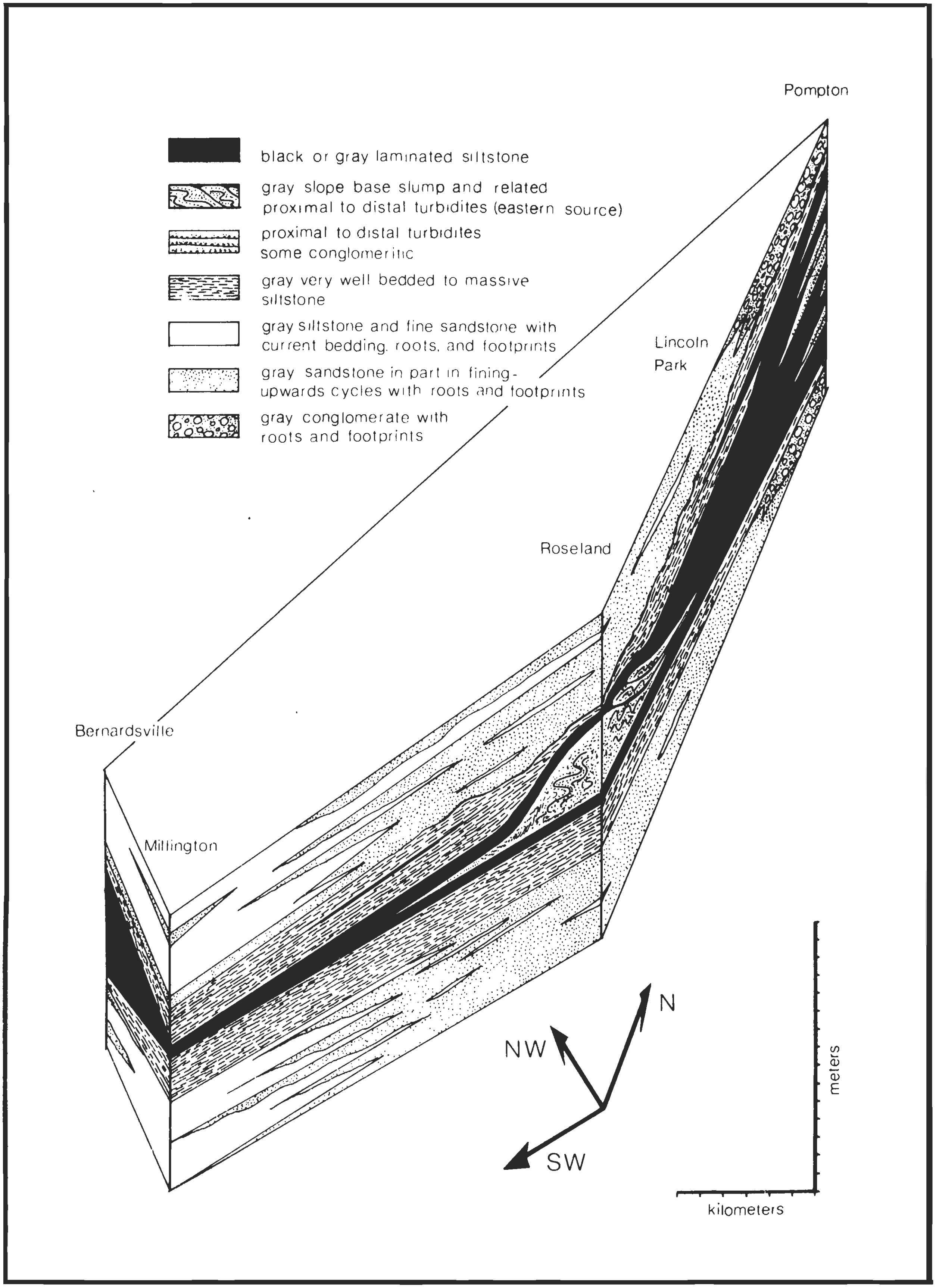

Fig. 14 Lateral facies relationship within divisions 1—3 of Towaco cycles.

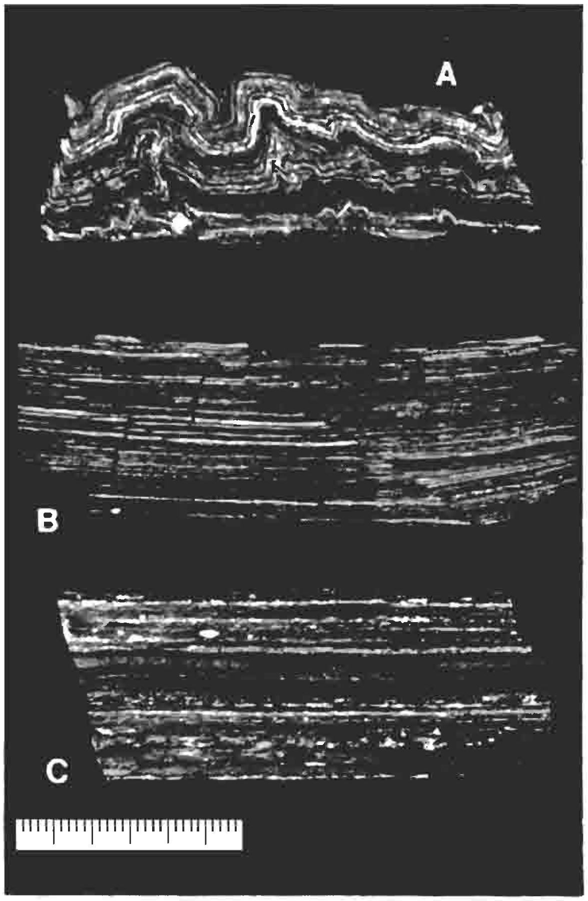

Fig. 15 Hand samples of the microlaminated portion of division 2 of Towaco cycles showing the northward increase in microlamina thickness: A, microlaminated silststone in disharmonic folds from upper cycle, Walter Kidde Dinosaur Park; B, microlaminated siltstone with small syndepositional fault from uppermost Towaco cycle, Toms Point, Lincoln Park, New Jersey; C, microlaminated siltstone from the third cycle from the top of the Towaco Formation, Wayne, New Jersey.

Samples arranged with the most northern sample, uppermost. Scale in cms.

crossbedding (transgressive facies); 2, a 1 to 5 m thick gray to black siltstone with a 0.1 to 5.0 m thick gray to black microlaminated calcareous portion often with numerous fish (deep water facies); 3, a 3 to 6 m gray clastic unit similar to division 1 (regressive facies); and 4, a thick (20 - 30 m) red clastic sequence often composed of several fining-upwards cycles containing abundant reptile footprints, root horizons, mudcracked surfaces, and beds with numerous carbonate rich nodules (fluvial, flood pain, and flood basin facies).

Individual Towaco cycles resemble the Washington Valley member of the Feltville Formation in lateral facies relationships (Figure 14), again contrasting with the Lockatong. All divisions of the Towaco cycle coarsen towards the north, and the microlaminated portion of division 2 thickens by more than an order of magnitude towards the Ramapo Fault. This

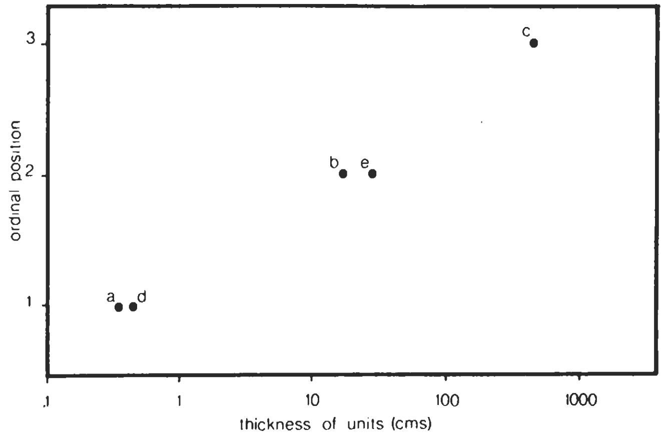

Fig. 16 Graph of the relationship between thickness and relative position of Towaco Formation turbidites at the Walter Kidde Dinosaur Park, "Ordinal" position refers to the position of each turbidite in the sequences of units a, b, c and d, e as shown in Figure 45.

microlaminated portion appears varved, similar to the microlaminated portions of Lockatong cycles and the Washington Valley member. Varve thickness increases in the same general direction as the entire microlaminated sequence (Figure 15), although only by a factor of five. The structures and fossils in these varved beds are consistent with the stratified lake model of deposition. However, the more massive fine siltstone portions of division 2 are more consistent with a model in which the lake experienced at least seasonal overturn; fossil fish are present in these beds but only as isolated bones and scales.

Lacustrine Turbidites of Towaco Cycles

At a number of exposures, division 2 of Towaco cycles contain beds which I interpret as lacustrine turbidites of two types. One series of turbidites, formerly exposed in the Roseland (Riker Hill) Quarry, conform to a proximal-to-distal turbidite model developed originally for marine flysche sequences by Allen (1969). This sequence, described in more detail for field trip Stop 5, appears to have been produced by the lateral migration of a submarine channel fan. Houbolt and Jonker (1968) described a similar sequence in Lake Geneva where turbidity currents are produced when the cool sediment-rich waters of the Rhone River underflow the relatively warm waters of the lake. The stream of the Rhone retains its integrity and flows towards the deepest part of the lake along a submarine channel to a depth of about 300 m where it dissipates into a channel fan. Houbolt and Jonker recognize channel deposits, levee deposits, channel fan sediments, fan margin beds, and central plain deposits, all deposited in deep water as a direct result of turbidity currents. I interpret the coarse-grained and crudely bedded units in the middle of the lower cycle at the Roseland (Riker Hill) Quarry (Stop 5)

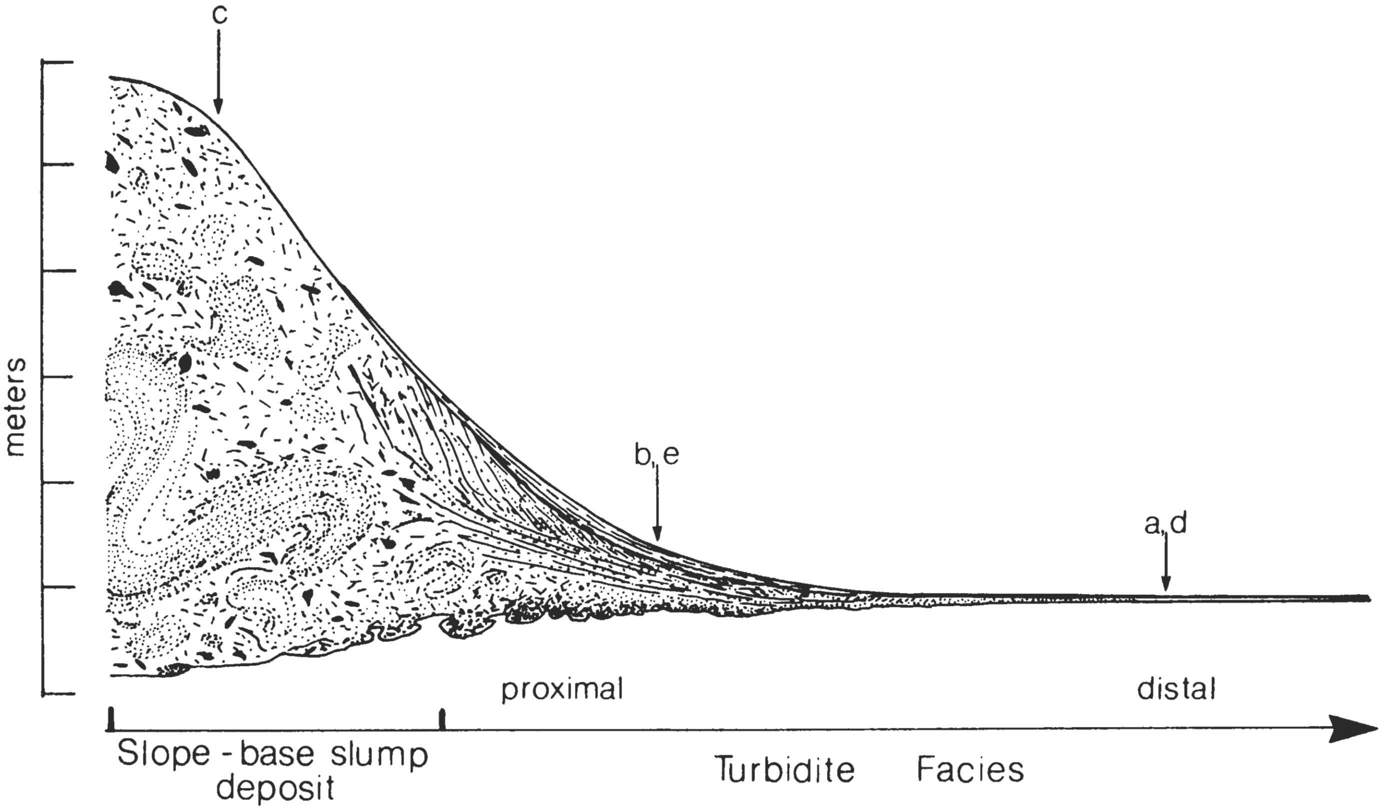

Fig. 17 Model of proximal to distal facies relationships in a single hypothetical Towaco Formation turbidite. Letters a, b, c, d, and e refer to actual turbidites described in Figure 45 and graphed in Figure 16. I do not mean to imply that all Towaco Turbidites originated from a slump.

as the result of lateral migration of a similar set of facies. The maximum thickness of these Towaco turbidites increases exponentially above the microlaminated siltstones in division 2 of the lower cycle (Figure 16) as might be expected of such a channel approaching a site at a nearly constant rate (Allen, 1969). The slope of the approaching fan would be the source of the slumped beds as depicted in Figure 17. In this model, water depth remains constant, but an alternative could involve a decrease in water depth resulting in the encroachment of the shore on the center of the lake. The sense of rotation of the folds in the slumped beds indicate transport from the east; presumably this was the direction from which the channel fan approached.

A second series of turbidites is exposed in Towaco cycles near the Ramapo Fault at Bernardsville and Wayne, New Jersey. These are graded beds, 0.5 to 20 cm thick, which occur throughout the otherwise microlaminated portions of division 2 and which resemble the turbidites of the Washington Valley member in the New Germantown Syncline. Some of the thicker turbidites are conglomeritic at their base and clearly scour the underlying microlaminated units. The pebbles found in these beds are up to 3 cm in diameter and suggest a source from the west. Thinner sandy turbidites often have casts of tool marks on their lower suface. These turbidites, apart from their clastic composition, resemble units deposited by turbidity currents in meromictic Green Lake, Fayetteville, New York (Ludlam, 1973). These turbidity currents begin along the lake basin margin as slumps, which slide down the basin slope, liquify as they mix with water.

The picture derived from facies analysis is one compatible with a model of a large perennial stratified lake which was wedge-shaped in cross-section, deepest near the Ramapo Fault, and receiving detritus primarily from the east but with a significant western input at the western lake edge.

Fluvial and Flood Plain Facies of Towaco Cycles

The broad area of Towaco Formation exposed between the northern and southern corners of the Watchung Syncline is characterized by cycles in which divisions 1, 3, and especially 4 consist primarily of fining-upwards cycles each much smaller than Towaco cycles (Figure 18). The lower portions of these cycles consist of fine to coarse sandstone or fine conglomerate which cuts down into the underlying siltstone of the previous fining-upwards cycle, often producing beds of rip-up-clasts. This portion of the cycle usually shows low angle inclined beds, each of which presents a variety of small scale current structures indicating flow about perpendicular to the original slope of the inclined beds (paleocurrent vector mean is N 39° W, while the mean for the dip direction of the inclined beds is S 24° W).

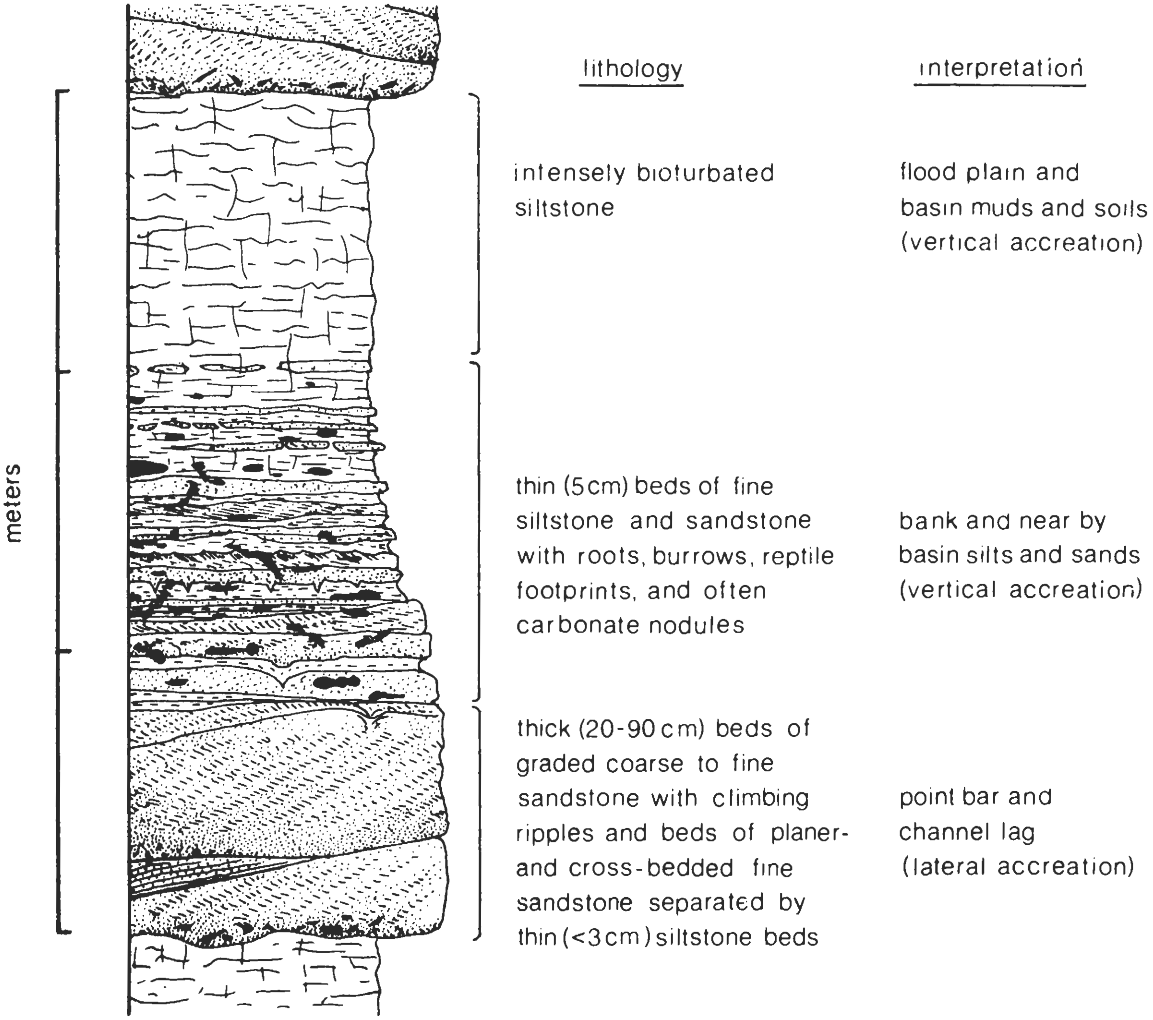

Fig. 18 Generalized fining - upwards cycle of Towaco Formation interpreted as due to laterally migrating streams.

This is followed in vertical sequence by beds of fining-upwards sandstones with climbing ripples, sole casts of reptile footprints and tool marks, alternating with beds of fine, often ripple bedded siltstone. The upper beds are fine, sometimes massive siltstone with much less prominent current bedding, frequent mudcracks, and dolomitic nodules. All portions of these fining-upwards cycles contain abundant roots; in gray beds these roots are preserved as coalified compressions, while in the red beds they are preserved as red siltstone casts.

Shallow laterally migrating rivers and streams could have produced these fining-upwards cycles. The lower portions of each cycle appear to be channel (lateral accretion) deposits, predominately point bar. The middle portion of the cycle probably represents a bank deposit and includes numerous levee and crevasse splay beds. The upper fine grained portion of each cycle appears to be a flood basin (ephemeral lake) and flood plain deposit. Following Allen's (1964, 1965, 1970) interpretation, deposition of these fining-upwards cycles occurred as follows: 1, the migrating channel cuts down into older beds in the direction of migration, redepositing the older sediments as channel deposits; 2, bank and then flood basin sediments follow in vertical sequence as the channel migrates away from a given section. The result at any section is a strongly asymetrical, fining-upwards cycle.

While the interpretation of these cycles as the result of laterally migrating channels is the first to come to mind, alternative models are possible. One, which I feel requires additional attention, regards the base of each fining-upwards cycle as a regressive shore facies of an ephemeral lake and the upper parts as a trangressive facies. These lakes would, of course, be much smaller than the lakes producing the full Towaco cycle. Critical tests of these hypotheses must be sought out.

Reptile Footprints

Reptile footprints occur abundantly in Towaco cycles,especially in fining-upwards cycles of division 4 adjacent to divisions 3 or 1. They can be a beautifully detailed record of living, moving animals. Ichnology, the study of footprints, should offer considerable insight into aspects of paleobiology unapproachable by conventional methods of analysis, for instance, how the

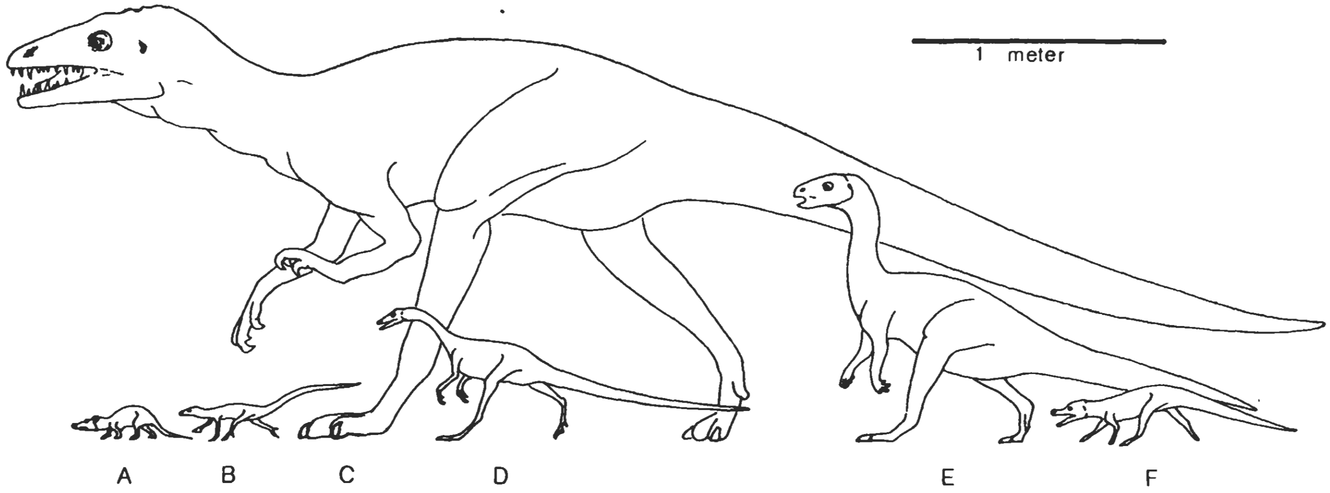

Fig. 19 Possible appearance of some representative Towaco Formation trackmakers: A, advanced mammal-like reptile or early mammal; B, lizard or lizard-like sphenodotid rhynchocephalian which produced *Rhynchosauroides*-type tracks; C, large carnivorous theropod dinosaur which produced the large grallatorid tracks usually called *Eubrontes* or *Anchisauripus minusculus;* D, small carnivorous theropod dinosaur responsible for the small grallatorid tracks of the *Grallator*- and *Anchisauripus hitchcocki*- types; E, small ornithischian dinosaur which produced *Anomoepus* tracks; F, small sphenosuchid thecodont (crocodilomorph) which probably made *Batrachopus* footprints.

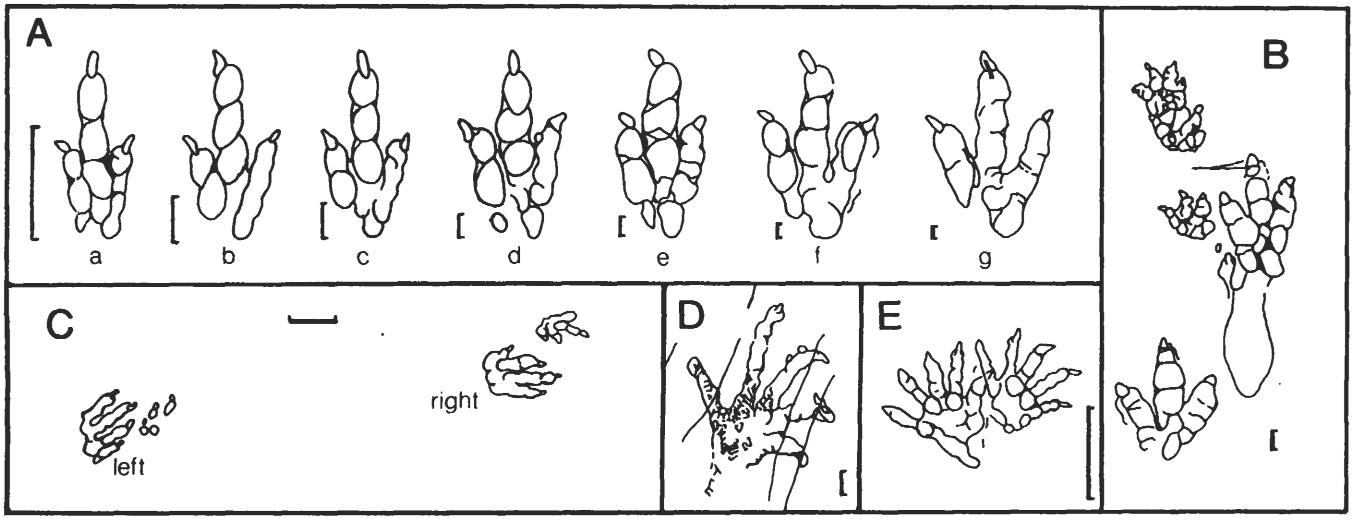

Fig. 20 Footprints from the Towaco Formation: A, Footprints of the *Grallator* type (footprints a-g arranged from left to right in order of increasing size, all right pedes, scale 2 cm); B, *Anomoepus,* two right pes impressions (one showing metatarsus impression), and three right manus impressions, scale 2 cm; C, left and right manus - pes sets of *Batrachopus,* scale 2 cm; D, *Rhynchosauroides,* left manus scale 2 mm; E, possible advanced therapsid (mammal-like reptile) or early mammal left manus and pes set, scale 2 cm.

A, (a) personal collection of John Colegrande, (b, c, d, g) RU main display slab, (e, F) lost specimens, Essex County Park Commission collection; B, RU main display slab; C, PU uncatalogued specimen; D, PU 18563; E, personal collection of Larry Felder.

animals moved and which ones inhabited the same small area. Ichnology can also provide biostratigraphic evidence where skeletal remains are lacking.

Unfortunately, no comprehensive work on Newark Supergroup footprints exists; the closest thing published is Lull's (1904, 1915, 1953) treatise on the "Triassic Life of the Connecticut Valley", and this work is very out of date. What follows is an outline of the footprints found in the Towaco Formation with some preliminary observations on their makers (Figure 19).

Rhynchosauroides sp.

A single natural cast of the imprint of a manus (fore foot) from an otherwise poor trackway is the only definite record of lepidosaurs (lizard-like reptiles) from the Towaco Formation. In Triassic deposits, this type of track is termed *Rhynchosauroides,* although the kind of manus it represents occurs in a large range of lepidosaurs including (essentially modern) lizards and sphenodontid rhynchocephalians. Both of these groups were present by the end of the Triassic and it is somewhat puzzling that this sort of track is not more common in post-Triassic deposits. This particular foot-

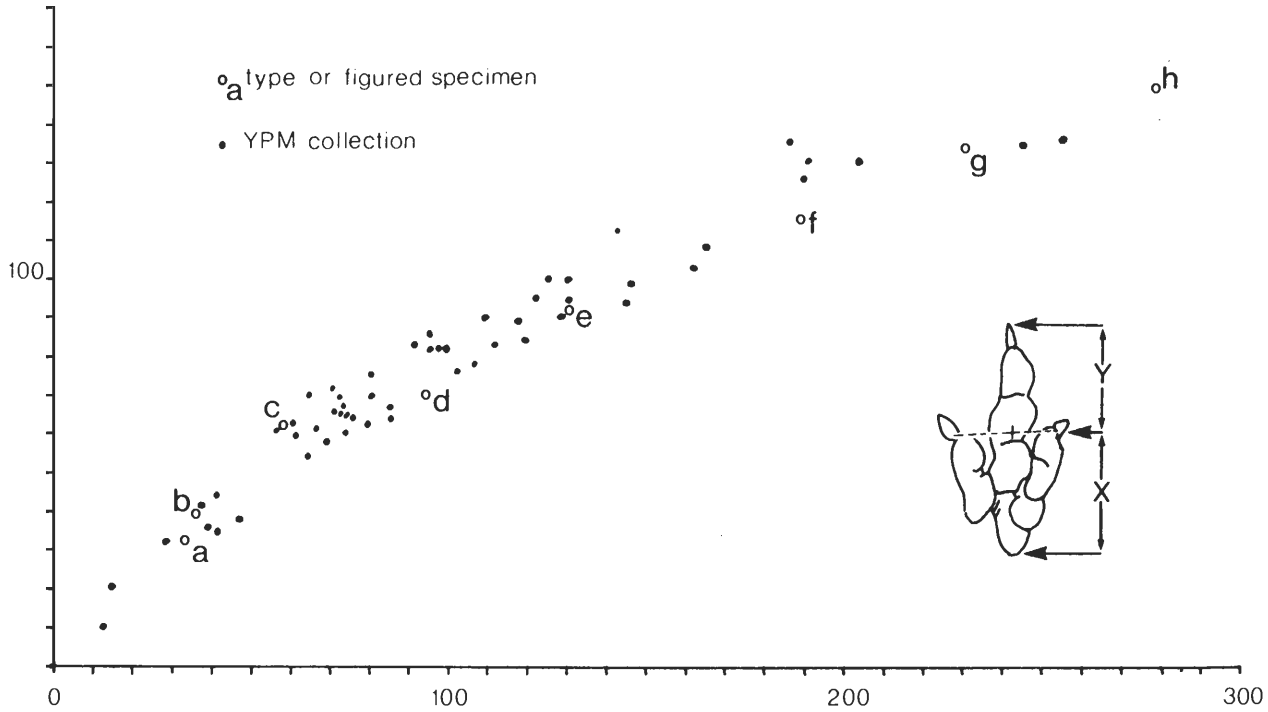

Fig. 21 The relationship between the projection of digit III past digits II and IV and the rest of the pes impression. Note the relative decrease in the projection of digit III with the absolute increase in the pes length.

print (Figure 20) is not quite like either of the two named Newark taxa, *Rhynchosauroides brunswickii* and *R. hyperbates* (Baird, 1957), but with only one well preserved footprint, formal description of this form is unwarranted.

Batrachopus sp.

Tracks assigned to the footprint genus *Batrachopus* (Figure 20) are the most abundant small non-dinosaur footprints in the Towaco Formation. The lack of a well-defined digit V on the pes (hind foot), and the small size of the manus with five subequal toes suggests a crocodilomorph as the maker of this track. Crocodilomorphs, including both true crocodiles and the more gracile sphenosuchids, are known from Early Jurassic rocks from various parts of the world.

Grallator Spp.

The most abundant footprints in the Towaco Formation are small to large, functionally three toed tracks which using Lull's (1915, 1953) terminology, would be called *Grallator, Anchisauripus,* and *Eubrontes* (Figure 20 and 21). There is never a manus impression, and the pes imprint is usually narrow - especially so in small individuals - with the angle between digit II and IV being from 15° to 45°. The shape of the pes and the nature of the skeleton reconstructed from it, clearly indicates the carnivorous theropod dinosaurs (Peabody, 1948; Baird, 1957, In Press; Galton, 1976).

The specimens illustrated by Lull (1915, 1953) as typical of *Grallator, Anchisauripus,* and *Eubrontes* show differences in proportions which probably reflect real differences in foot structure (Baird, 1957); the main factor responsible for this, however, is principally the relative length of digit III. A reasonable measure of this factor is the projection of digit III past II and IV. If this measure is graphed against the remaining length of the foot (Figure 21), it becomes apparent that the shape of the pes impression changes continuously with size. It is my opinion that the footprint genera *Grallator, Anchisauripus,* and *Eubrontes* form a continuum similar to what would be expected of tracks of individuals of different ages perhaps representing a single dinosaur species. It is therefore reasonable to synonymize the junior names *Eubrontes* and *Anchisauripus* with the senior name *Grallator.* This is not to say that all Towaco *Grallator* foot-prints were necessarily made by a single dinosaur species. Although I believe there were several species of theropod dinosaur trackmarkers, I also believe that without further detailed analysis, different species of *Grallator* should not be recognized in the Towaco assemblage.

Anomoepus Spp.

Anomoepus tracks (Figure 20) are generally small (pes 1.5 - 20 cm) and are characterized by a broad, often four toed pes and a manus with five (rarely four) subequal digits. The structure of *Anomoepus* tracks fits what is known about several small herbivorous early Mesozoic ornithischian dinosaurs such as fabrosaurs. As is the case for *Grallator,* there were probably a number of species (if not genera) of small ornithischians

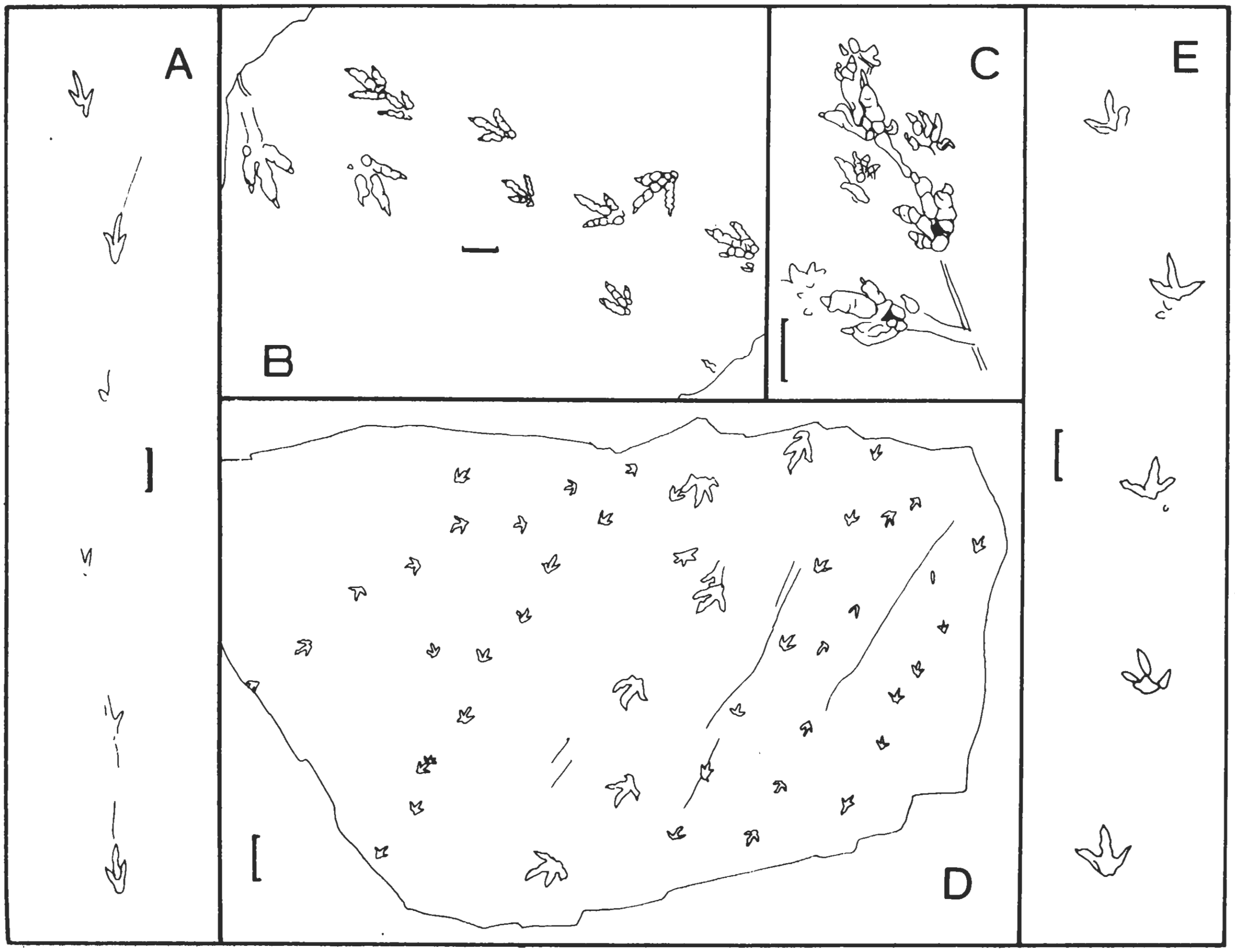

Fig. 22 Footprints plausibly produced by juveniles of the animals, which made *Grallator* and *Anomoepus:* A, grallatorid footprints (cast is YPM 5900, original in personal collection of Robert Salkin); B, *Anomoepus* - type footprint (PU uncatalogued); C, *Anomoepus* - type footprints with manus impressions (personal collection of John Colegrande); D, *Anomoepus* - type trackways -two different sizes of individuals (personal collection of Anthony M. Lessa); E, possible *Anomoepus* - type trackway (cast is YPM 5901, original in personal collection of Robert Salkin).
Scale: S, B, C, E, 2 cm; D, 5 cm.

capable of making *Anomoepus* tracks present during Towaco deposition.

Baby Dinosaurs

Tracks of reptiles like those in Figure 20 are common throughout early Jurassic beds of the Newark Supergroup (Olsen and Galton, 1977) and are also known from the early Jurassic rocks of southern Africa and the southwestern United States. What makes the assemblage of tracks in the Towaco Formation unusual is the abundance of very small (less than 3 cm) dinosaur footprints. Some of these probably represent small adult forms but most make sense as baby dinosaurs (Figure 22). Two basic kinds of these small tracks have been found - one clearly of the *Grallator* type, the other of the *Anomeopus* type. Judging from the extremely large numbers of small *Anomoepus* tracks on single bedding plains (Figure 22), the juvenile trackmakers may have been gregarious, as has been suggested for a number of other dinosaurs (Ostrom, 1972; Horner and Makela, 1979).

Among the many small vertebrate footprints so common at the Dinosaur Park are several quadrupedal trackways of a type new to the Newark Supergroup (Figure 20, E). The manus and pes impressions are five-toed and almost equal in size; the pes has a large "heel pad" on its lateral side. The only latest Triassic and Early Jurassic vertebrates with skeletal structure comparable to these tracks are advanced mammal-like reptiles or early mammals. If the latter is correct, these footprints represent the oldest New World record of mammals.

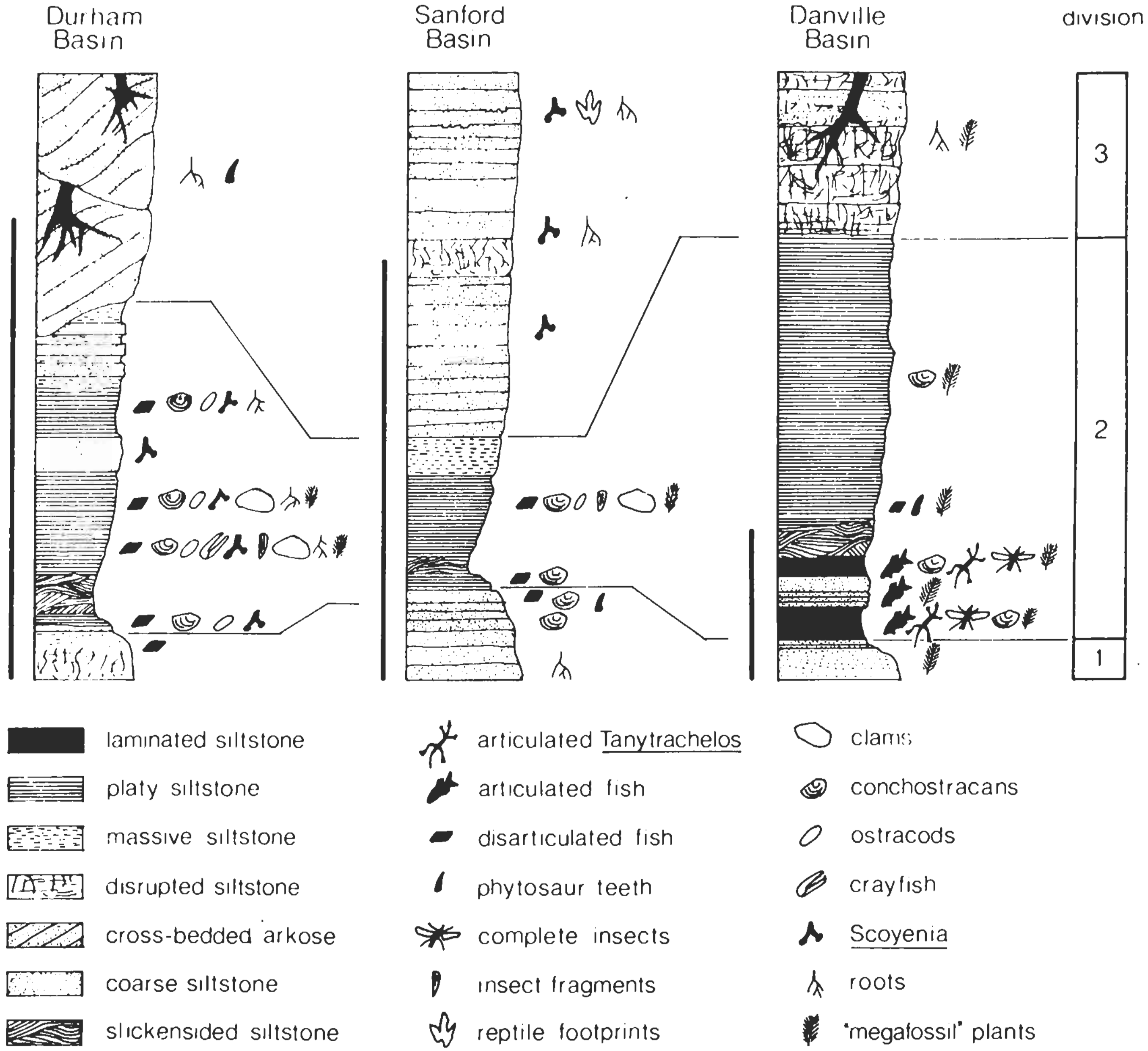

Fig. 23 Lockatong-like sequences from other portions of the Newark Supergroup. Durham Basin section consists of red and green-gray clastics while Sanford and Danville Basin section are gray and black. Durham Basin section from Bain and Harvey, 1977; Sanford Basin section from exposures along State Road 1621 in Carbonton, North Carolina; Danville Basin section from Olsen, et al., 1978.

Comparative Paleolimnology

Cyclic lacustrine sequences similar to detrital cycles and Towaco cycles occur in other basins of the Newark Supergroup. Lockatong-like sequences are present in the New Oxford Formation of the Gettysburg Basin, the Cow Branch Formation of the Dan River Basin (Olsen, et al., 1978), the Cumnock Formation of the Sanford Basin (Deep River Basin), and the unnamed lacustrine unit of the Durham Basin (Deep River Basin) (Bain and Harvey, 1977) (see Figure 23). The age of all these units is Middle to Late Carnian of the Late Triassic (Cornet, 1977; Olsen, McCune, and Thomson, In Press). Each of these lacustrine sequences was produced by an individual lake, although each closely resembles a portion of the range of facies present in Lockatong detrital cycles. While the Cow Branch Formation, like the Lockatong, shows the "full" lateral sequence of deep to shallow facies of division 2 of the cycles, the Cumnock and New Oxford formations show only the middle-to shallow-water facies, and the unnamed Durham Basin unit shows only the shallow-water facies. The features which make the Lockatong-like sequences resemble each other include the details of sediment-organism relationships and the nature of the lateral changes in facies. The same features are very different in Newark Supergroup lacustrine sequences of other ages.

Towaco-like sequences (Figure 24) include the Washington Valley member of the Feltville Formation, the "Durham Fish Bed" of the Shuttle Meadow Formation, the East Berlin Formation (both in the Hartford

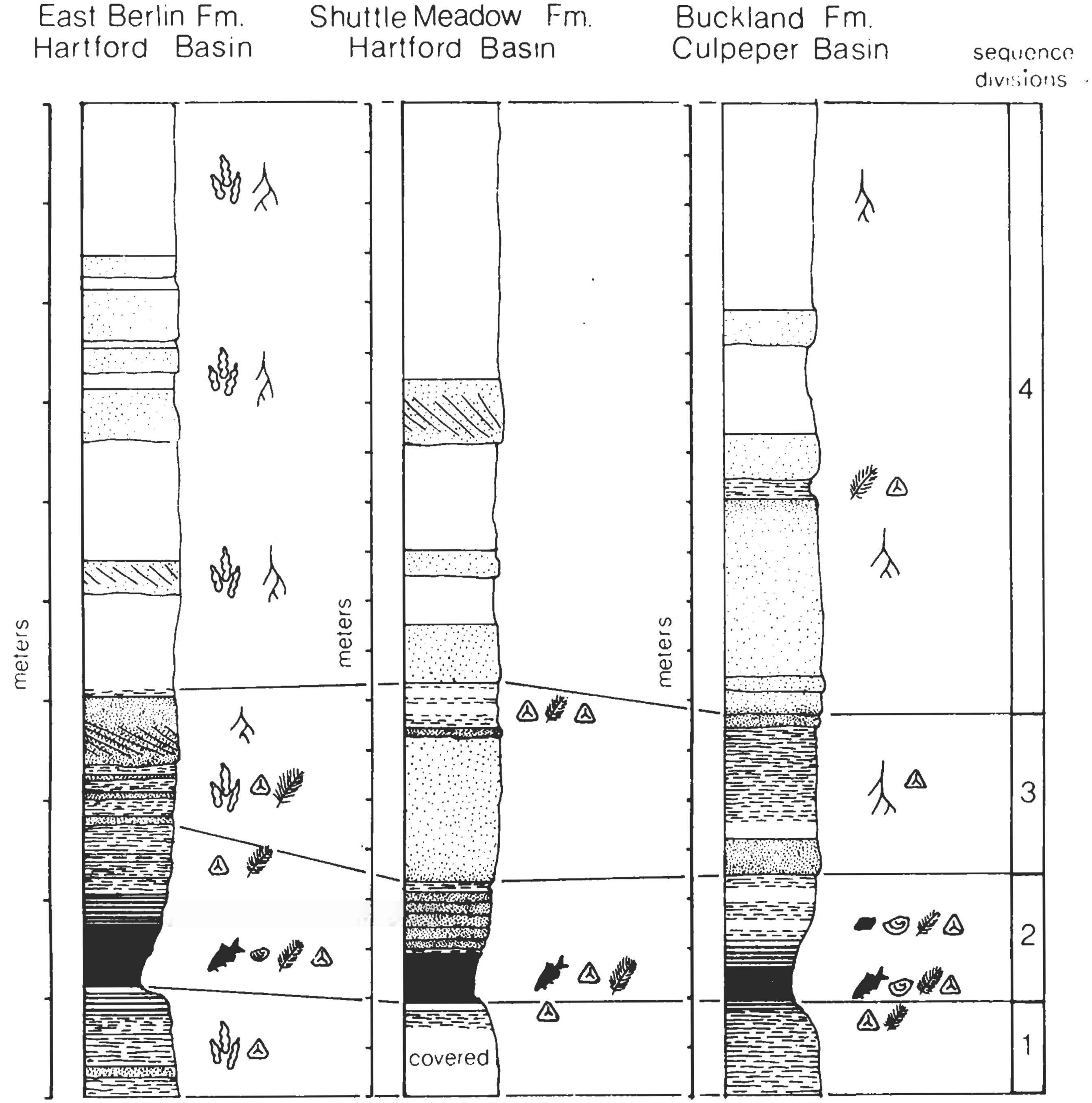

Fig. 24 Towaco-like sequences from other portions of the Newark Supergroup. Lithologic and fossil symbols from Figure 44 except for the conchostracans which are from Figure 23.

East Berlin Formation section adapted from Hubert, Reed, and Carey, 1976; Shuttle Meadow Formation section adapted from Cornet, Traverse, and McDonald, 1973; Buckland Formation section adapted fom Cornet, 1977.

Basin) (McDonald, 1975; Cornet, Traverse and McDonald, 1973; Hubert, Reed, and Carey, 1976), and sedimentary member I-II of the Buckland Formation of Lindholm (1980). For all these cases (except the last,for which the data are not compiled), division 2 of the units thicken towards the down dip edge of their respective basins. The age of all these beds is Hettangian or Sinemurian (Early Jurassic) (Cornet, 1977; Olsen, McCune, and Thomson, In Press).

There are a great many lacustrine sediment types in the Newark Supergroup which I have not mentioned or discussed but which show repetitive patterns in lithology and paleontology very different from Lockatong or Towaco-type sequences. Study of these sequences is crucial to understanding the larger picture into which fit the sediments discussed above.

The differences between Lockatong, Feltville, Towaco, and other Newark lacustrine sequences are partly due to such physical factors as climate, lake basin morphology, and chemical input from source rocks. Analogy with modern lakes is an effective tool for interpreting these differences for physical processes. The other crucial, non-repeating aspect of the differences between Lockatong and Towaco-like sequences are biotic namely the evolution, origination, and extinction of groups of organisms which influence lacustrine sedimentation. Of course, these factors are intimately intertwined, so much so that many aspects of ancient lake ecology and history may be impossible to untangle, especially given the limitations of the fossil record. However, comparative limnology has been a major tool of limnologists working on interdependent processes in modern lakes, and I believe a similar approach can be used to identify some of the features of Mesozoic lakes which are common to them, but which may be missed if they are interpreted strictly according to modern conditions. Clearly this goal cannot be obtained without first identifying the factors that are shared with modern lakes. If a wide range of lake systems deposited over a "short" interval of time, (say the Late Carnian), are examined at least the effects of biological evolution (on the scale effecting lake sediments) could be held constant. Likewise, looking at lake systems in similar physical environments through time should point up the roles of biological change. By deducing from biologically mediated processes in modern lakes we can see if the ancient lakes conform to "predictions" based on these processes. As yet, this approach is essentially untried in paleolimnology, although I hope that a study of the differences between various Newark lacustrine sequences is a step in that direction.

Climatic Change and Lake Ontogeny

The regularity of Lockatong and Towaco cycles and their periodicity in thickness suggest a cyclic and periodic cause of the rise and fall of the lakes which produced them. The analysis of this cause is one of the most difficult and challenging of paleoecological and paleolimnological problems. Limnologists working on modern lakes tend to concentrate on the origin of the lake basin as the proximal cause of the lake - the beginning of what is usually seen as an inexorable succession of stages leading to the filling in of the lake by vegetation and sediments (Wetzel, 1975). Intrinsic, biologically mediated changes have been stressed as the major factors in lake ontogeny (Odum, 1959, 1969) rather than external forcing processes such as climatic change. While this largely successional approach to lake ontogeny (see Drury and Nisbet, 1973) may be valid for ponds and some lakes, for large lake systems such as the African Great Lakes or Newark Supergroup lacustrine sediments it may have little to offer. For example, the thickness of a Lockatong detrital cycle (mean of 5.2 m in the central Newark Basin) is simply too small to represent the infilling of a lake, which during its deeper stages covered more than 6000 km^2 and deposited microlaminated sediments. Here, paleolimnology offers evidence which shows much of the existing work on lake ontogeny to be on a scale inappropriate to large lakes. Lake Michigan is unlikely to meet its end by the action of watercress.

The gross expansion of Lockatong and Towaco lakes most likely was the result of large external forces,specifically climate and tectonics. It is difficult, however, to find evidence which is exclusively explained by only *one* of these causes. It may be futile too; there is no need for there to be only *one* sufficient cause for the phenomenon. At the present, I favor the hypothesis that cyclic changes in precipitation caused the rise and fall of these lakes, a hypothesis first put forth by Van Houten (1962, 1969). Climatic changes act within the context of tectonic changes, which in themselves seem inadequate to explain the periodicity in thickness of the cycles. Periodically fluctuating climate is, at this point, much easier to envision and explain (Croll, 1890; Milankovitch, 1920, 1941; Imbrie, 1979). Indeed, the modern African Great Lakes appear to fluctuate in response to changing climate in ways similar to those hypothesized for Newark lakes. Livingston (1975) provides evidence that 14,000 years ago Lake Victoria was 75 m shallower than now (present maximum depth 88 m) and Hecky and Degens (1973) suggest that Lake Tanganyika was 600 m shallower than now (present maximum depth 1470 m). Increased precipitation appears to be the cause of the great rise in lake level since that time (Livingston 1975) and this increase in precipitation is tied into the periodic climatic cycles of the Holocene (Kukla, 1977; Hays, Imbrie, and Shackelton, 1976; Williams, 1975). As in these modern lakes, I believe that Newark lake basins themselves were created and controlled in depth by tectonism, but that the rise and fall of lake level within that basin was largely controlled by climate.

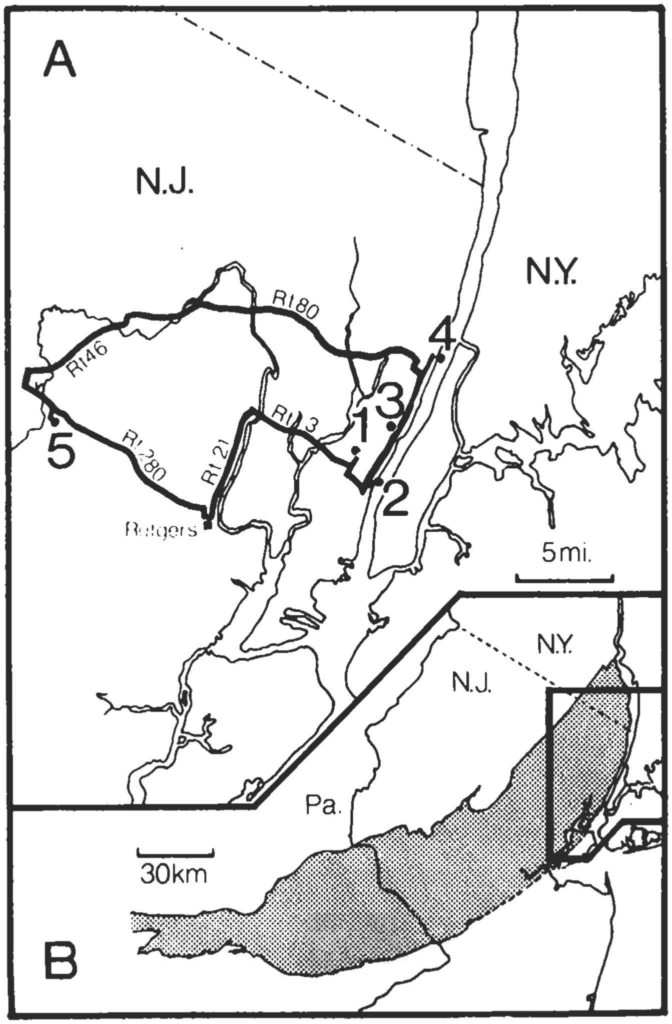

Fig. 25 A, Field Trip Route showing stop locations; B, Newark Basin (shaded) and position of map in A (outlined box at northern end of Newark Basin.)

ROAD LOG

Mileage	
0.0	Leave Rutgers University parking lot; turn left onto Warren Street. Rutgers University, Newark Campus sits on late Norian or earliest Rhaetic sandstones and siltstones of the Passaic Formation.
0.1	Turn left (north) onto Washington Street, pass Newark Museum on left.
0.4	Cross Broad Street onto Harrison Avenue heading east.
0.6	Turn left on to McCarter Highway (Route 21) and head north. Route 21 follows the west bank of the Passaic River along the strike of the Passaic Formation.
3.2	Pass Belleville Avenue. Just north of Belleville Avenue and 1.1 miles east of Route 21 is the old Schuyler Copper Mine worked from about 1720 to about 1900 (Lewis, 1906). The ore occurs in gray arkosic sandstone and gray siltstone invaded by small dikes and sills of diabase. Lewis (1906) lists chalcocite, chrysocolla, and malachite as the major copper minerals with minor amounts of azurite, cuprite, and native copper.
4.8	Fragments of phytosaur skull and reptile footprints found in Passaic Formation "brownstone" quarry near here (Edwards, 1895; Lull, 1953).
6.6	Turn right onto exit road for Route 3. Take ramp for Route 3 east.
7.0	Enter Route 3 east heading towards Lincoln Tunnel. Route 3 cuts across strike through Norian and Late Carnian Passaic Formation. This portion of the Passaic Formation is the lateral equivalent of the entire Delaware River section of the Passaic and upper Lockatong (see Van Houten, this Fieldbook)
8.4	Entering Hackensack Meadows. About 0.2 mi. southwest of this point are excellent exposures of Passaic Formation including a series of gray sandstone beds (ca. 2 m) stained with chalcocite, malachite and azurite. Old (?exploratory) shafts are evident in the outcrops. Lithology of copper-bearing units very similar to beds at Schuyler Mines. I have found reptile footprints assignable to ***Rhynchosauroides brunswickii*** and ***Grallator*** sp. and in addition, horseshoe crab tracks called ***Kouphichnium*** and ***Scoyenia*** burrows in the fine red siltstones surrounding the gray sandstone. Lower red beds of exposure contain well developed caliche horizons similar to those described by Hubert (1977) from more or less contemporary beds of the New Haven Arkose (Hartford Basin). Further southwest, (0.3) mi are additional exposures along former Erie Lackawanna Railroad tracks showing an unusual reverse fault dipping to the west and downthrown on the east. Slickensides confirm the dipslip nature of the fault. Hackensack Meadows, over which Route 3 crosses, are underlain by relatively fine-grained red and minor gray beds of Passaic Formation.
11.7	Ridge just south of here (Secaucus) has exposures of gray sandstones and siltstones which could be lateral equivalent of McLaughlin's (1948) Graters Member.
12.2	Exit right for North Bergen (Plank Road).
12.3	Cross over Route 3 heading east on Plank Road.
12.8	Veer left at fork in road.
12.9	Turn left (north) on Route 1 and 9 (Tonnelle Avenue).
13.6	On right is open cut in Stockton Formation and west portal of tunnel for Penn Central Railroad. Cut exposes upper Stockton beds described by Darton (1883). At east end of cut at tunnel is excellent exposure of the contact between the Stockton Formation and the Palisade Diabase. Stockton beds dip at 15° NW while the irregular contact dips at 60° NW. This contact is locally welded according to Darton (1890) and Lewis (1908). This is one exposure where the Palisade Sill is described as having a dike-like appearance. Actually, these exposures and similar ones nearby are perhaps better explained by a local stepping up of the Palisade Sill as shown in Figure 26.
14.3	Contact of uppermost Stockton with Palisade Sill directly on right (east). Stockton dips 15° NW and the contact dips 45° to 80° NW. This appears to be a continuation of the contact surface exposed at the Penn Central tunnel previously described. Recrystallized arkose of Stockton

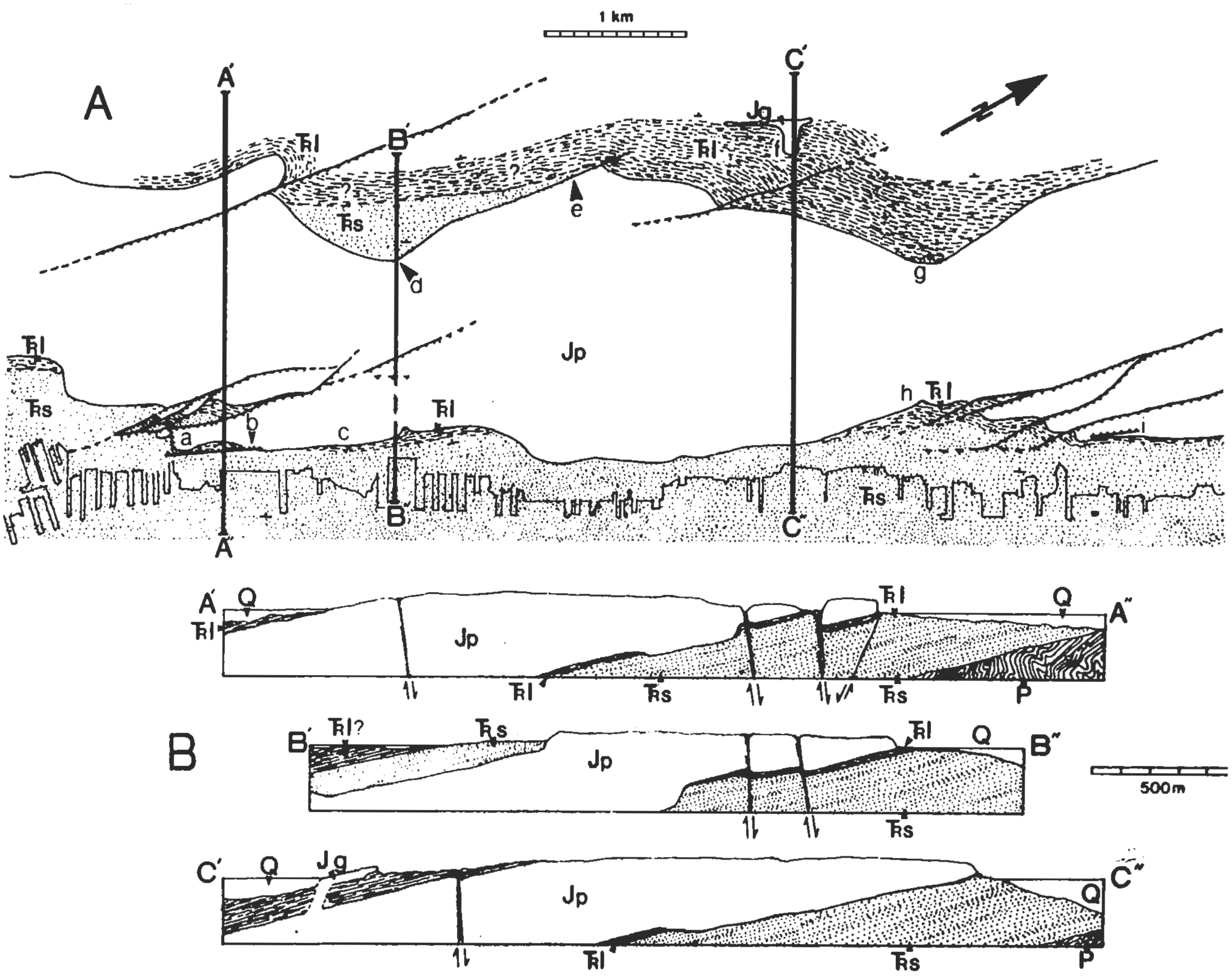

Fig. 26 Map of the Weehawken area (A) and interpretive sections (B): Trs. Triassic Stockton Formation; Trl, Triassic Lockatong Formation Jp, Jurassic Palisade Diabase; Jg, Jurassic Granton Sill; P, metamorphic Palaeozoic rocks; Q, Quaternary sediments of the Hudson River and Hackensack Meadows; a, King's Bluff (stop 2); b, "two runs" exposures below the "duelling grounds"; c, Gratacap's (1886) locality; d, west portal southern tunnel of old New York, Susquehanna and Western Railroad Tunnel; e, exposure at mileage 14.3 of Field Trip; f, Granton Quarry (stop 1); g, west portal old northern tunnel of New York, Susquehanna Railroad; h, Gorge and River Roads exposures (stop 3); i, west dipping normal fault in small quarry, Edgewater.

Formation is sheared and dragged upwards close to contact with fine slickensides indicating down-dropping to the west. There are no indications of movement in the diabase, however. Basal Lockatong hornfels 100 m to the north, dip 15° NW and lie concordantly on the Palisade Sill. A possible interpretation of these exposures might be that the apparent movement in the Stockton occurred during intrusion of the sill.

14.5 Dip slope of Palisade Sill mantled by northwesterly dipping Lockatong Formation. Contact appears concordant from here to Granton Quarry.

15.1 **STOP 1** Abandoned Granton Quarry in lower Lockatong Formation hornfels and overlying Granton Sill. Turn left off Route 1 and 9 into parking lot for Shop-Rite employees at Diana Stores Corporation.

Eleven Lockatong cycles are exposed on the sill-capped hill: seven are exposed on the south facing exposure (Figure 27); three additional cycles are exposed on the east facing exposure; and all 11 cycles are exposed on the north facing exposure but are not accessible without special permission. The base of the section appears to be 38 - 46 m above the contact with the Palisade Sill (Van Houten, 1969). This contact may be following what was, prior to intrusion, the Stockton-Lockatong contact.

According to Van Houten (1969) these Lockatong hornfels include calc-silicate varieties in the middle carbonate-rich part, and extensively feldspathized and recrystallized diopside-rich arkose in the upper part. Some beds of arkose show well developed crossbedding (Figure 28). Because of the buff arkose at the top of nearly every cycle, these are the most visually graphic of the detrital cycles seen on this field trip; here the many correlated changes occurring though individual cycles can be easily seen (Figure 29).

Cycles 3 and 7 (Figure 29) have produced representatives of all the known (skeletal remains of) Lockatong

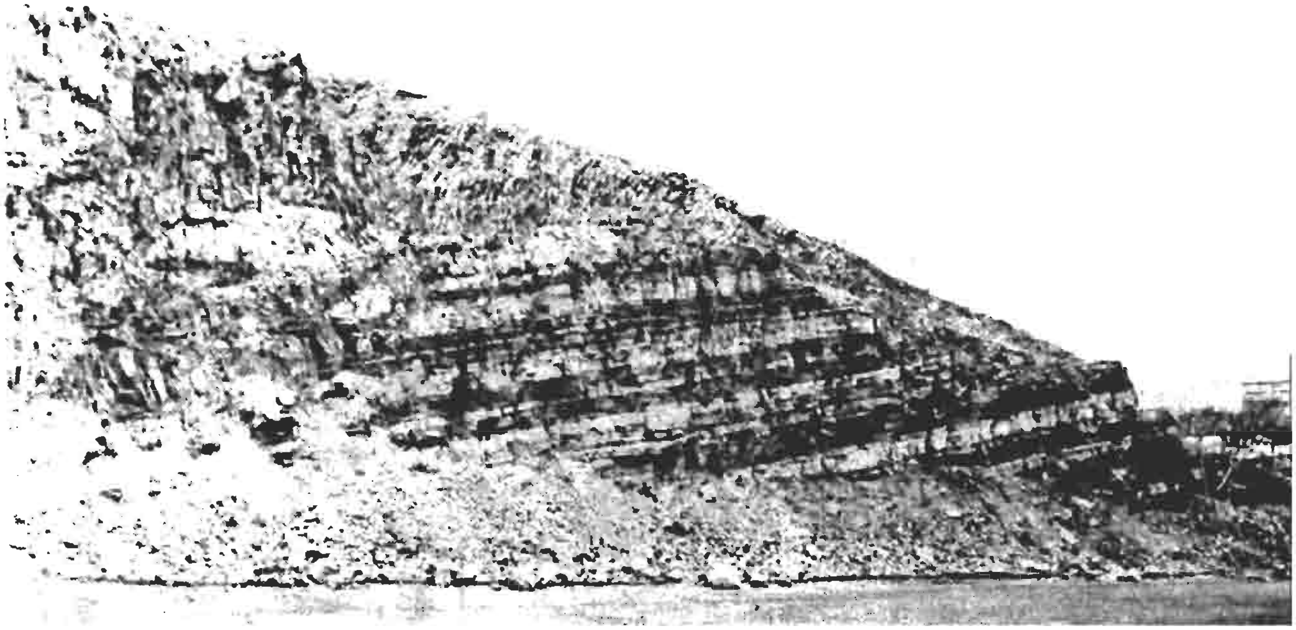

Fig. 27 South facing wall of remnant of Granton Quarry showing detrital clycles G1-G7 and Granton Sill. View is to the northeast and dip-slope of Palisade Sill is visible in the background.

Fig. 28 Cross bedding in buff arkose of cycle G9 (see Figure 29). Exposure on north face of quarry remnant.

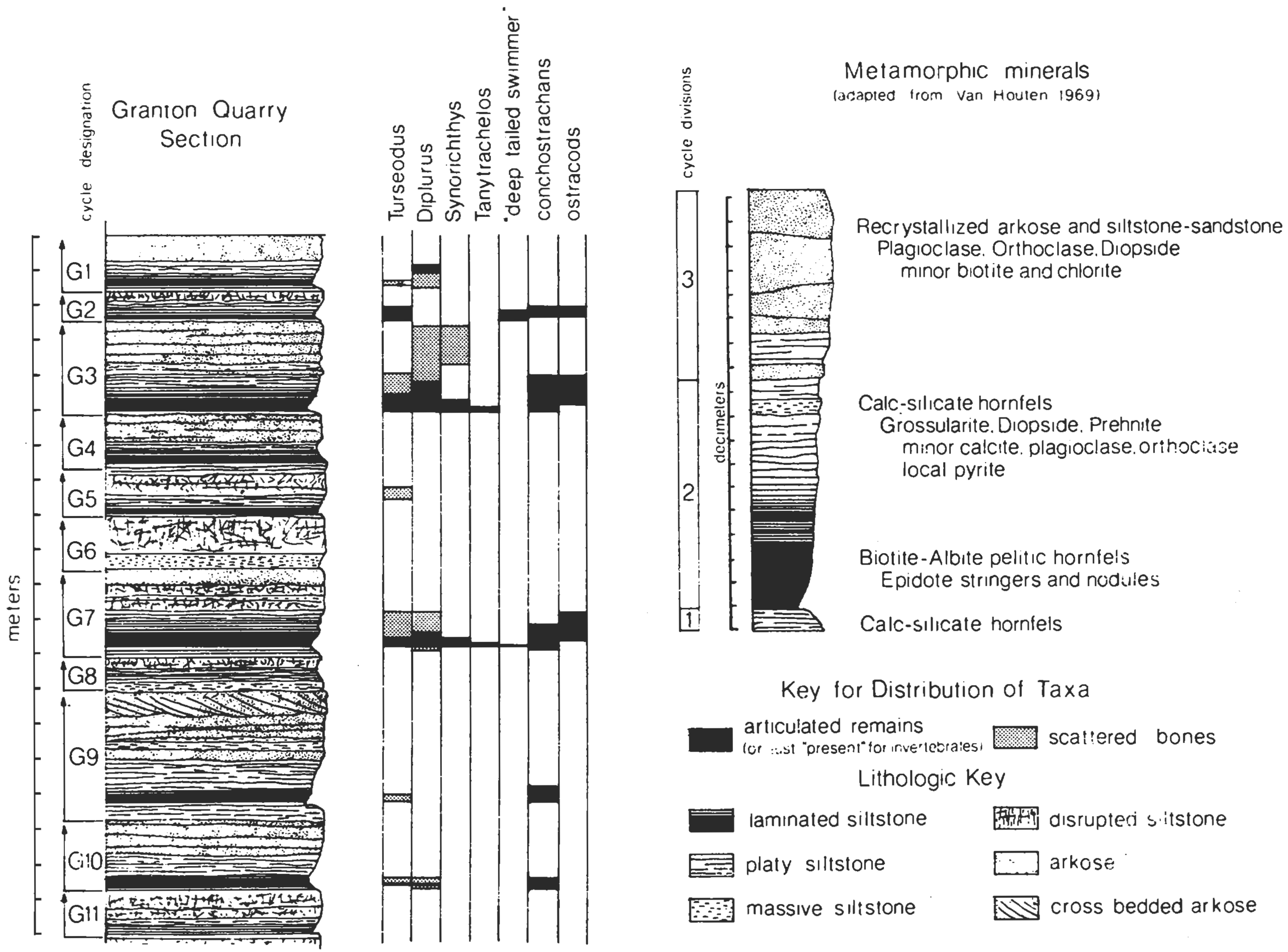

Fig. 29 Granton Quarry section showing fossils and distribution of metamorphic minerals in generalized cycle.

Fig. 30 Newly discovered virtually complete *Tanytrachelos* skeleton from the basal portion of division 2 of cycle G7. Neck is partly disarticulated and twisted back over body so skull rests just right of the middle of the back.

This specimen was discovered by James Leonard and Steve Steltz this year.

holostean *Semionotus*, and the amphibian *Eupelor*. The basal portions of division 2 of both of these cycles have extremely high densities of fossil fish, especially the coelacanth *Diplurus newarki* Schaeffer (1952). Small reptiles are also surprisingly abundant (Figure 30). Many important fish and unique reptile skeletons have been discovered here by dedicated amateurs, and donated to various museums through the years (Colbert, 1965, 1966; Schaeffer, 1952; Schaeffer and Mangus, 1971; Colbert and Olsen, In Prep.; Olsen and Colbert, In Prep.).

At the south-facing exposures, cycles 1 and 2 are broken and injected by diabase of Granton Sill (Van Houten, 1969). Notice the absence of prominent folding at the diabase-sediment contact. The total thickness of the sill is 20 m.

One or two bedding plane thrust faults, always thrusting to the east, are present in division 2 of nearly every cycle at Granton Quarry. Slickensides are usually present and indicate that movement occured parallel to dip. All joint sets are cut by these thrusts, their displacement indicates each fault has a net slip of .5 to 1.5 cm. This type of minor thrust fault is evident in virtually all Newark Supergroup lacustrine cycles and can be seen at every stop of this trip.

15.2 Return to Route 1 and 9, turn right and head south.

17.7 Exit for Lincoln Tunnel and Route 495. Turn right off Route 1 and 9 (Tonnelle Avenue) onto entrance ramps and follow signs around for Lincoln Tunnel onto Route 495. Cloverfleaf at this intersection rests on Lockatong hornfels and Palisade Sill (Fluur, 1941).

18.2 Open cut for Route 495 in Palisade Diabase. Construction of cut exposed a number of easterly down-dropping dip slip faults which were described by Fluur (1941).

19.2 Take right hand exit "Last exit in New Jersey" (Pleasant Avenue, Weehawken); get immediately in right lane after exit. Reentrant in Palisade Escarpment at this point created by differential weathering along a series of dip slip faults, the cumulative dip slip amounting to about 70 - 80 m.

19.4 Turn right onto Boulevard East (heading south). This street parallels one of the larger faults, in this case one responsible for the abrupt truncation of the western portions of Kings Bluff directly to the left (east) (Flurr, 1941).

19.6 Turn left at light onto Baldwin Avenue. According to Fluur (1941), construction along this road revealed a small fault striking nearly E-W.

19.7 Cross Conrail tracks and follow road around to left. Watch out for trucks and trains!

19.9 **STOP 2** Kings Bluff, Weehawken. East face of Palisade ridge with exposures of long series of Lockatong cycles, tongues of Stockton-like beds, and alternating concordant-discordant contacts with the Palisade Sill. Park in lot on west side of road near the railroad tracks.

This is the first of three stops designed to show the lateral continuation of individual detrital cycles and the lateral change in sedimentary and metamorphic facies.

Lockatong and Stockton sediments and their contacts with the Palisade Sill are exposed at numerous places along the Palisade escarpment from Hoboken, New Jersey to Haverstraw, New York. Study of these exposures is permitting a cycle-by-cycle correlation of the Lockatong for at least 15 km of this distance; the cycles mapped so far are designated informally in Figures 31, 32, and 33. To the south at Hoboken the Palisade Sill rests near the base of cycles 5 and 6 (Figure 31). To the north towards the Lincoln Tunnel Toll Plaza, the contact drops more than 250 m into the Stockton Formation. At Kings Bluff, this contact abruptly rises again to cycle 0, staying within division 2 of this cycle for at least 300 m north. The olivine zone of the Palisade Sill produces an obvious bench along the escarpment, essentially paralleling the lower contact of the sill as observed by Walker, 1969 (Figure 31).

Note the thin sill which branches off from the main sill intruding between cycles a and b. This sill definitely runs north for at least 400 m and was encountered during the excavations for the ventilation buildings for the Lincoln Tunnel (Figure 31) (Fluur, 1941). It may go at least another 200 m (Figure 36).

About 30 m south of the ventilation buildings, my colleagues and I opened a quarry (Figure 34) in cycles 5 and 6 for Lockatong fossils as part of a larger project studying fish evolution headed by Dr. Keith S. Thomson of Yale. So far, more than 3000 fish and reptiles have been recovered from the two cycles. The position of all the collected vertebrates was carefully noted with preliminary results shown in Figure 35. Note the very specific sequence in which various kinds of fossils appear and disappear through the section, the difference in dominant taxon in cycles 5 and 6, and the correlation of fish and reptile preservation with sediment lamination; this pattern is present at all exposures of these cycles.

The color of the microlaminated beds at the Yale quarry is slate gray (when fresh) due to finely divided particles of organic material (less than 1%). The color remains essentially the same after soaking in HCl. Bone is black in color and conchostracans are preserved as silvery compressions. To the south, near where the Palisade Sill cuts down into lower cycles, the color of division 2 of cycles 5 and 6 darkens, all traces of black organic material disappears, bone turns white, and conchostracans are preserved only as impressions; in HCl the rock turns white. The same phenomenon can be seen just north of the ventilation building. Here the poorly contrasting microlaminae in division 2 of cycle 5 are altered to bold white and black and the laminite is visibly recrystallized. Despite the gross alteration, vertebrates remain well preserved and occur in the same sequence as at the Yale quarry. The alteration at the north side of the ventilation building appears to be associated with a west dipping normal fault which lies within a few meters east of these exposures, and not with its proximity to the Palisade Sill.

This fault was well exposed during construction of the ventilation buildings and is described in Thomas Fluur's excellent work on the geology of the tunnel (1941). According to Fluur (p. 197), "The strike of the fault is approximately N 35° E and the dip 65° NW. Slikensides on the fault indicate that the movement had carried the block on the west side of the fault downward in respect to the east side with practically no horizontal component of movement. The fault is accompanied by numerous joints in both the shale and the sandstone members... The movement was sufficient to bring up sandstones from a horizon much below that of the baked shales and in the movement the edges of the shale members were dragged upwards, so that close to the fault they show a maximum dip of 55° instead of the usual 15°." Indeed at the exposures just north of the ventilation buildings the dip of the beds of cycles 6 - 3 is increased to 35°-40° from the 15° seen at the Yale quarry.

The projection of this fault along strike intersects the Palisade escarpment about 200 m north of the ventilation buildings (Figure 31). At the point of intersection, there are, in fact, a series of deformation features all showing downward displacement to the west (Figure 36). Two small dikes cut the arkosic beds between cycles a and 6 and their strike and dip is parallel to that of Fluur's fault. A hypothesis which places the formation of these faults and folds (Figure 36) at or prior to the intrusion of the Palisade Sill explains the physical alteration of the beds along the fault and their apparent invasion by diabase.

20.2 Return to Boulevard East and turn right (north). Follow dog-leg to right and left and remain on Boulevard East, heading north.

20.9 Alexander Hamilton was shot by Aaron Burr on the morning of July 11, 1804 in the park, overlooking the Hudson just south of this point.

21.6 At base of Palisade escarpment, at this point, is an outcrop of cycles 5, 6, and 0 which have produced the usual vertebrate remains, including an excellent *Tanytrachelos* from cycle 6. This locality was discovered by Friedrich Braun about 1886 (Gratacap, 1886). Large collections were made by Braun, primarily of *Semionotus* from cycle 6, and later split between Charles Schuchert of Yale and the American Museum of Natural History.

22.3 Turn right opposite 60th Street and head down road leading down to River Road. Take River Road north.

22.4 Olivine zone in Palisade Sill on left. Stockton Formation outcrops along road shortly thereafter.

23.3 Old quarry at Guttenberg on left. Exposures show contact of Palisade Sill with coarse arkose of Stockton Formation and thin subsidiary sill within Stockton.

23.7 Ridge of coarse, crossbedded Stockton arkose on left.

23.9 Palisade Sill contact jumps up again into Lockatong on left.

24.3 **STOP 3** Gorge and River Roads exposures of cycles 1 ' - 6 and a and b. Turn right into empty lot outside entrance for Celotex Corperation.

Cycles 1 ' - 6 exposed along Gorge Road and cycles a - c on west side River Road opposite Mobil Service Station (Figure 37). These are the same cycles seen at Stop 2. Cycles 5 and 6 are virtually unchanged with the exception of an increase in ostracod density in the upper parts of division 2 of both cycles, fewer fish in division 2 of cycle 6, minor color changes, and the presence of calcareous nodules in division 2 of cycle 5. Cycles 1, 3, and 4 appear unchanged from Stop 2, while cycle 1 ' is less disturbed and cycle 2 has more fish than at Stop 2.

In contrast with the relative lack of change from Stop 2 in cycles 1 '-6, the siltstone units between cycle 6 and cycle a (Figures 32 and 33) are nearly completely replaced by 5.5 m of arkose with crossbedding indicating transport to the west and southwest (Van Houten, 1969). I believe this arkose tongue and the thin siltstones present in this interval at Stop 2 to be the lateral equivalent of chemical cycles present in the central Newark Basin. Cycles a, and b appear virtually the same as at Stop 2.

The detailed correspondence between beds and vertical changes in lithology and paleontology in cycles 5 and 6 (Figure 38) between Stops 2 and 3 is illustrative of the large area over which the factors responsible for the details of the cycles operated. The region represented by stops 2 and 3 was evidently far enough from shore (during the deposition of division 2) that the normal heterogeneous depositional environments of the shore had virtually no influence on cycles 5 and 6. This, in turn, is indirect evidence that the size of the lake which produced cycles 5 and 6 was considerably larger than the 15 km traced so far.

Note that Gorge Road follows fault-line ravine north of Lockatong exposures; eastern block is downthrown about 53 m (Van Houten, 1969).

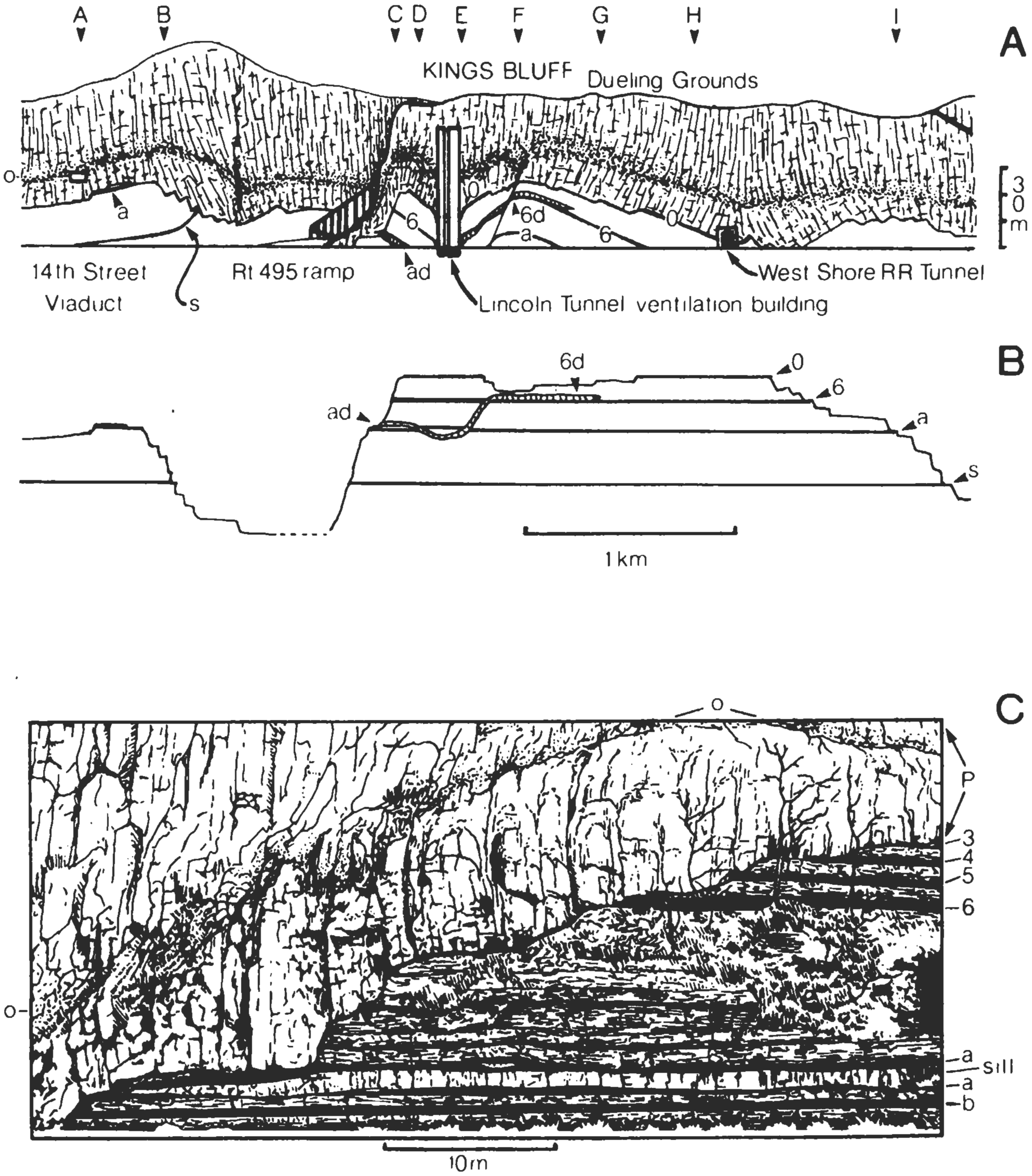

Fig. 31. A, view of Palisades Escarpment looking northwest -note vertical exaggeration: (A, exposure below west portal 14th street viaduct, Hoboken; B, exposures west of west end of Chestnut Street, Hoboken; C, Kings Bluff, Weehawken; D, position of "Yale quarry" in cycles 5 and 6, Weehawken, E, exposures of cycles 0-6 at north side of ventilation building, Weehawken, F, "two runs" exposures of cycles 4-f and position of folded beds in Figure 36, G, position of Gratacap's (1886) Weehawken fossil fish locality in cycle 6, H exposure of cycle 0 at south side of west portal southern tunnel of New York, Susquehanna and Western Railroad; I, area where diabase cuts down into Stockton Formation; O, a-6, cycles thus designated; 5, Stockton-Lockatong contact; ad, thin diabase sill intruding cycle a; 6d, thin diabase sill intruding cycle 6; 0, olivine zone of Palisade Sill

B, section from Hoboken to West New York reconstructed with fault displacement removed showing large irregularities of hornfels-diabase contact. Abbreviations as in A.

C, section exposed on east face Kings Bluff show Palisade Diabase cutting obliquely accross cycles 3-b and thin sill intruding cycle a: P, Palisade Diabase; other abbreviations as in A.

Drawing is adapted from Darton 1880.

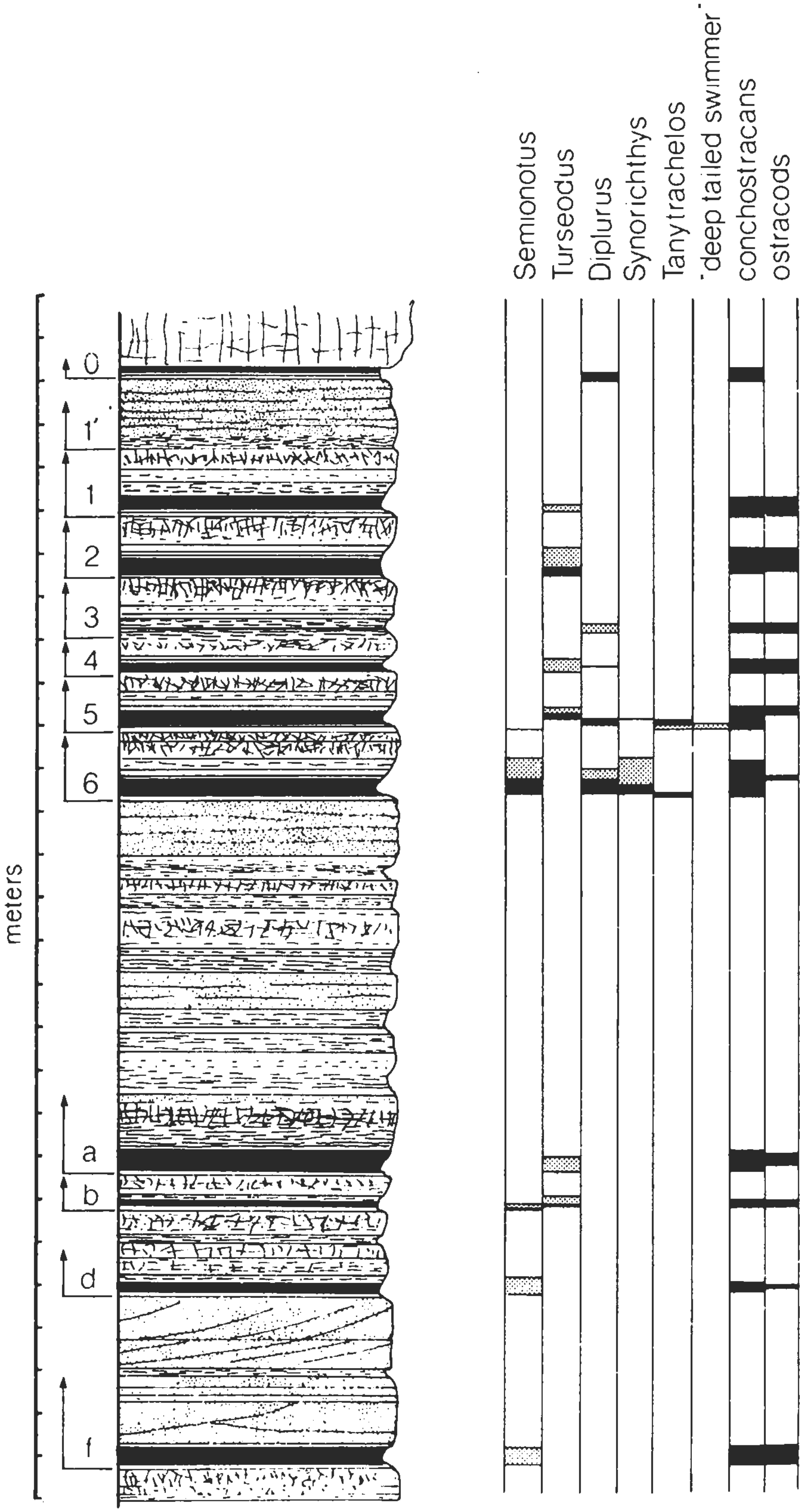

Fig. 32 Section showing position and nature of fossils, Kings Bluff, Weehawken. Symbols as in Figure 29.

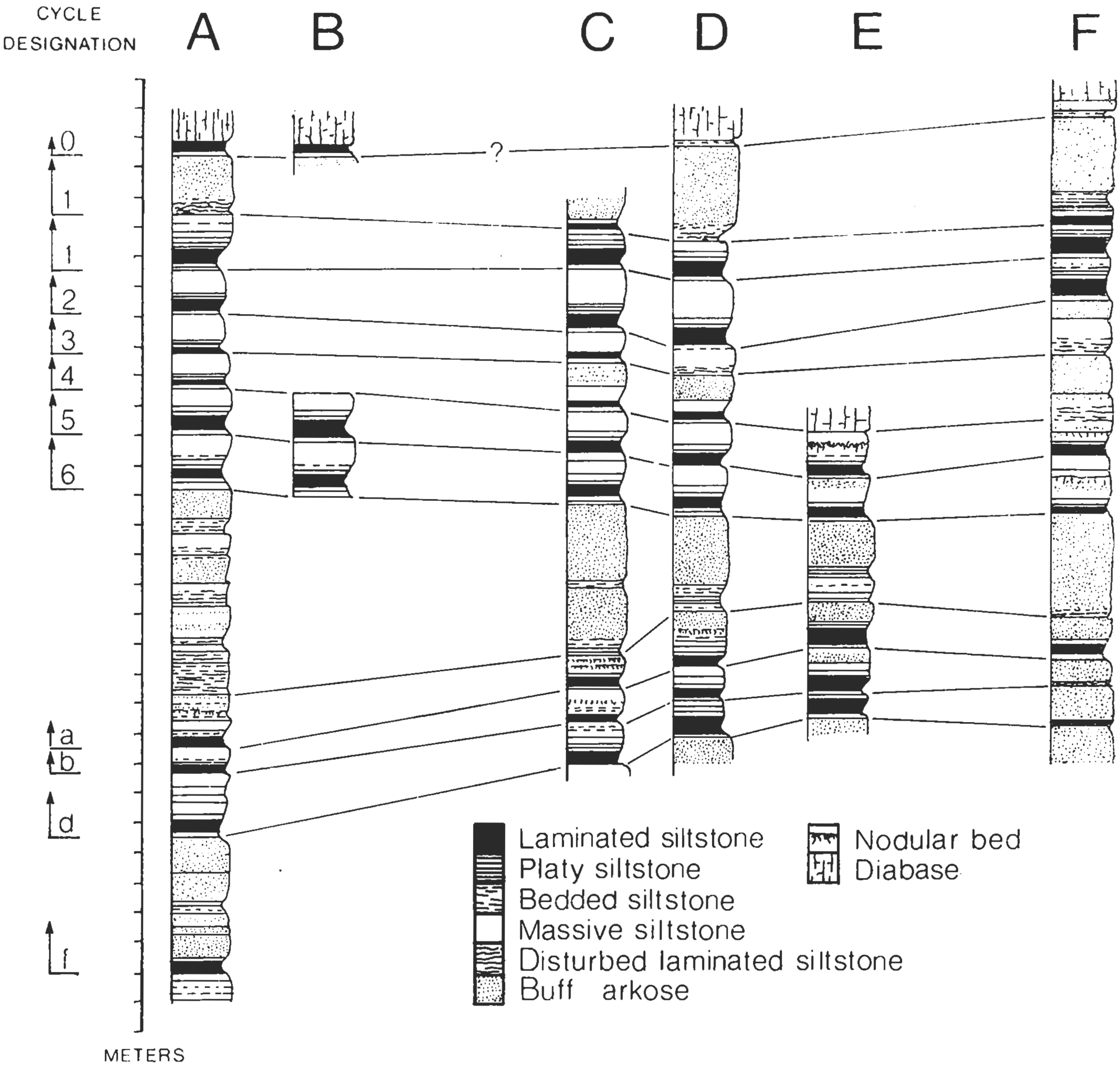

Fig. 33 Correlation of cycles from Kings Bluff, Weehawken to Ross Dock, Fort Lee; A, Kings Bluff exposure; B, Gratacap's (1886) Weehawken locality and exposure of cycle 0 to the north; C, Gorge and River Roads exposure, Edgewater; D, exposure at east portal northern tunnel for old New York, Susquehanna Southwestern Railroad; E, "old trolley route" below old Palisades Amusement Park, Fort Lee; F, exposures west of Ross Dock, Palisades Interstate Park, Fort Lee. Exposures A and F are 12 km apart; the other sections are positioned to scale.

24.4 Turn right back onto River Road and head north.

24.6 Large xenoliths exposed on left (west) in excavation behind Virginia Lee Lace Co. (Van Houten, 1969).

24.8 Passing over eastern portal of tunnel for former New York Susquehanna and Western Railroad. Directly under bridge for River Road is complete section of Lockatong cycles 1'-6 and a. This same section is then repeated by a fault striking north. Cycle 2 is unusually fossiliferous, producing large numbers of well preserved *Turseodus* and fragmentary large *Diplurus*. At west portal of tunnel is a large open cut in upper Stockton and lower Lockatong. Contact with sill dips 65° NW while Stockton and Lockatong dip 15° NW. These exposures appear to be a repeat of the pattern seen at mileages 13.6 and 14.3 as shown in Figure 26.

25.2 Old quarry on left with excellent exposures of cycles 4 - f and underlying Stockton Formation. Small fault exposed at back of quarry which drops down the western block.

26.3 Up hill on left on west side of Undercliff Avenue is long series of outcrops along abandoned trolley route (Van Houten, 1969). Exposures include upper Stockton Formation and lower Lockatong including cycles 5 and 6 and a, b, and c. The base of Palisade Sill is well exposed with large xenolith of cycle 5 suspended about 5 m above Lockatong-sill contact. Cycle 5 below contact contains scapolite-

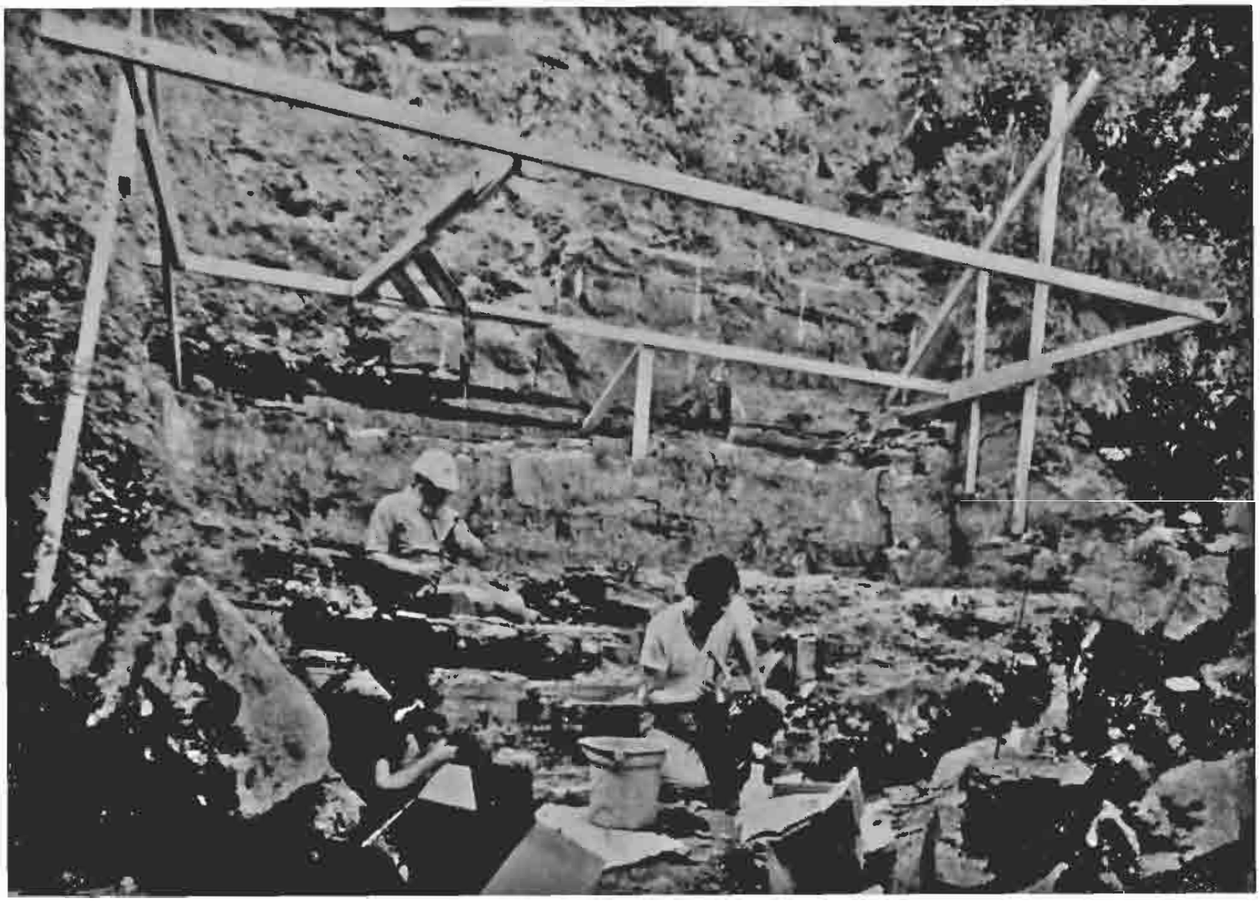

Fig. 34 "Yale quarry" during summer of 1979. From left to right Amy R. McCune, Donald Baird, and Keith S. Thomson. Wooden frame is device for recording horizontal position of specimens in excavation. Rear portions of frame rest on division 2 of cycle 5. Donald Baird is sitting on upper parts of division 2 of cycle 6.

aegirine and Na-feldspar hornfels, while xenolith of same unit consists of very course grained biotite, Na-feldspar hornfels with minor pyroxenes, and beds of cordierite, biotite Na-feldspar hornfels (Van Houten, 1969).

27.5 Turn right off Right Road into entrance for Palisade Interstate Park. Follow park road around to north. A significant portion of a large phytosaur skeleton was found in upper Stockton beds near here in 1911. The skeleton, named *Rutiodon manhattanensis* by Friedrich von Huene (1913), is not generically determinate because it lacks a skull.

Reentrant in Palisade escarpment at this point is due to a few east dipping normal faults.

27.6 Olivine zone of Palisade Sill on left. Diabase below olivine zone has distinct laminated appearance.

28.0 Irregular contact of Palisade Sill with Lockatong Formation -stratum uncertain (Figure 39).

28.1 Pass under George Washington Bridge.

28.2 Additional exposures of Lockatong-sill contact on left -largely conformable. On the right, at the base of the hill, is a foot path along which are exposures of buff arkose and red and purple siltstone of the upper Stockton Formation. These are the most southerly exposures of a facies of the Stockton Formation visible along the Hudson from here to Haverstraw, New York (Olsen, Baird, Selden, and Salvia, In Prep.).

28.4 Circle in park road at base of shear face of Palisade Sill. Take road which veers off on right towards Ross Dock.

28.7 **STOP 4** Ross Dock, Palisade Interstate Park. Lunch and extensive exposures of cycles 1 ' - 6 and a - c and irregular lower contact of Palisade Sill. Park in lot, have lunch, then take stone steps up hill (west) to road at level of circle (River Road of park) and walk north along road to exposures of Lockatong (Figure 40).

Proceed north along road, slowly walking down section (Figures 40 and 41). Cycle 1 ' and overlying 4 m of arkose with no sign of cycle 0 which presumably pinched out or was cut out south of here. Cycle 1 is present but poorly exposed. Cycle 2 is very well exposed and contains the same fossils as at mileage 24.8, although there are fewer whole *Turseodus*. Cycles 3 and 4 are evidently replaced by buff, crossbedded arkose. Cycles 5 and 6 very well exposed. Middle part of division 3 of cycle 6 contains distinctive nodular calcareous bed resembling caliche. Cycle 5 still shows the same basic sequence of beds and vertebrates as previous stops, but cycle 6 is noticeably coarser with fewer less well laminations and there are less fish. Upper division 1 of cycle 6 has produced a partial arthropod of uncertain relationships about 20 cm long.

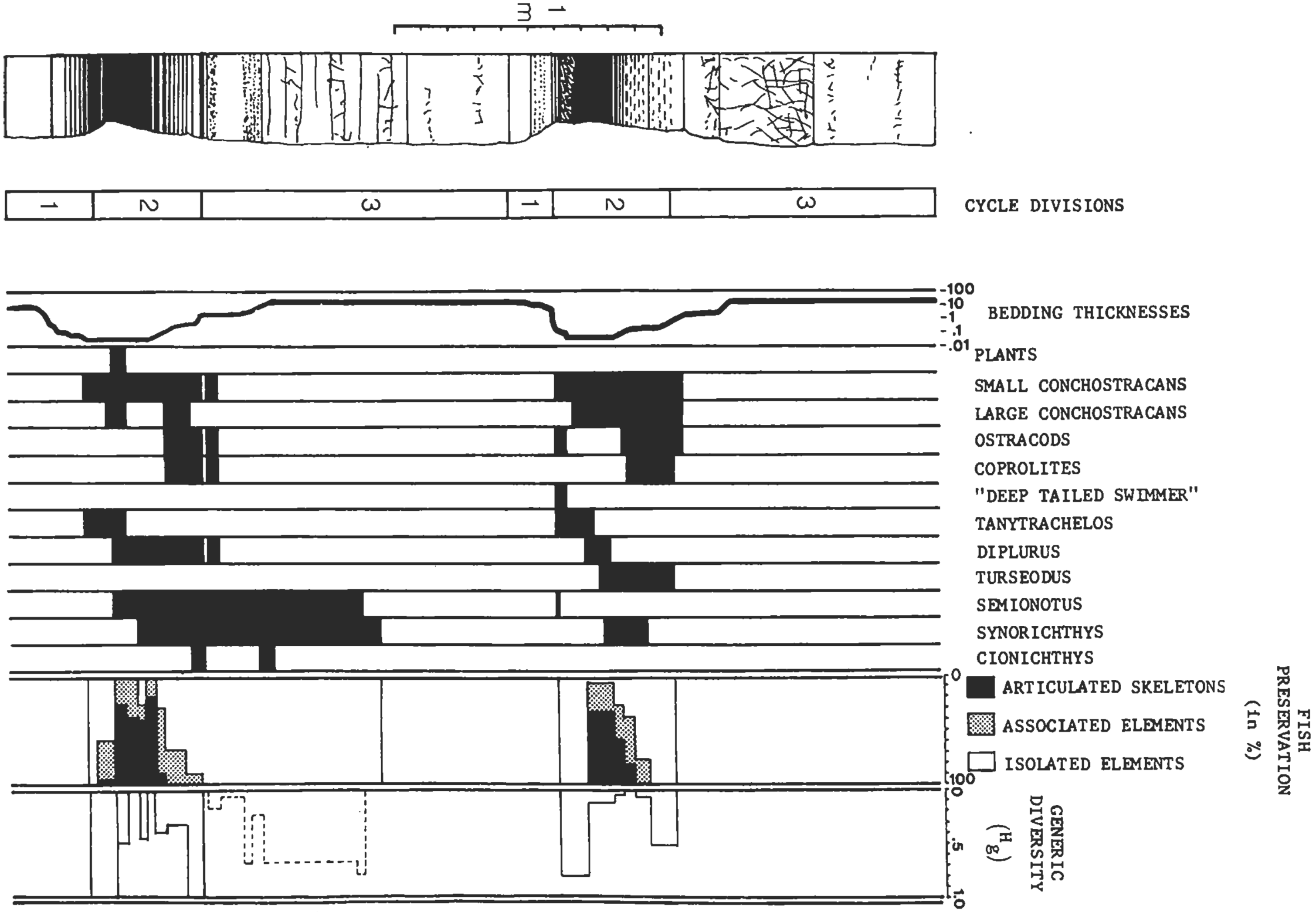

Fig. 35 Preliminary results of excavations in cycles 5 and 6, Kings Bluff, Weehawken. Symbols as in Figures 29 and 38. Generic diversity (Hg) is the Shannon—Weaver (1949) information index.

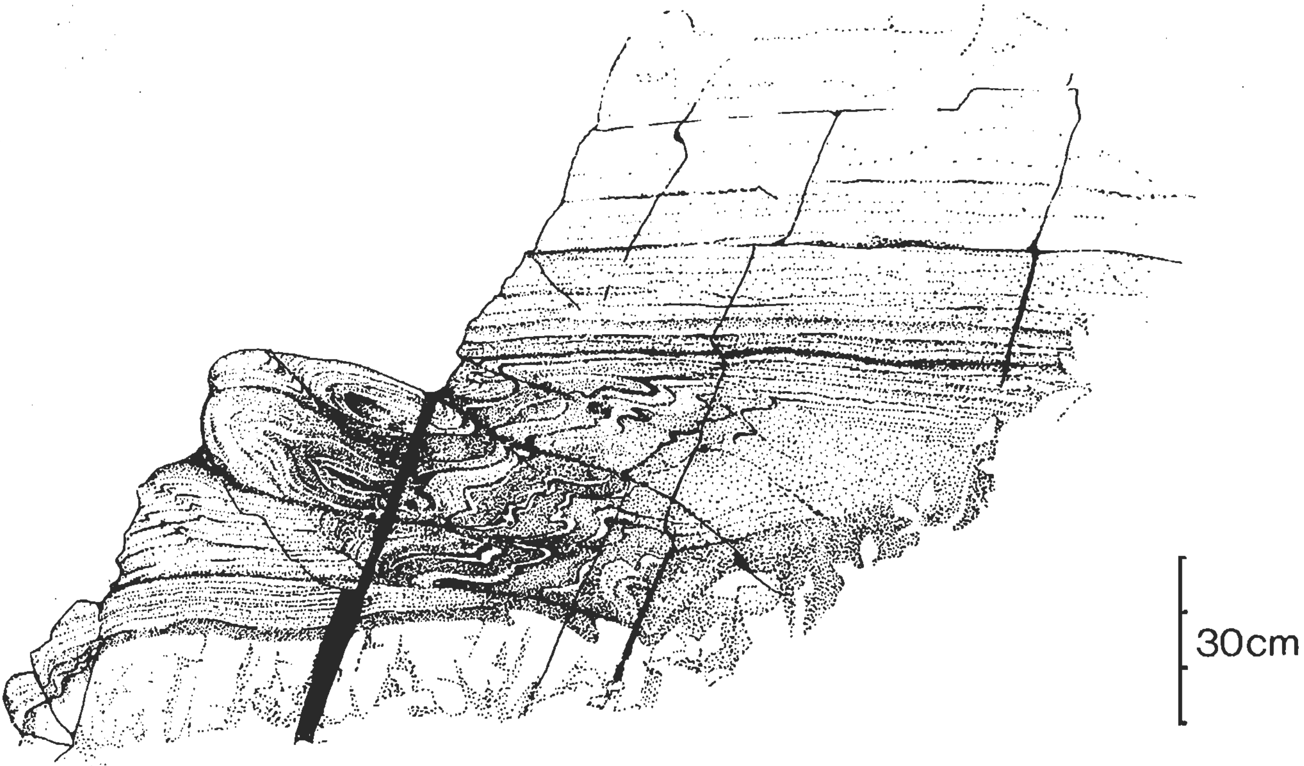

Fig. 36 Folding associated (but not necessarily causally connected) with westward dipping normal faults at "two runs" outcrops (see Figure 31). Plane of outcrop is parallel to regional strike of beds.

The tongue of buff arkose between cycles 6 and a is thinner than at Stop 3 and coarsely crossbedded. Lower arkose cuts down into cycle a at this exposure, eliminating its division 2 (Figure 42). Mean paleocurrent vector for these crossbeds is N 59° W (based on 8 readings).

Cycle a is penetrated by numerous *Scoyenia* burrows (which were definitely not present at mileage 26.3) as are what appear to be cycles b and c. We are clearly in the shallow water facies of division 2 of cycles a - c at this point but only just leaving the deep water facies of division in cycles 2, 5, and 6.

Cycle a shows well developed fracture cleavage in division 1. Cleavage dips 25° to 30° and strikes S 78° W. Cleavage is strata-bound but discontinuous, passing laterally into breccia or non-cleaved beds. What is the significance of these structures?

The facies trend in the Lockatong from Stops 2, 3, and 4 is from a more central basin facies to a marginal facies. The monotony in horizontal continuity gives way laterally to heterogeneity (Figures 33 and 38). Those cycles with the best developed microlaminae and the best preserved fish at Stop 2 are also those which persist the longest with the least change.

29.9 Return to park entrance. Leave park and turn right.

30.0 Turn left onto Main Street (Bergen County Route 11), proceed west.

30.5 Turn right onto Lemoine Avenue, continue north crossing over west portal George Washington Bridge.

30.8 Turn left (west) onto Cross Street. Keep left.

31.4 Veer left onto entrance ramp for Route 95 - 80. Proceed on Route 95 S.

32.4 Open cut in Palisade Sill and Lockatong hornfels. According to Van Houten (1969), hornfels include grosularite-andradite, prehnite, and diopside varieties. Lockatong cycles fossiliferous, as usual, and these cycles may tie in with Granton Quarry cycles (Stop 1).

34.0 Veer right onto exit for Route 80.

34.5 Beginning of type section of Passaic Formation (section A Olsen, this Fieldbook) in open cuts for Route 80.

37.6 Section B of type section of Passaic Formation.

38.7 Section C of type section of Passaic Formation.

42.5 Section D of type section of Passaic Formation.

44.2 Garrett Mountain visible on left (south), Passaic Falls is on the right (north). The upper Passaic Formation of Rhaetic age (latest Triassic) has produced near here a series of well preserved skeletons of the highly specialized procolophonid reptile *Hypsognathus* (Colbert, 1946). About one skeleton or skull is found per decade.

44.7 Contact of Passaic Formation with overlying Orange Mountain Basalt on left (south). This is section E of the type section of the Passaic Formation. A series of faults cut the Orange Mountain Basalt here, some of which are visible in the cut on the left, just west of the Passaic-Orange

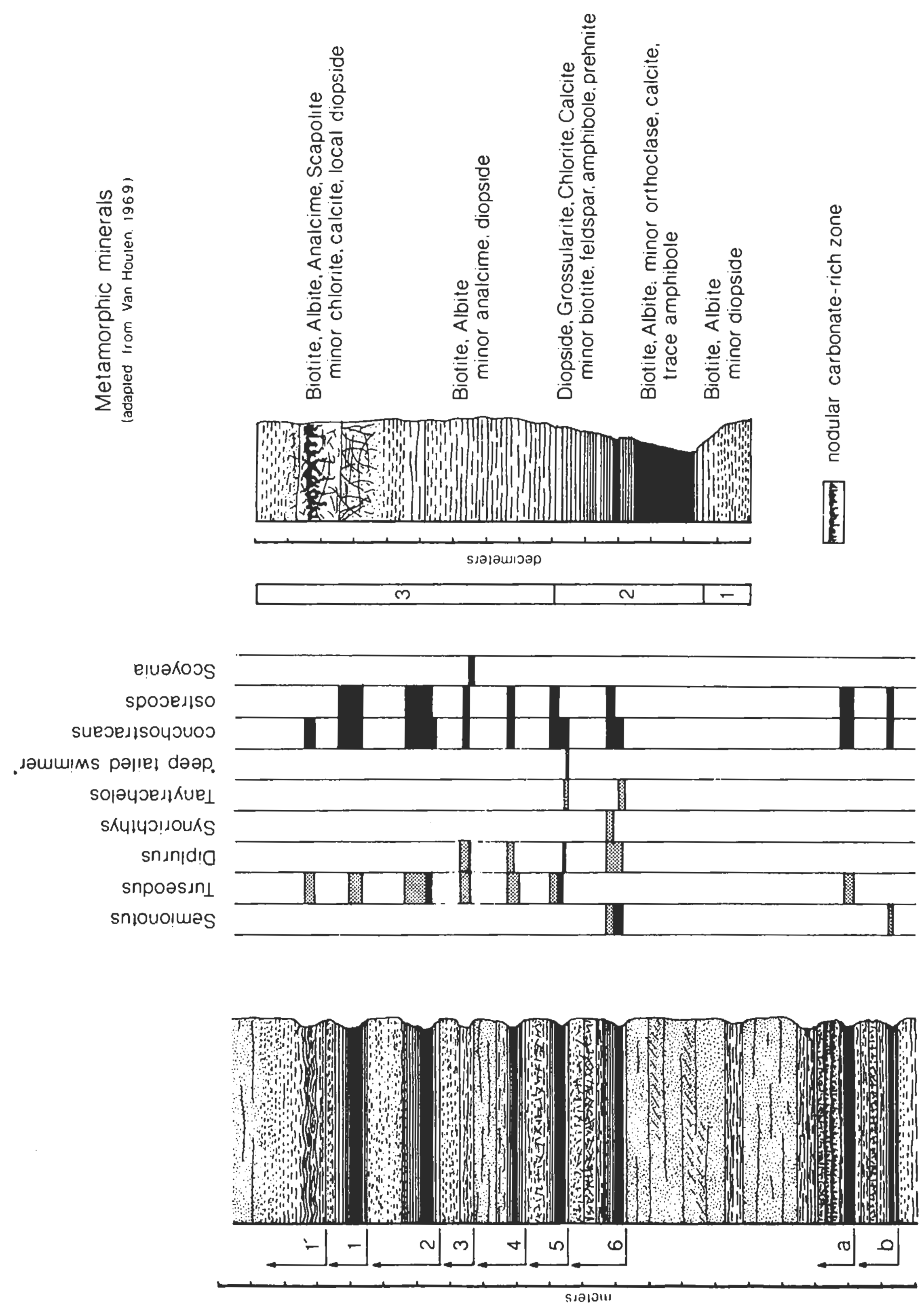

Fig. 37 Section at Gorge and River Roads, Edgewater showing position and nature of fossils and metamorphic minerals in generalized cycle. Lithologic symbols as in Figures 24 and 39.

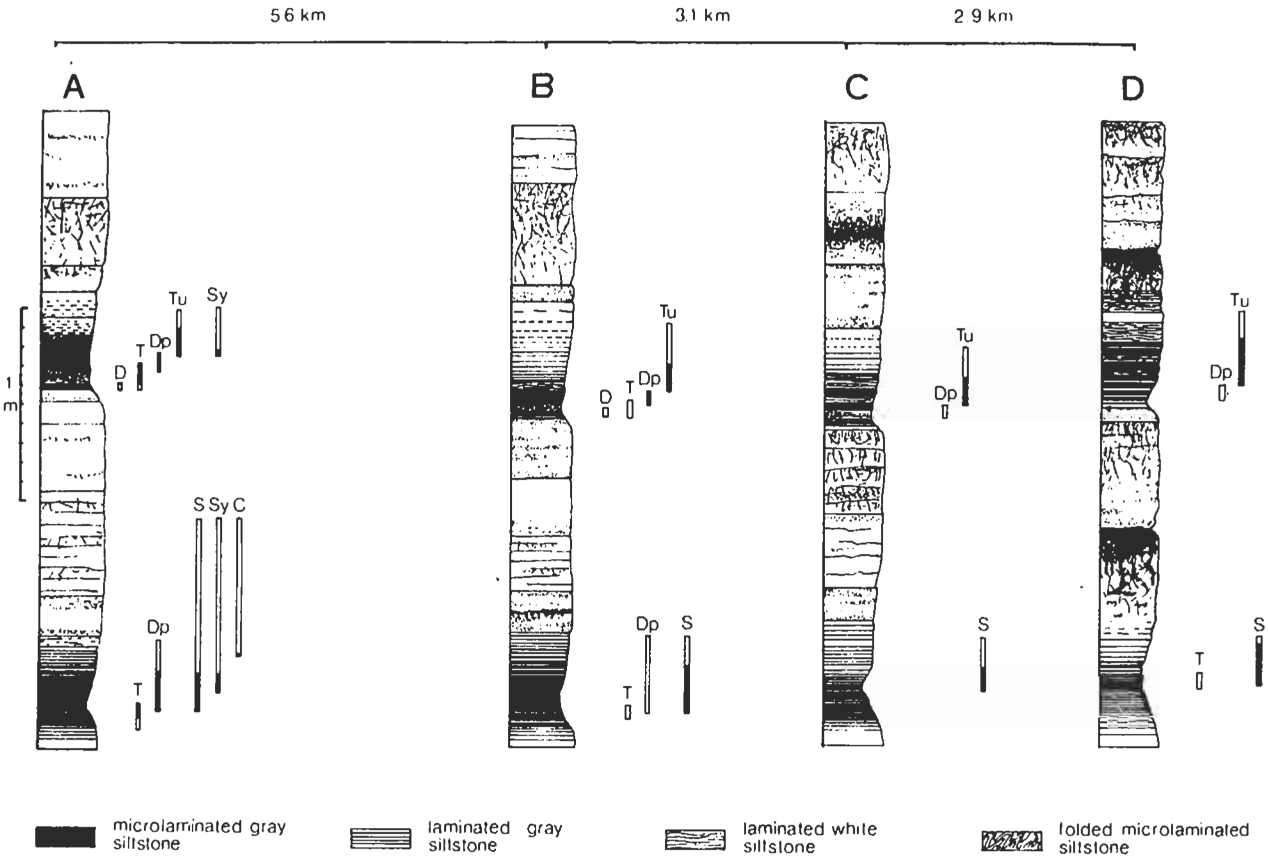

Fig. 38 Comparison of section of cycles 5 and 6 showing distribution and preservation style of fish: A, Kings Bluff, Weehawken; B, Gorge and River Roads, Edgewater; C, "old trolley route", Fort Lee, D, west of Ross Dock, Palisades Interstate Park, Fort Lee.

Abbreviations for fossils as follows: D, "deep tailed swimmer"; Dp, *Diplurus;* C, *Cionichthys;* T, Tanytrachelos; TU, *Turseodus;* Sy, Synorichthys; S, *Semionotus.* Open column under abbreviation of taxon stands for presence of dissarticulated fish while solid column indicates the presence of complete specimens.

Lithogic symbols as in Figures 29 and 30 except as shown.

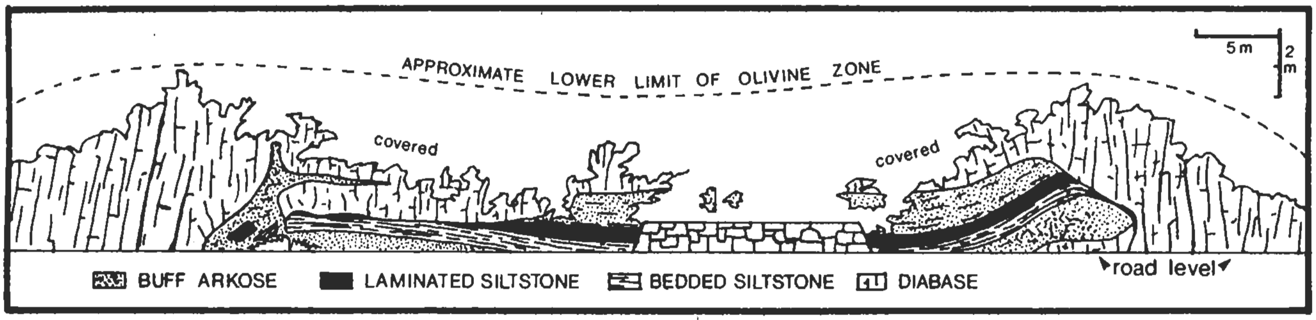

Fig. 39 Exposures of discordant contact of Palisade Diabase and Lockatong Formation, south of George Washington Bridge on road from River Road to Ross Dock in Palisades Interstate Park, Fort Lee.

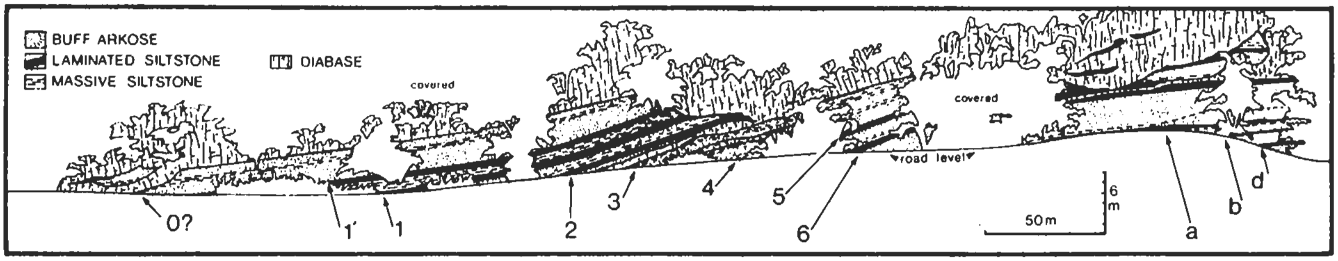

Fig. 40 Exposures of Palisade Diabase and cycles 0-d west of Ross Dock, Palisades Interstate Park, Fort Lee.

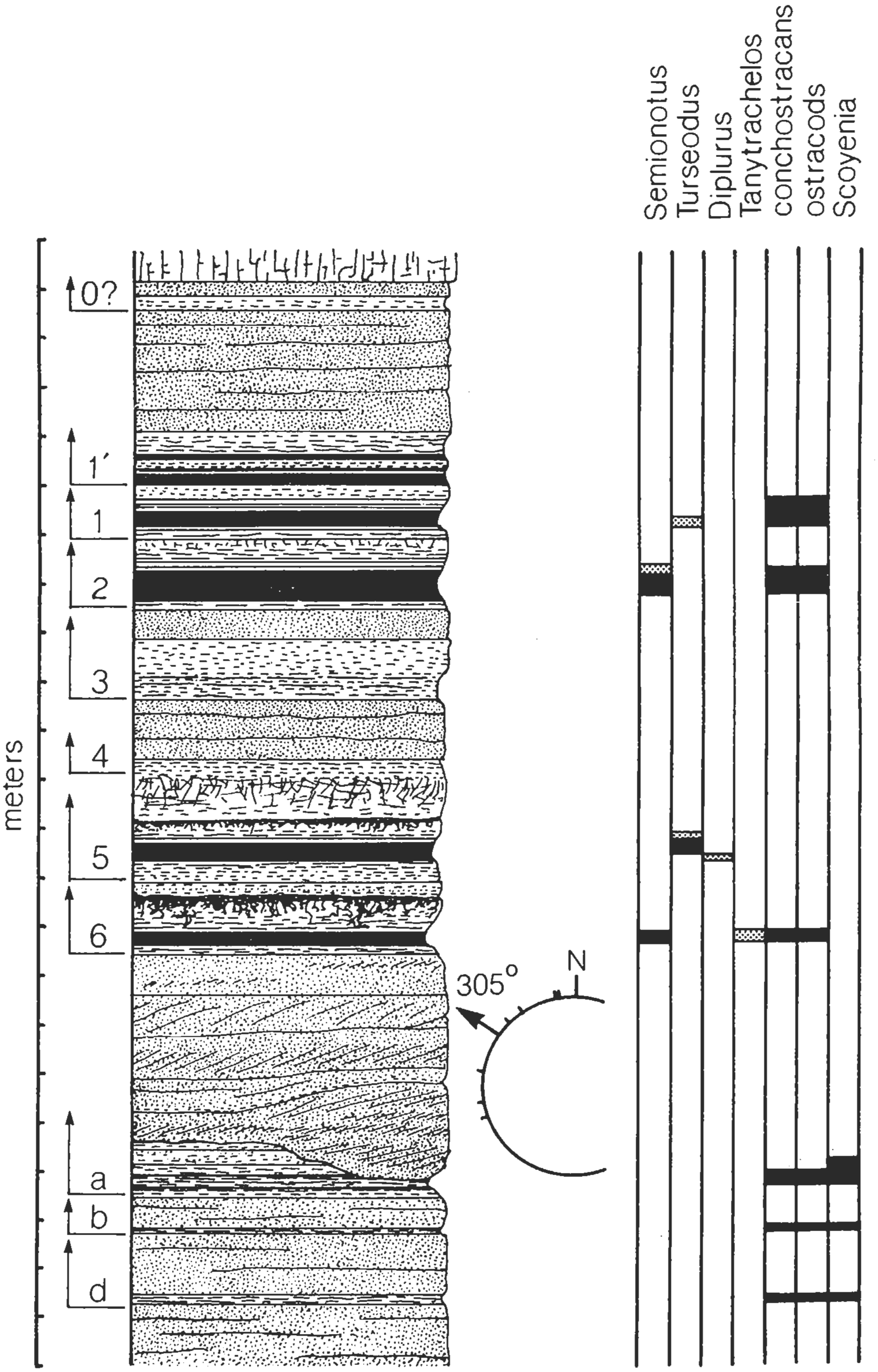

Fig. 41 Section west of Ross Dock, Palisades Interstate Park, Fort Lee showing distribution of major fossils and paleocurrent data (n-7) for crossbedded buff arkose between cycles 6 and a.

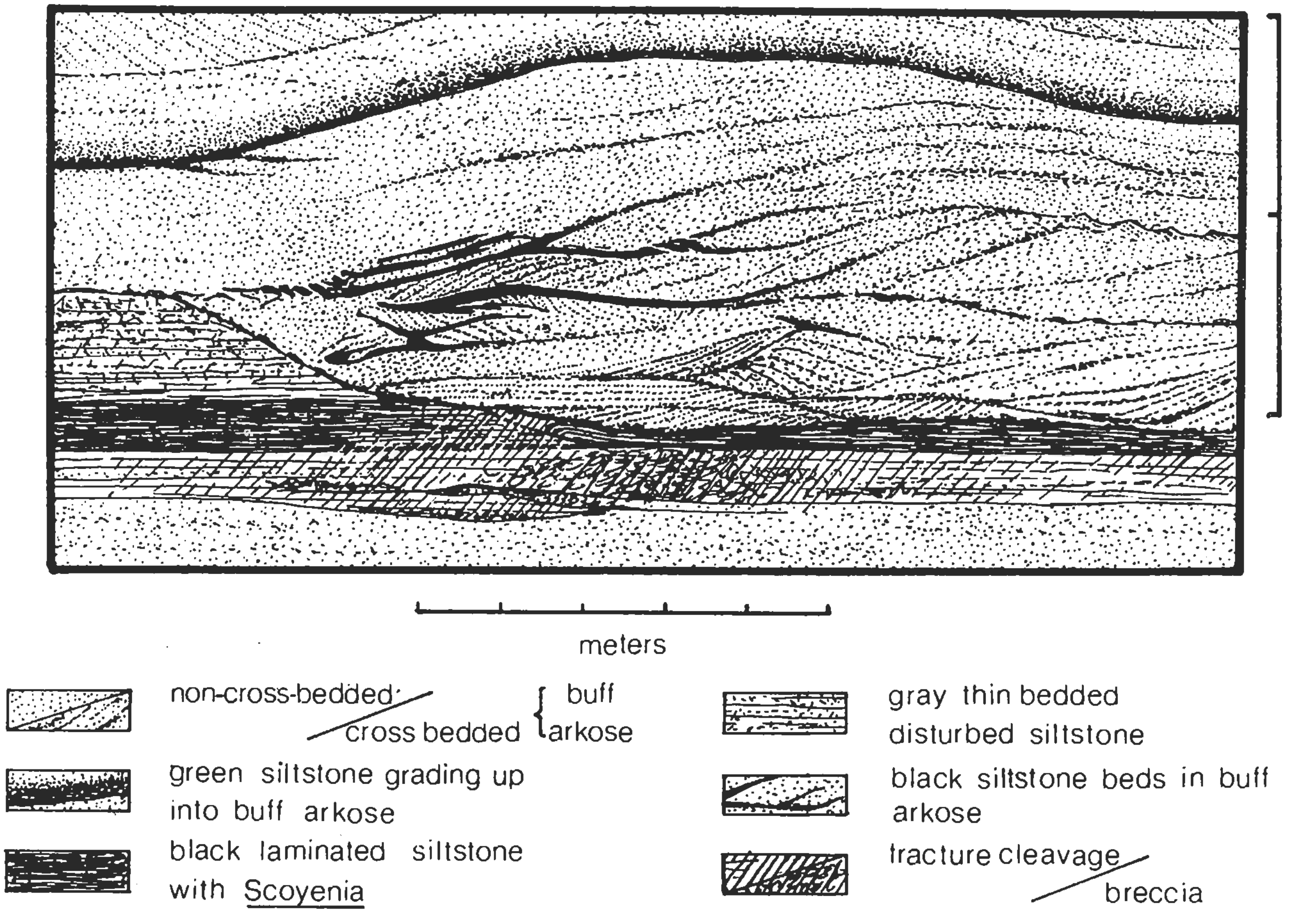

Fig. 42 Down-cutting crossbedded arkose which eliminates most of cycle a (black laminated siltstone with *Scoyenia)*. Exposure is most northern of those shown in Figure 40.

Mountain Basalt contact. Triassic - Jurassic boundary is somewhere within a few meters below contact.

46.2 Crossing Passaic River, which here follows the Feltville-Orange Mountain Basalt contact.

48.7 Intersection with Route 46 W. Take exit on right for Routes 23 and 46.

48.9 Veer right onto exit for 23 South and 46 West.

49.4 Veer right onto exit for Route 46 West. Proceed on Route 46 west over broad flat expanse of Towaco Formation mantled by Pleistocene and Recent deposits.

54.7 Type section of Hook Mountain Basalt is on right (north) in cuts for Hook Mountain Road and Route 80. Pass into Boonton Formation.

55.1 Take right hand exit for New Road. Follow around to left (south) and head south along New Road towards Route 280.

56.0 Intersection for Route 280 east. Leave New Road, turn right onto entrance ramp for Route 280 east.

58.3 Exit on right for Eisenhower Parkway south (Exit 4A). In this area we cross back over buried portion of Hook Mountain Basalt which links up Riker Hill and Hook Mountain (see Olsen, this Fieldbook).

59.0 Excellent exposures on left (east) of contact between Towaco Formation and Hook Mountain Basalt in Nob Hill Apartment complex (former east half of Roseland (Riker Hill Quarry). Two flows of Hook Mountain Basalt visible here (cumulative thickness 110m).

59.3 Turn left onto Beaufort Avenue. Take Beaufort Avenue south following along the back slope of Riker Hill.

59.7 Turn left into entrance road for Riker Hill Park of Essex County Department of Parks, Recreation, and Cultural Affairs (former Essex County Park Commission). Follow road up dip slope of Hook Mountain Basalt. Follow signs to Geology Museum.

60.1 **STOP 5** Geology Museum and Walter Kidde Dinosaur Park (former west side Roseland (Riker Hill) Quarry). Park in lot and look over exhibits at Geology Museum. Then take access path from Geology Museum over the crest of Riker Hill and down, through wooded area into Dinosaur Park. *Always get permission before entering park.*

As it stood in 1975, the Roseland Quarry occupied 55 acres, exposed 95 m of upper Towaco Formation - including two complete Towaco cycles, and exposed about 50 m of the overlying Hook Mountain Basalt (Figures 43 and 44). The quarry became very well known in the late 1960's

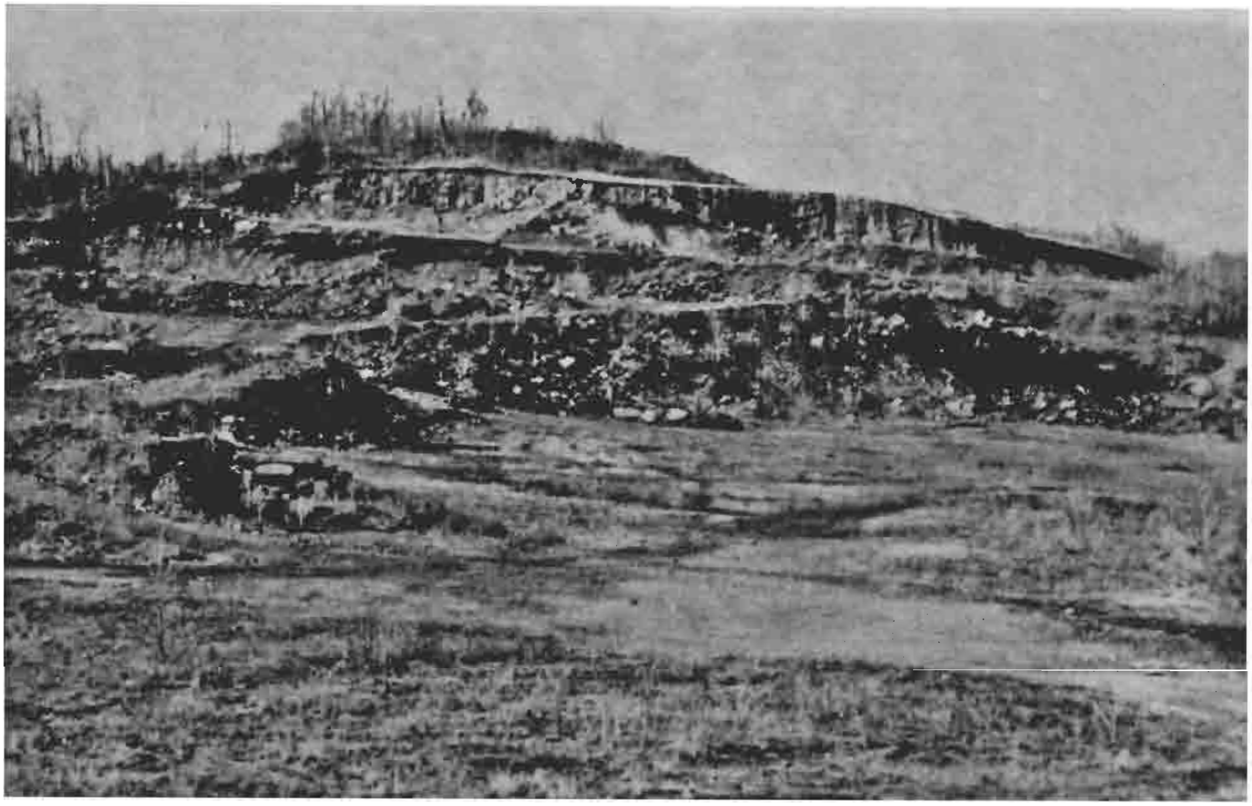

Fig. 43 Roseland Quarry in 1975 prior to development of "Nob Hill". View is to the west.

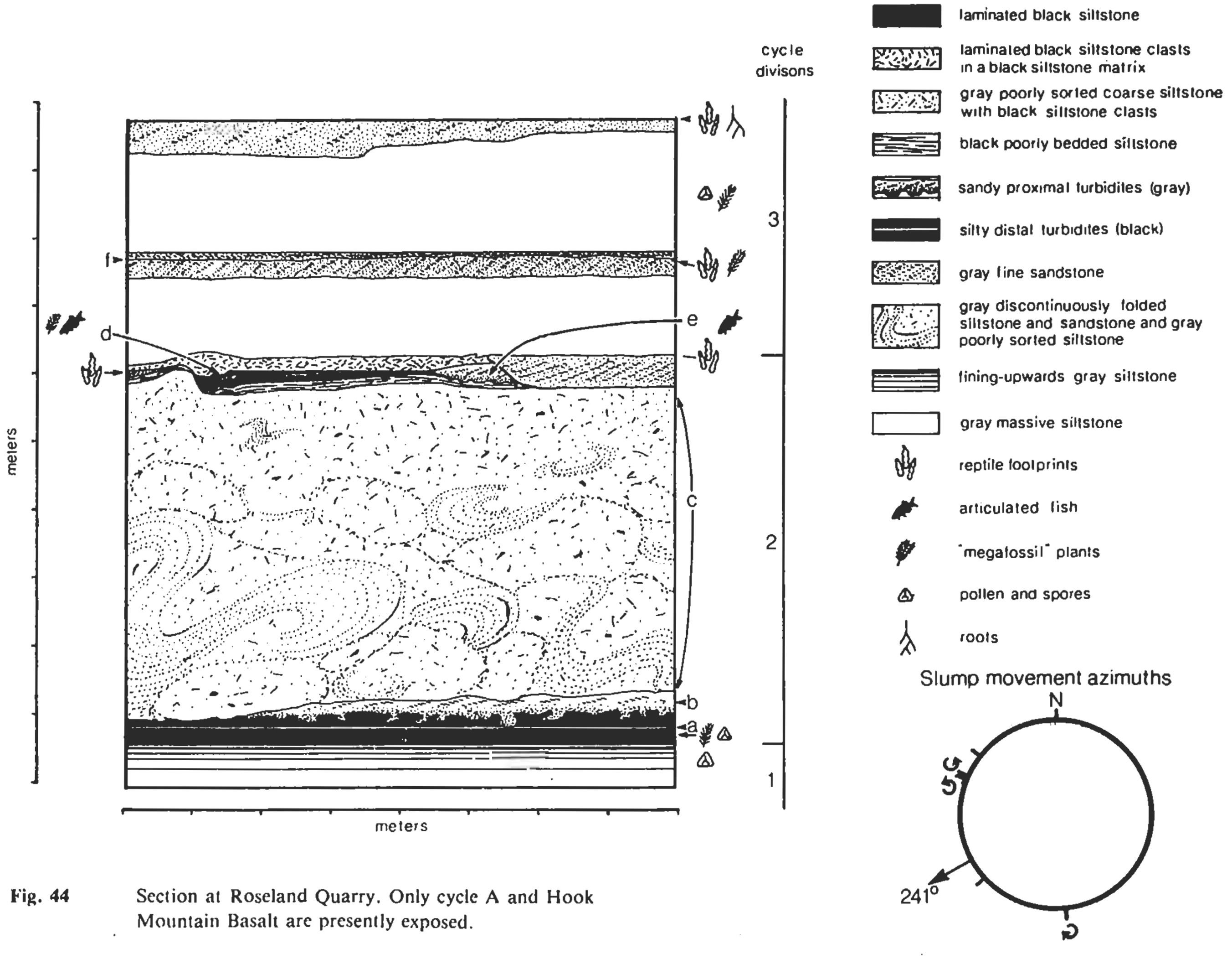

Fig. 44 Section at Roseland Quarry. Only cycle A and Hook Mountain Basalt are presently exposed.

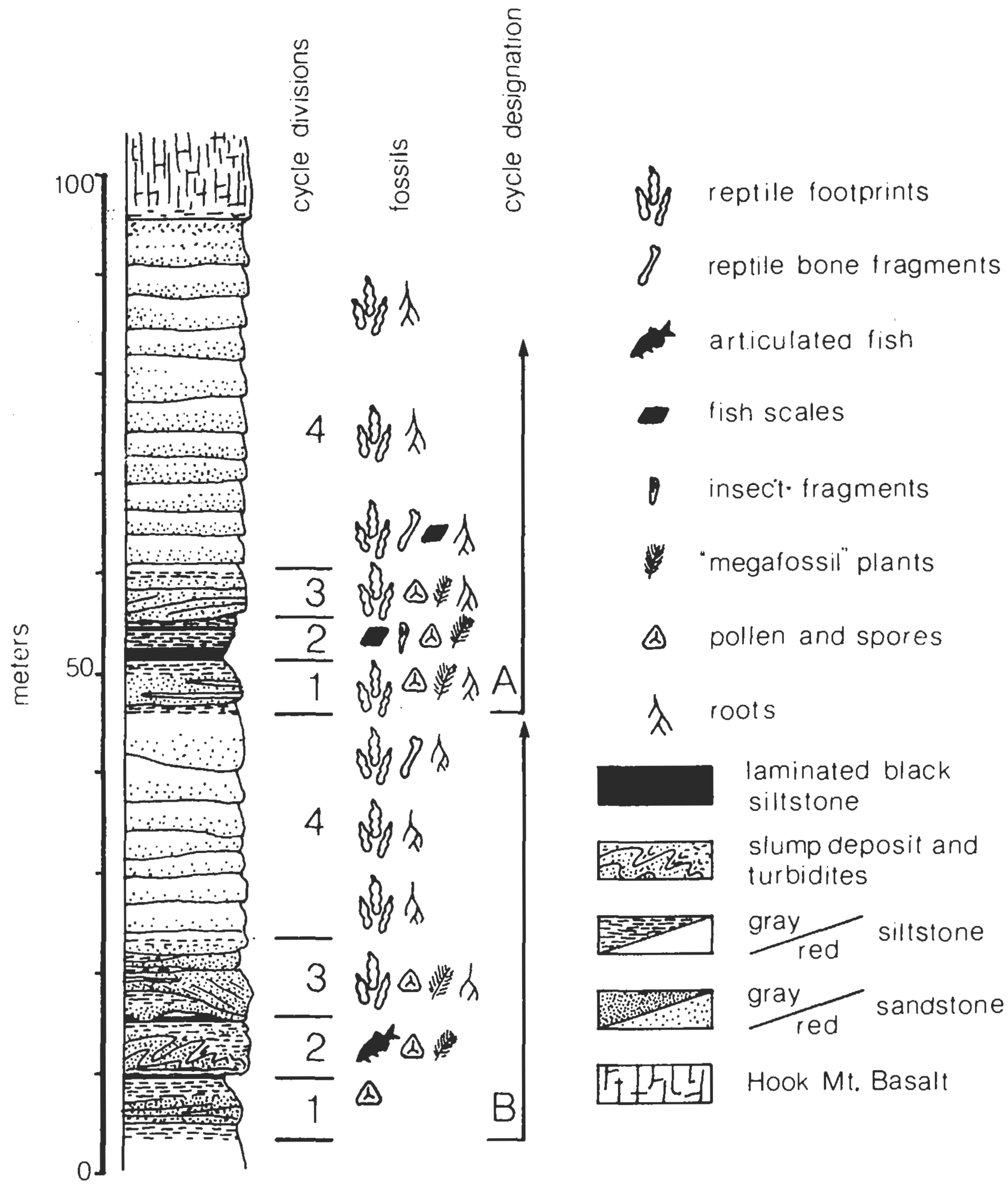

Fig. 45 Section along strike of upper part of division 1, all division 2, and lower division 3 of cycle B Roseland Quarry, now no longer exposed.

and early 1970's for its prolific dinosaur footprints. Because of the scientific and educational potential of the site the then owners, Walter Kidde and Co. Inc., donated the most productive 15 acres to the Essex County Park Commission. The site now awaits development.

Before the other 40 acres were developed as the Nob Hill development, the following features could be seen:

1 , lateral changes in facies within divisions 1 - 3 of the lower cycle (Figure 45). The microlaminated beds of division 2 produced many fossil fish, all *Semionotus* (Figure 46) as did a number of the thinner (30 cm) turbidites.

2 , two upwards coarsening turbidite sequences, the lower being by far the larger (Figure 45). The lower sequence shows large scale slumped beds resembling "wild flysche" associations. Some of the "roll over" structures are 2 to 3 m in diameter. Transport was from the east.

3 , abundant dinosaur footprints in possible crevasse splay (in division 3) of channels about 70 m to north of tracks (Figure 47). Orientation of trackways proved to be parallel to paleocurrent directions derived from ripple marks within the footprint-bearing bed and oriented plant debris in overlying beds.

4 , Series of 7 fining-upwards cycles of division 4 of the lower Towaco cycle in the Quarry. Middle 3 cycles had

Fig. 46 *Semionotus* from division 2 of cycle B at Roseland Quarry. Specimen Lost. Quarter for scale.

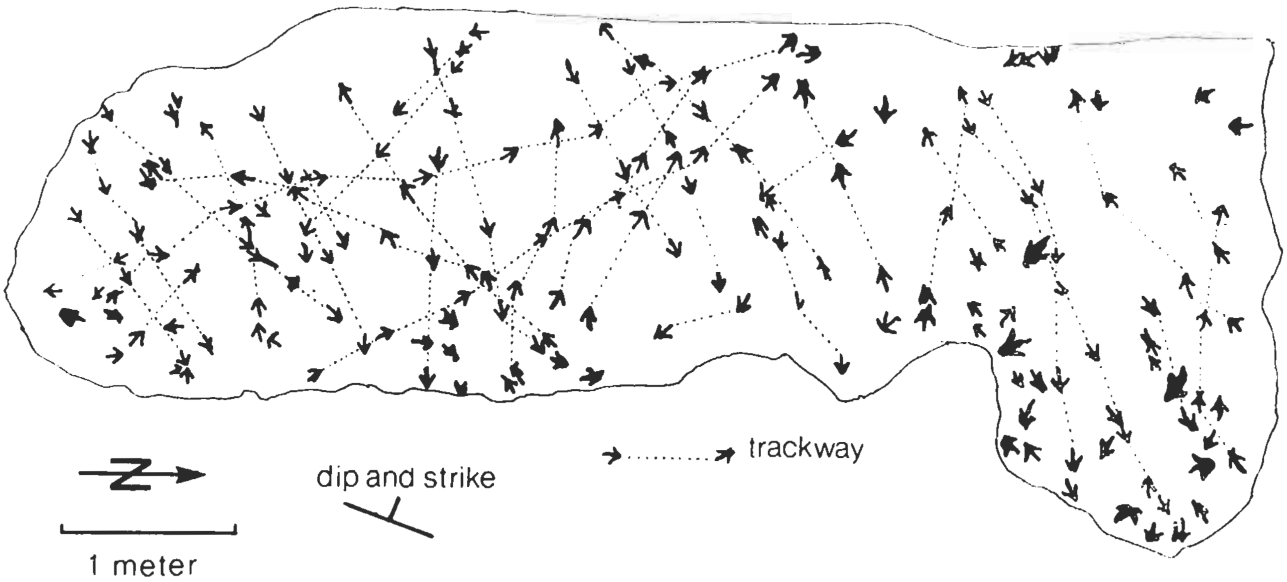

Fig. 47 Grallatorid footprints from the lower part of division 3 of cycle B, Roseland Quarry. These tracks occur in unit marked F on Figure 45. Specimens destroyed.

extensively developed dolomitic nodules and deeply mudcracked beds. Second fining-upwards cycle from the bottom with laminated silty beds (?flood basin) with abundant clay filled root casts, many of which are surrounded by dolomitic nodules (Figure 48).

In the presently exposed beds the following can be seen:

1, uppermost fining-upwards cycle of lower Towaco cycle still exposed along eastern boundary of park. The upper and middle parts of this cycle have the best reptile footprints in the quarry and hold the key to the park's development. Footprints are especially abundant in interbedded sequences of possible crevasse splay sandstone and flood basin siltstone. Basal sandstone portions of cycle are locally deeply down cut into underlying beds and contain beds of mud-chip conglomerate and casts of tree limbs and roots. Uppermost portions of the cycle consist of fine siltstone transitional into the lower parts of division 1 of the upper Towaco cycle. Transitional beds with numerous red siltstone roots surrounded by greenish halos.

2, exposure of complete Towaco cycle. Division 1 contains prominent fine sandstone beds with large calcareous concreations which weather out to form limonite filled cavities and extensive large (1-4 cm) coalified roots which probably belong to conifer trees. Crevasse splay beds in division 1 covered with little dinosaur footprints. Identical beds occur in division 2 of this cycle exposed in Chatham, New Jersey, 13 km south of here.

Fig. 48 Dolomitic nodules around root-casts in red coarse siltstone division 4 of cycle B Roseland Quarry.

3, microlaminated portion of division 2 has very well developed white-black microlaminae (Figure 15) - but no fish have been found yet, however. Upper parts of microlaminated beds contain distinctive nodules of black chert. Black, coally-looking siltstone surrounding chert bed has several bedding thrusts similar to those seen in the Lockatong at Stops 1 - 4. Microlaminated beds locally involved in disharmonic folds (Figure 15). Like the beds of division 1, these portions of division 2 look exactly the same in the Chatham exposures.

4, casts of a salt present in coarse siltstone beds above microlaminated portion of division 2.

5, massive fine gray siltstone in upper parts of division 2 have well-preserved conifer foliage, pollen and spores, individual fish scales *(Semionotus)*, and rare insect fragments.

6, complex series of sandstones and siltstones of division 3 showing features suggestive of both laterally migrating channels and prograding deltas.

7, lowest fining-upwards cycle in division 4 (Figure 49) shows slip-off faces of point bar and beds of intraformational conglomerate with coprolites, fish scales, reptile bone fragments, and abundant dinosaur footprints. The latter features could represent a dinosaur "wallow".

8, 10 successive fining-upwards cycles of division 4. Rill marks very well developed in bank portions of one of the middle cycles (Figure 50). These sorts of rill marks, typical of channels with rapidly dropping water levels, have long been confused with plant remains (it is easy to see why) and have received the name *Dendrophycus* (Newberry, 1888).

9, unique small reptile footprints with structure highly suggestive of advanced mammal-like reptiles or mammals (Figure 20) are present in upper fining-upwards cycles. If they do represent mammals, they will be the oldest North American record.

10, very badly weathered "tuff" between normal Towaco Formation and Hook Mountain Basalt. This unit is enigmatic but very widespread at this stratigraphic position. Fresh exposures were described by Lewis in 1908 (see Olsen, this Fieldbook).

60.5 Leave Walter Kidde Dinosaur Park and Riker Hill Park returning to Beaufort Avenue. Turn right (north) onto Beaufort.

60.9 Turn right off Beaufort onto Eisenhower Parkway heading north.

61.9 Take right hand exit for Route 280 east. Head east on 280 up dip slope of Preakness Mountain Basalt. Outcrop width of Preakness Basalt is very large in this area, suggesting a thickness of 500 m for the basalt. I believe this is due to a number of small strike faults and the true thickness is closer to 300 m. These faults in combination with the multiple flow character of the Preakness Basalt produced the many small ridges visible while driving up the dip slope.

64.8 Type section of the Preakness Basalt in deep open cut for Route 280. Section exposes about 100 m of the lower flow. Note distinctive "splintery" nature of the lower 50 m (see Olsen, this Fieldbook). This section is cut by a series of faults all apparently left lateral and all showing little or no apparent dip slip offset (Figure 51).

65.2 Contact between Preakness Basalt and Feltville Formation poorly exposed on south side of road.

65.6 Unexposed contact between Feltville Formation and underlying Orange Mountain Basalt below this point.

65.9 Exposures of ?second flow of Orange Mountain Basalt.

66.3 Type section of Orange Mountain Basalt in very long and deep open cut for Route 280 (see Olsen, this Fieldbook; Manspeizer, this Fieldbook). Section exposes about 55 m of lower flow as well as a number of left lateral faults similar to those seen at mileage 64.8. Left lateral faults are present here as they are at mileage 64.8. At one portion of the cut, on the north side is 20 m long horizontally slickensided fault plane. Note the very different appearance of basalt (in terms of jointing) from the Preakness Basalt.

66.7 Contact of Orange Mountain Basalt and Passaic Formation was well exposed during construction of this cut, at this point.

66.8 Cuts in uppermost Passaic Formation here have produced phytosaur footprints called *Apatopus* and the possible crocodilio-morph tracks called *Batrachopus*. The Triassic -Jurassic boundary lies somewhere within the upper few tens of meters of the Passaic Formation here.

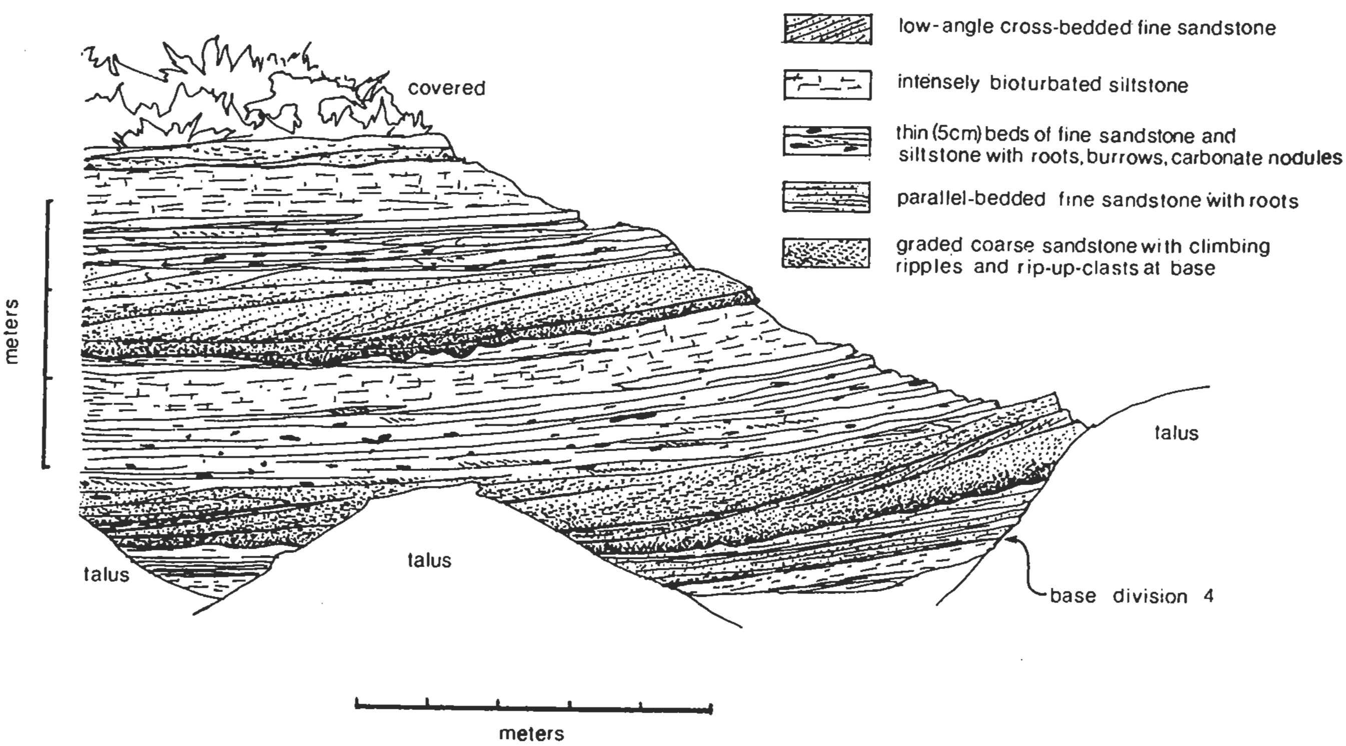

Fig. 49 Outcrop of fining - upwards cycles lower part of division 4, cycle A.

71.2 Sedimentary cycle in Passaic Formation formerly exposed here. A very well preserved palynomorph assemblage recovered from fine gray siltstones of this unit suggest a lower Rhaetic age (Cornet, 1977). This unit has also produced a series of reptile footprints including large and small *Grallator* and *Chirotherium* sp. *Scoyenia* is abundant as is the conchostracan *Cyzicus*. Equivalent beds are exposed at the same stratigraphic position in New Brunswick, New Jersey. The entire Passaic Formation section from this unit to the Orange Mountain Basalt is above the entire Delaware River section of the Passaic Formation, which extends upwards only into Norian beds (Cornet, 1977).

71.3 Take 1st Street exit, turn right.

71.6 Turn left onto Central Avenue.

72.6 Turn right onto Washington Street.

72.7 Turn right onto Warren Avenue.

72.8 Rutgers University parking lot - end field trip.

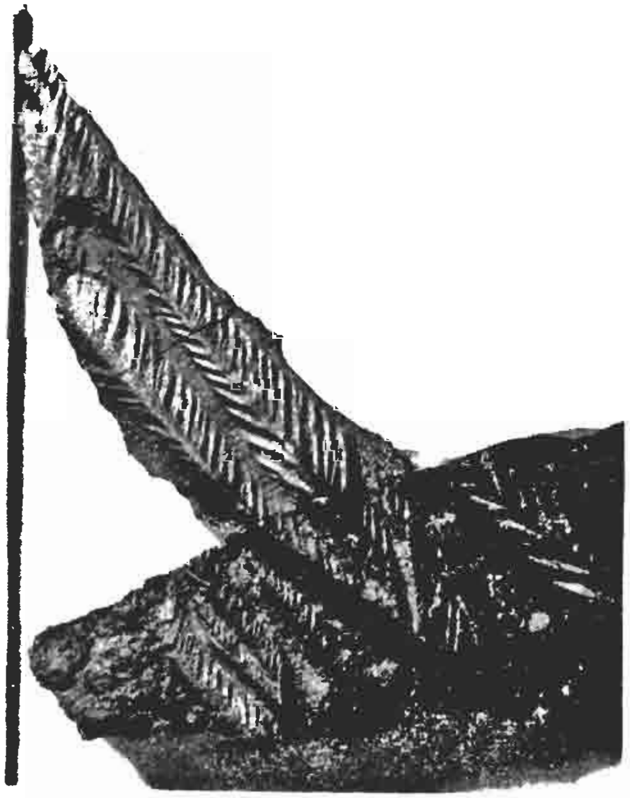

Fig. 50 Natural cast of rill marks, middle portion division 4, cycle A. Specimen in private collection.

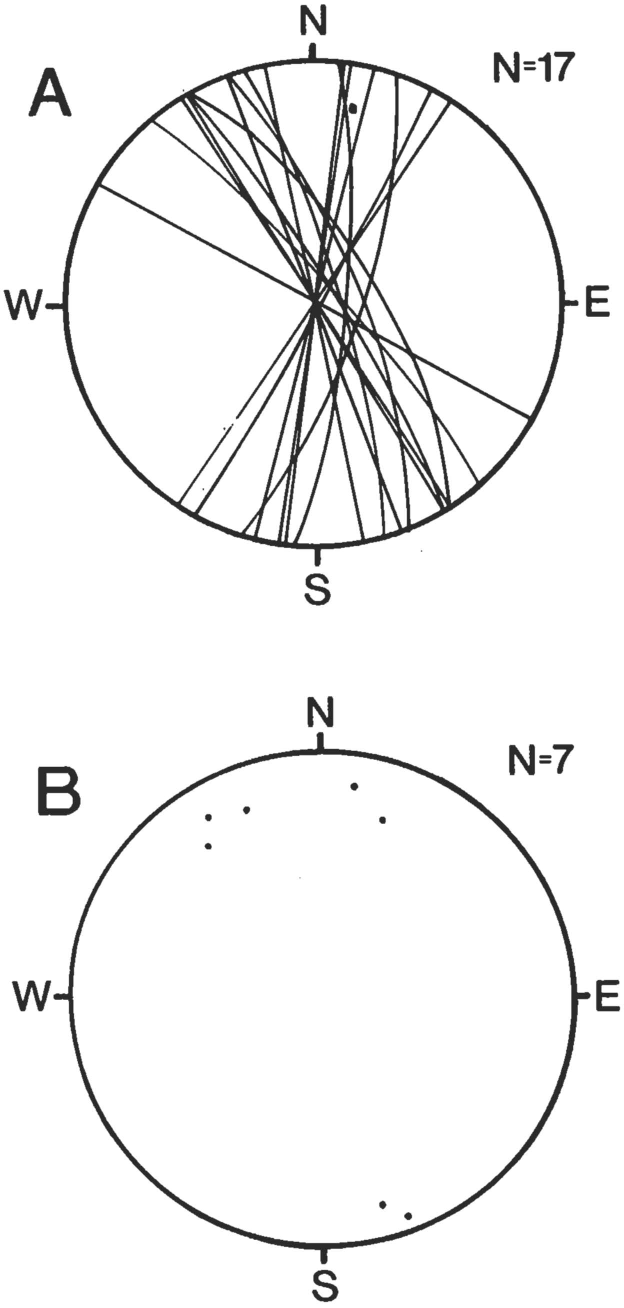

Fig. 51 Plots of faults exposed in type sections of Orange Mountain and Preakness basalts along Route 280: A, equal area net plot of seventeen fault planes; B, equal area net plot of lines parralel to slickensides present in seven of the faults in A. Lower hemisphere projections.

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