TRIASSIC AND JURASSIC FORMATIONS OF THE NEWARK BASIN

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Abstract

Newark Supergroup deposits of the Newark Basin (New York, New Jersey and Pennsylvania) are divided into nine formations called (from bottom up): Stockton Formation (maximum 1800 m); Lockatong Formation (maximum 1150 m); Passaic Formation (maximum 6000 m); Orange Mountain Basalt (maximum 200 m); Feltville Formation (maximum 600 m); Preakness Basalt (maximum +300 m); Towaco Formation (maximum 340 m); Hook Mountain Basalt (maximum 110 m); and Boonton Formation (maximum +500 m). Each formation is characterized by its own suite of rock types, the differences being especially obvious in the number, thickness, and nature of their gray and black sedimentary cycles (or lack thereof).

Fossils are abundant in the sedimentary formations of the Newark Basin and provide a means of correlating the sequence with other early Mesozoic areas. The Stockton, Lockatong, and most of the Passaic Formation are Late Triassic (?Middle and Late Carnian-Rhaetic) while the uppermost Passaic Formation (at least locally) and younger beds appear to be Early Jurassic (Hettangian and Sinemurian) in age. The distribution of kinds of fossils is intimately related to sequences of rock types in sedimentary cycles.

INTRODUCTION

Far from being the consequence of the last gasps of the Appalachian Orogeny, Late Triassic and Early Jurassic Newark Supergroup basins formed in dynamic association with the opening of the Atlantic Ocean (Sanders, 1974; Van Houten 1977; Manspeizer, Puffer, and Cousminer, 1978; Olsen, 1978). In addition, Newark Supergroup rocks, once thought to be nearly barren of fossils, are now known to be exceptionally rich in organic remains (Thomson, 1979), replete with plants, invertebrates, and vertebrates spanning some 35 million years of the Early Mesozoic (Cornet, 1977). Finally, long episodes of unusually continuous deposition coupled with an abundance of laterally extensive stratigraphic "marker" beds (McLaughin, 1946), makes this deposit ideal for studying time-facies relationships and evolutionary phenomena. These recent discoveries have focused new interest on Newark strata.

The Newark Basin (Fig. 1 and 2) is the largest of the exposed divisions of the Newark Supergroup, covering about 7770 km^2 and stretching 220 km along its long axis. The basin contains the thickest sedimentary sequence of any exposed Newark Supergroup basin and correspondingly covers the greatest continuous amount of time. Thus, the Newark Basin occupies a central position in the study of the Newark Supergroup as a whole.

In well over a century of study the strata of Newark Basin have received a relatively large amount of attention. By 1840, the basic map relations were worked out (Rogers, 1839, 1840, Cook, 1868) and by 1898, the major rock-stratigraphic subdivisions of the basin section were delimited and named (Darton, 1890; Kümmel, 1897, 1898). Despite this long tradition, fundamental aspects of its historical and structural geology have remained essentially unexplored. The lithostratigraphy of the younger sediments, in particular, has received short shrift. Recently I have revised certain aspects of Newark Basin stratigraphy with an emphasis on the younger rocks (Olsen, in press). In the process I haveproposed a number of new formational names (Table 2). Here I will review the formations of the Newark Basin and attempt to place their broader lithostratigraphic features into biostratigraphic context.

OVERVIEW OF NEWARK BASIN FORMATIONS

As currently defined (Olsen, 1978; Van Houten, 1977; Cornet, 1977), the Newark Supergroup consists of predominantly red clastics and volumetrically minor basaltic igneous rocks exposed in 13 major and 7 minor elongate basins preserved in the Piedmont, New England, and Maritime physiographic provinces of eastern North America (Figure 1, Table 1). In general, the long axes of these basins parallel the fabric of the

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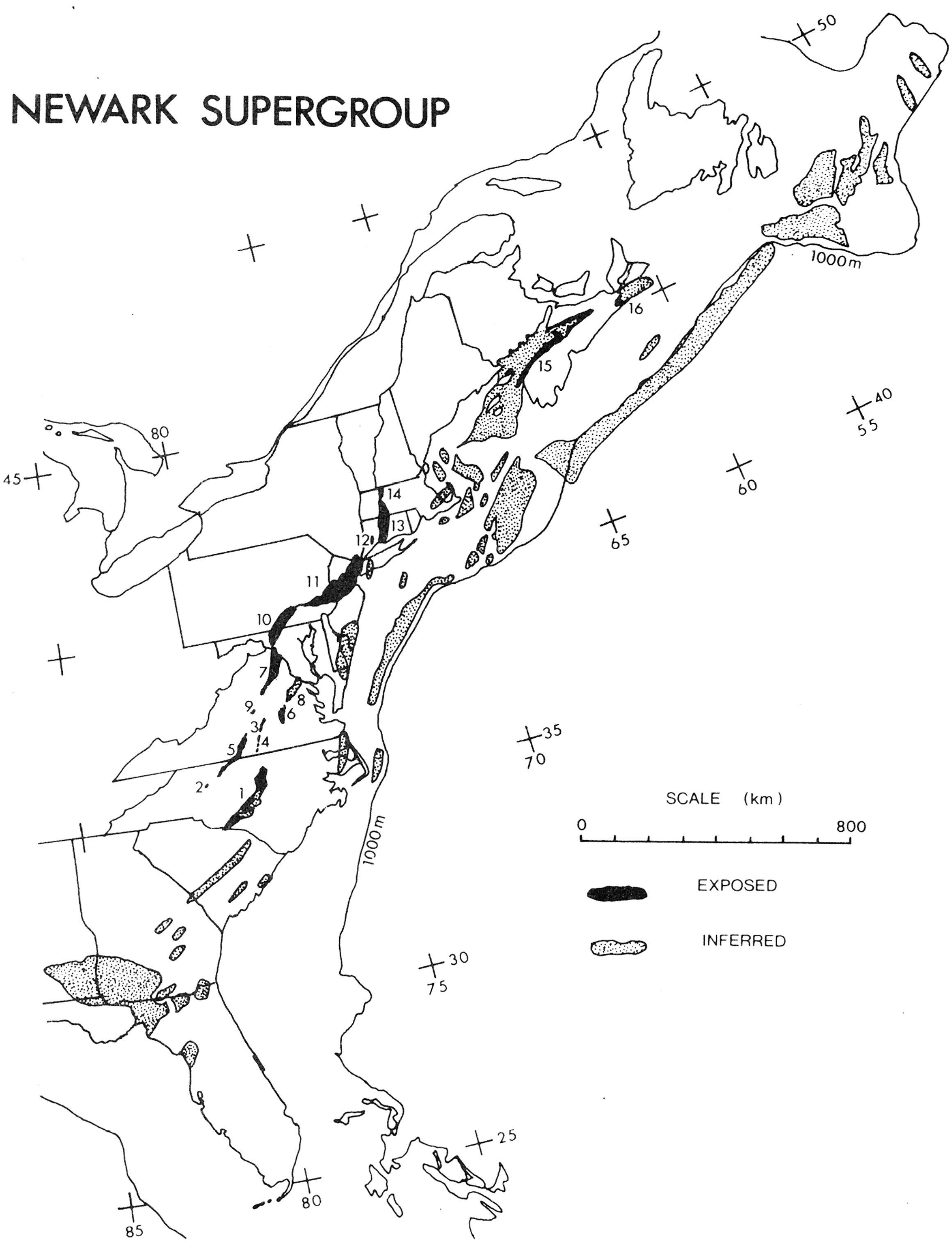


Fig. 1 Newark Supergroup of eastern North America. Key to numbers given in Table 1. The Newark Basin is 11. Data from Olsen, 1978.

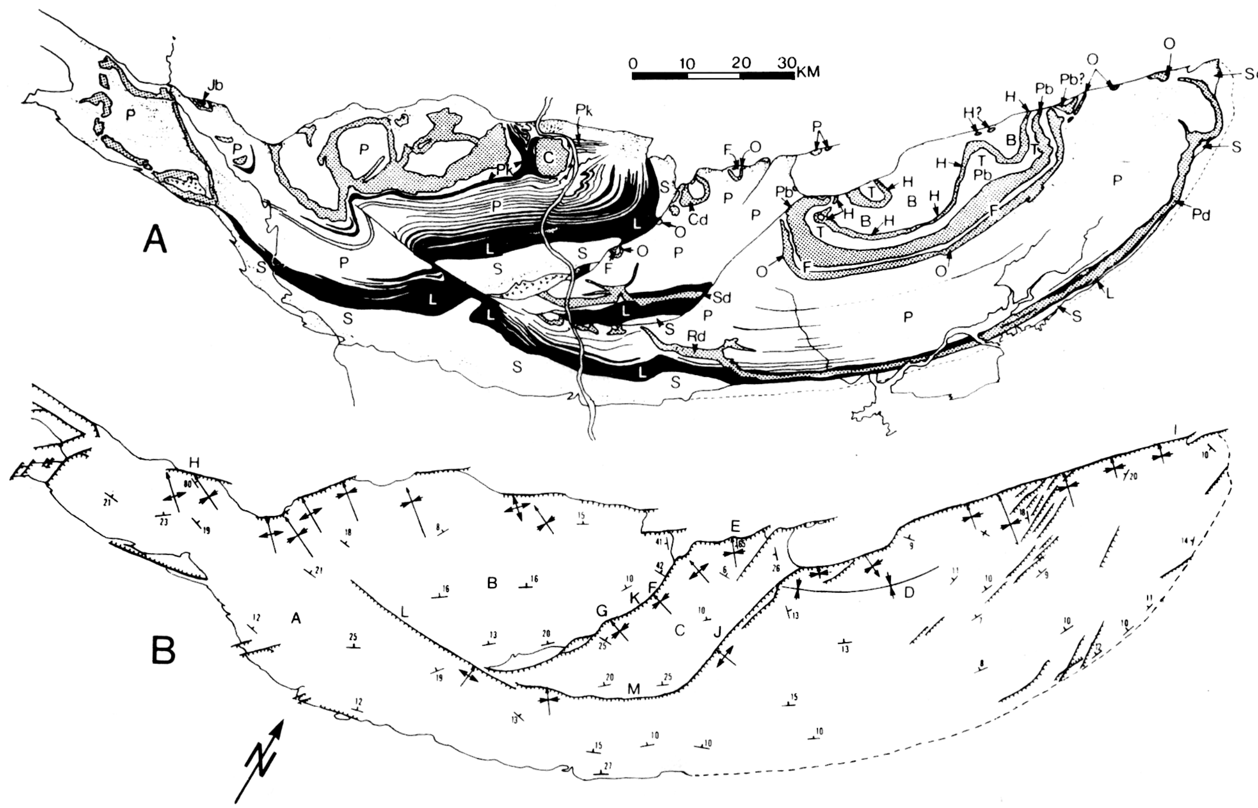


Fig. 2 The Newark Basin.

A. Geologic map showing distribution of formations, conglomeritic facies (irregular stipple), and major clusters of detrital cycles in Passaic Formation (parallel black lines) -- abbreviations of formations and diabase bodies as follows: B, Boonton Formation; C, Coffman Hill Diabase; Cd, Cushetunk Mountain Diabase; F, Feltville Formation; H, Hook Mountain Basalt; Hd, Haycock Mountain Diabase; Jb, Jacksonwald Basalt; L, Lockatong Formation; O, Orange Mountain Basalt; P, Passaic Formation; Pb, Preakness Basalt; Pd, Palisade Diabase; Pk, Perkasie Member of Passaic Formation; Rd, Rocky Hill Diabase; S, Stockton Formation; Sc, carbonate Facies of Stockton Formation; Sd, Sourland Mountain Diabase; T, Towaco Formation.

B. Structural features of the Newark Basin. Faults are all drawn as normal with dots on the down-thrown side; portions of basin margin not mapped as faults should be regarded as onlaps. While all the faults are mapped here as normal, it is clear many, if not all of them, have some component of strike slip, although the significance of this component is unclear. Symbols for the names of structural features used in this paper are as follows: A, Montgomery-Chester fault block; B, Bucks-Hunterdon fault block; C, Sourland Mountain fault block; D, Watchung syncline; E, New Germantown syncline; F, Flemington syncline; G, Sand Brook syncline; H, Jacksonwald syncline; I, Ramapo fault; J, braided connectoin between Ramapo and Hopewell faults; K, Flemington fault; L, Chalfont fault; M, Hopewell fault.

Data for A and B from Kümmel, 1897; Lewis and Kümmel, 1910-1912; Darton, 1890, 1902; Darton, et al., 1908; Glaeser, 1963; Sanders, 1962; Van Houten, 1969; McLaughlin, 1941, 1943, 1944, 1945, 1946a, 1946b; Bascom, *et al.,* 1909; Willard, *et al.,* 1959; Faille, 1963; Manspeizer, pers. comm.; Olsen, in press, and personal observation.

Appalachian Orogene (Rodgers, 1970; Van Houten, 1977). The rocks of these basins present a relatively unified lithology and structure and unconformably overlie (or intrude) Precambrian and Palaeozoic rocks. They are in turn overlain by post-Jurassic rocks of the Coastal Plain, Pleistocene deposits or Recent alluvium and soils. In addition, early Mesozoic red clastics, basaltic volcanics, and evaporites at the base of some sequences on the continental shelf and also at least 12 units recognized beneath the Atlantic Coastal Plain probably should be grouped in the Newark Supergroup (Figure 1).

Precambrian and early Paleaozoic rocks of the southwestern prongs of the New England Upland border the Newark Basin along its northeast and northwest margins (Figure 2). The southeastern and southwestern portions of the Newark Basin overlie and are bordered by Palaeozoic and Precambrian rocks of the Blue Ridge and Piedmont Provinces. Newark Basin sediments rest with a profound unconformity on basement rocks and mostly dip 5° - 25° to the northwest. The entire stratigraphic column reaches a cumulative trigonometrically calculated thickness of over 10,300 m (the sum of the maximum thicknesses of all the formations), although the total thickness of sediments actually deposited at any one spot was probably much less. Red clastics are the dominant sediments; intrusive and extrusive tholeiites are the dominant igneous rocks. The oldest sediments are probably middle Carnian (early

Table 1

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

Table 2

Lyman, 1895	Kummel, 1897; Darton, 1890	Baird and Take, 1959; Baird, 1964; Colbert, 1965	(Olsen, in press) This Article
American New Red Sandstone	Newark System (of Newark Basin)	Newark System (of Newark Basin)	Newark Supergroup (of Newark Basin)
	Brunswick Formation	Boonton and Whitehall Beds	Boonton Formation
	"3rd" Watchung Basalt	Hook Mountain Basalt	Hook Mountain Basalt
	Brunswick Formation	Brunswick Formation	Towaco Formation
	"2nd" Watchung Basalt	"2nd" Watchung Basalt	Preakness Basalt
	Brunswick Formation	Brunswick Formation	Feltville Formation
	"1st" Watchung Basalt	"1st" Watchung Basalt	Orange Mountain Basalt
Pottstown Shales Perkasie Shales Lansdale Shales	Brunswick Formation	Brunswick Formation	Passaic Formation
Gwynedd Shales	Lockatong Formation	Lockatong Formation	Lockatong Formation
Norristown Shales	Stockton Formation	Stockton Formation	Stockton Formation

Late Triassic) in age while the youngest appear to be Sinemurian (middle Early Jurassic) (Cornet, 1977; Olsen, McCune, and Thomson, in press). Cretaceous and younger Coastal Plain deposits overlap Newark beds with an angular unconformity along the basin's eastern edge. The northern quarter of the basin is mantled by Pleistocene and recent deposits.

The first lithostratigraphic terms for the sedimentary formations of the Newark Basin were introduced by Lyman in 1895 (Table 2). Although he clearly demarcated the units in their type areas (southeastern Pennsylvania), mapped and briefly described them, his terms never gained wide acceptance. In 1897, Kümmel introduced his own nomenclature for equivalent rocks in New Jersey (Table 2). Since their introduction, Kümmel's terms have been widely used. While the rule of priority applies to stratigraphic names, no practical purpose is served by resurrecting those of Lyman. This is in accordance with Code of Stratigraphic Nomenclature, 1961 (hereafter C. N. S.), article 11b, and with the International Stratigraphic Guide, 1976 (hereafter I. S. G.), chapter 3e.

Kümmel (1897) divided the Newark Basin sequence into three formations: Stockton, Lockatong, and Brunswick. The Stockton Formation (maximum thickness ca. 1800 m) consists of thick beds of buff or cream colored conglomerate and sandstone and red siltstone and sandstone forming the basal formation of the Newark Basin. Throughout the exposed central portion of the Newark Basin, the Stockton Formation is overlain by the Lockatong Formation (maximum thickness 1150 m) which is made up of beds of gray and black siltstone. These siltstones are arranged, as Van Houten (1969) later showed, in distinctive sedimentary cycles. The youngest formation Kümmel recognized is the Brunswick. Throughout the Newark Basin, the lower half of this formation consists mostly of red siltstone, sandstone, and conglomerate with clusters of laterally persistent cycles of gray and black siltstone similar to that in the Lockatong Formation (Kümmel, 1897, 1898; McLaughlin, 1943; Van Houten, 1969). The upper Brunswick, on the other hand, is made up of three major, multiple-flow, basalt sheets (units Darton in 1890 called the Watchung Basalts), two major interbedded sedimentary units, and a thick overlying sedimentary unit. The latter sedimentary sequences have escaped even preliminary lithologic description.

Field work by myself and others (Olsen, in press) has shown that Kümmel's Brunswick Formation consists of a heterogeneous mix of major, mappable units of differing and distinctive lithology, each as distinct and perhaps originally as widespread as the Stockton or Lockatong; "Watchung Basalt" and the interbedded and overlying sedimentary beds are lithologically distinct from the stratigraphically older beds. In addition, Kümmel's upper Brunswick is Early Jurassic, rather than Late Triassic as most authors have assumed (Cornet, Traverse and McDonald, 1973; Cornet and Traverse, 1975; Cornet, 1977; Olsen and Galton, 1977; Olsen, McCune, and Thomson, in press). It now seems that these Jurassic rocks are in many ways different from the Late Triassic lower Brunswick Formation, Lockatong, or Stockton formations.

I have proposed elsewhere (Olsen, in press) that the terms Brunswick Formation (Kümmel, 1897) and Watchung Basalts (Darton, 1890) be dropped and their components subdivided to form seven new formations. Despite the wide (although inconsistent) use of those terms over the years, it is inappropriate to conserve them for the following reasons:

1. The division of the Brunswick Formation of Kümmel into four sedimentary formations constitutes a major redefinition of the unit. C.S.N. article 14b recommends that "When a unit is divided into two or more of the same rank as the original, the original name should not be employed for any of the revisions." Thus, while it could be argued that the term Brunswick Formation should be retained for the pre-basalt sediments of the Newark Basin, such use could be a source of confusion, and it seems better to establish a new term for the pre-basalt, post-Lockatong beds.

2. Darton's Watchung Basalt has been traditionally recognized as a single formation embracing the three major multiple flow units interbedded in Kümmel's upper Brunswick Formation (see, for example, Wilmarth, 1938, p. 896; Faust, 1975, 1978; Van Houten, 1969, p. 327). Since both the C.S.N. (article 10h) and the I.S.G. (chapter 5f, 1c) state that repetition of geographic names in formations is considered informal nomenclature, it is appropriate to drop the formal use of the term Watchung Basalt and recognize three basalt formations with individual names (Table 2).

The new formational names I have proposed to replace Kümmel's and Darton's formations are (from the bottom up): Passaic Formation, Orange Mountain Basalt, Feltville Formation, Preakness Basalt, Towaco Formation, Hook Mountain Basalt, and Boonton Formation. These new divisions of the Newark Basin section are similar in scale to Emerson's (1898) and Lehman's (1959) widely used divisions of the Hartford Basin and Klein's (1962) divisions of the Fundy Group, and are in accordance with the letter and intent of the C.S.N. and I.S.G. In this way, formal names are given to beds critical to the overall pattern of Newark Basin historical geology.

A NOTE ON THE CALCULATION OF STRATIGRAPHIC THICKNESS

The arguments which center on the accuracy of trigonometrically computed stratigraphic thicknesses of Newark Basin sections (Rogers, 1840, 1865; Kummel, 1898; Faill, 1973; Faust, 1975; Sanders, MS) concern two components. First, deposition along the stepfaulted northwest margin decreases the real thickness of beds preserved at any one place. This is a major concern, but the problem can be at least partially resolved by careful analysis of existing outcrops and geophysical data (see Faill, 1973, for a review and Dunleavy, 1975, and Olsen, in press, for particulars) (see Figure 5). Second, there are a large number of hidden strike faults with large dip-slip components. This problem has no clear quantitative solution in some important areas. In parts of the Newark Basin, such as the entire northern third of the basin, this is a substantial problem, as the following examples show (Figure 2).

1. A suite of faults has long been known to offset the northern segments of the Watchung ridges (Kümmel, 1897; Darton, et al., 1908; Olsen, in press). These series cut the type sections of both the Orange Mountain Basalt and the Preakness Basalt. 2. Another suite of faults cuts the Palisades ridge, especially in the area of Weehawken and Edgewater, New Jersey (Kümmel, 1898; Van Houten, 1969; Olsen, in press). 3. Faults duplicate 30 % of the exposed Lockatong Formation at Gwynned, Pennsylvania (Watson, 1958). Many other examples are know (Willard, et al., 1959; Rima, Meisler, and Longwill, 1962).

Most of these faults are visible because they cut ridges with topographically expressed offsets; in areas of low topography, they do not show up. In certain areas, such as the Passaic Formation type section (Figure 6), the distribution of such faults is essentially unknown. Those faults presently mapped which cut the Watchung ridges must continue and cut the Passaic Formation,though they may eventually die out. Thus, the trigonometrically computed thickness for the Passaic Formation in the northern third of the Newark Basin is certainly an overestimation.

In contrast, the field relationships of mapped gray and black siltstone and conglomerate beds in the Bucks-Hunterdon fault block (see Figure 2) show that these small strike faults are absent over broad areas. In these areas the trigonometrically computed thicknesses have been confirmed by some deep well records (Lesley, 1891; McLaughlin, 1943). This inconsistency over parts of the Newark Basin demonstrates that there can be no single constant to correct for "hidden faults." Rather, if a correction is attempted (as in Figure 6) it must be based on extrapolation of the local fault patterns. For thin units, such as the northern outcrops of the Lockatong or the basalt formations, these small faults usually do not present much of a problem since there are single outcrops covering much of each unit.

As a general guide, I place most confidence in thickness determinations in the Bucks-Hunterdon Block and the least confidence in the calculated thicknesses at the northeastern and southwestern portions of the

Newark Basin.

STOCKTON FORMATION

The Stockton Formation is the poorest known of all Newark Basin formations. It is also the oldest and most widespread deposit, forming the basal beds of the Newark Basin section everywhere except along portions of the northwest border. The Stockton is thickest near the Bucks-Montgomery county line in the Bucks-Hunterdon fault block (Figure 2), where it reaches a calculated stratigraphic thickness of 1830 m (Willard, *et al.*, 1959). Along its type section (Figure 3, Table 3) along the shores of the Delaware River near Stockton, New Jersey, the formation is 1500 m thick (McLaughlin, 1945). Measured from the base of the lowest continuous black siltstone unit of the overlying Lockatong Formation, the Stockton thins in all directions from this central area (Kümmel, 1897). Towards the south at Norristown, Pennsylvania it is 1221 m and at Phoenixville, Pennsylvania it is 700 m; to the north near Clinton, New Jersey it is 1350 m; to the east near Princeton, New Jersey it is 920 m; and to the northeast at Hoboken and Weehawken, New Jersey it is less than 250 m. The predeformational shape of the Stockton Formation lithosome is thus an asymmetrical lens with the thickest portion near the center of the Bucks-Hunterdon fault block (see Figure 4). McLaughlin (in Willard, *et al.*, 1959) presents evidence that the Stockton Formation in the southern Newark Basin thins by a progressive onlap of younger Stockton beds onto basement.

Stockton lithology is diverse. The dominant sediment types are gray and buff colored arkose and arkosic conglomerate, and red siltstone and arkosic sandstone. In broad view, the Stockton Formation fines upward with the coarsest sediments near the base. As noted by McLaughlin (In Willard, *et al.*, 1959) the Stockton coarsens in the same directions it thins; thus conglomerate bodies and coarse arkose are found high in the section along the eastern edge of the basin.

The belt of Stockton Formation which runs through the Bucks-Hunterdon fault block and through the Montgomery-Chester fault block (Figure 2) has been divided into members by McLaughlin (In Willard *et al.*, 1959) and by Rima, Meisler and Longwill (1962), primarily on the basis of texture (Table 3). They did not attempt to extend these member names into other parts of the Newark Basin. Upper Stockton fissile red sandstone and siltstone pass upwards into hard non-fissile red siltstones (argillite) in the Bucks-Hunterdon belt. These siltstones have been grouped with the overlying Lockatong Formation by a number of authors (McLaughlin, 1945; McLaughlin, In Willard et al., 1959; Van Houten, 1969). I believe the Stockton-Lockatong boundary should be defined at the base of the lowest continuous black siltstone bed. This is in accord with Kümmel's own definition which does not seem to include 30 m of red beds at the base of the Lockatong, although I think his definition is somewhat vague. I group these red siltstones with the Stockton.

While the predominant facies trend is clearly upward fining, important beds of different lithology occur throughout. Basal Stockton beds, where they are exposed, rest on a locally irregular surface. Where basal Stockton beds rest on Cambro-Ordovician limestones, red matrix limestone breccia and red siltstone fill apparent solution cavities. Elsewhere, there are basal red-matrix conglomerate and breccia composed of underlying basement rocks (Olsen, in press). The main masses of Stockton Formation conglomerate in the central part of the basin, however, are definitely not basal and rest some 100 m above the base of the formation. These conglomerates are gray and buff, but are never red (Rima, Miesler, and Longwill, 1962; McLaughlin in Willard, *et al.* 1959).

Red siltstones of the Stockton Formation are characteristically intensively bioturbated by roots and burrows, notably the arthropod burrow *Scoyenia* (see Olsen, 1977). Purple and mauve siltstone beds with a markedly disrupted fabric occur near the middle and top of the formation. These beds are usually densely penetrated by roots, but rarely burrowed by *Scoyenia.* Beds of greenish-gray and brown carbonate-rich pellets occur throughout the formation. These are often associated with bases of buff arkose beds. Well-bedded gray and gray-green siltstone beds are present locally in the upper Stockton, and these beds are the source of most of the Stockton fossils found so far. How these units, which are unusual compared to the bulk of the Stockton sequence, fit in the overall facies pattern remains obscure.

LOCKATONG FORMATION

The beds of the Lockatong Formation rest conformably on the Stockton Formation over most of the Newark Basin. The Lockatong is composed primarily of gray and black siltstones arranged, as shown by Van Houten (1962, 1964, 1965, 1969, 1977), in sedimentary cycles. In the Bucks-Hunterdon fault block, near the Lockatong's type section along Lockatong Creek, the formation reaches its maximum thickness of 1150 m (Figure 2, Table 4). The formation thins in all directions away from this central area, passing into Passaic and Stockton formations along exposed edges of the Newark Basin.

Van Houten (1962, 1964a,b, 1965, 1969, 1977) recognizes two end-members to the range of short cycle

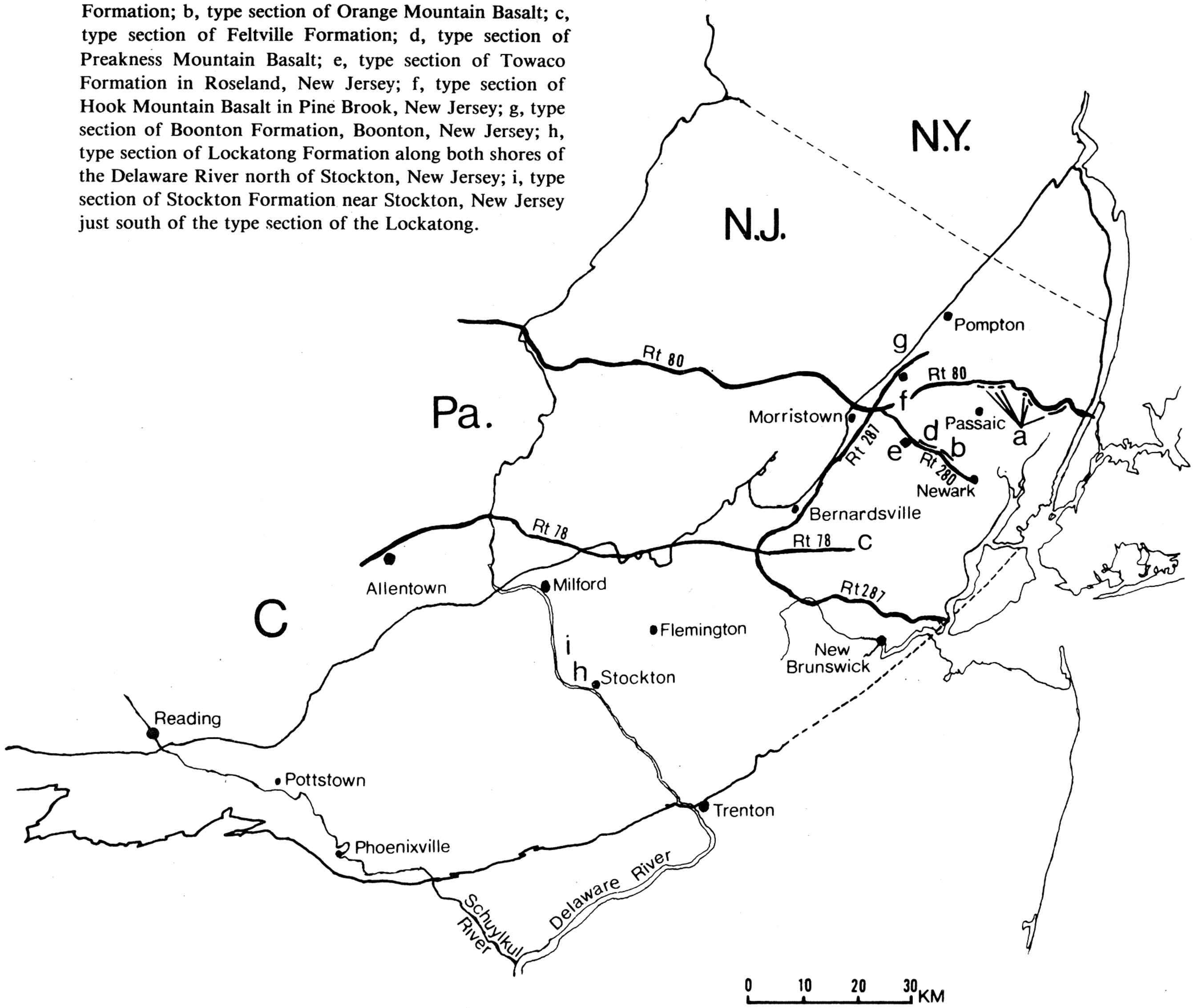


Fig. 3 Geographic map of Newark Basin showing locations of type sections of formations: a, type section of Passaic Formation; b, type section of Orange Mountain Basalt; c, type section of Feltville Formation; d, type section of Preakness Mountain Basalt; e, type section of Towaco Formation in Roseland, New Jersey; f, type section of Hook Mountain Basalt in Pine Brook, New Jersey; g, type section of Boonton Formation, Boonton, New Jersey; h, type section of Lockatong Formation along both shores of the Delaware River north of Stockton, New Jersey; i, type section of Stockton Formation near Stockton, New Jersey just south of the type section of the Lockatong.

types present in the Lockatong; he terms these detrital and chemical. In the Delaware River section of the formation the detrital cycles are an average of 5.2 m thick and consist of a lower platy black calcareous siltstone succeeded upwards by beds of disrupted dark gray, calcareous siltstone, ripple-bedded siltstone, and fine sandstone. In the same area, chemical cycles average 3.2 m thick. Their lower beds consist of platy black and dark gray dolomitic siltstone, broken by shrinkage cracks, and containing lenses of pyritic limestone. The upper beds are massive gray or red analcime- and carbonate-rich siltstone, intensively and minutely disrupted. The massive beds often contain pseudomorphs after analcime and glauberite.

Detrital and chemical cycles are not distributed randomly through the Lockatong. In vertical section, in the central Newark Basin, the two cycle types occur in clusters; the center of each detrital cycle cluster is about 107 m from the next. Detrital cycle clusters are separated by clusters of chemical cycles. Again, in vertical section, there are more detrital cycles in the lower than in the upper Lockatong. Evidence gathered so far (Olsen, this Fieldbook) indicates that individual detrital cycles can be traced for over 20 km. Judging from the outcrop pattern of detrital cycle clusters in the upper Lockatong and lower Passaic Formation, it seems likely that individual detrital cycles can be traced basin-wide. Chemical cycles, on the other hand, are predominantly restricted to the central 97 km of the Newark Basin, passing laterally into beds indistinguishable from the Stockton and Passaic formations. At the southwestern end of the Newark Basin at Phoenixville, Pennsylvania, the Lockatong is 350 m thick; the formation consists of clusters of detrital cycles separated by red siltstone and some beds of gray sandstone. At the northeastern end of

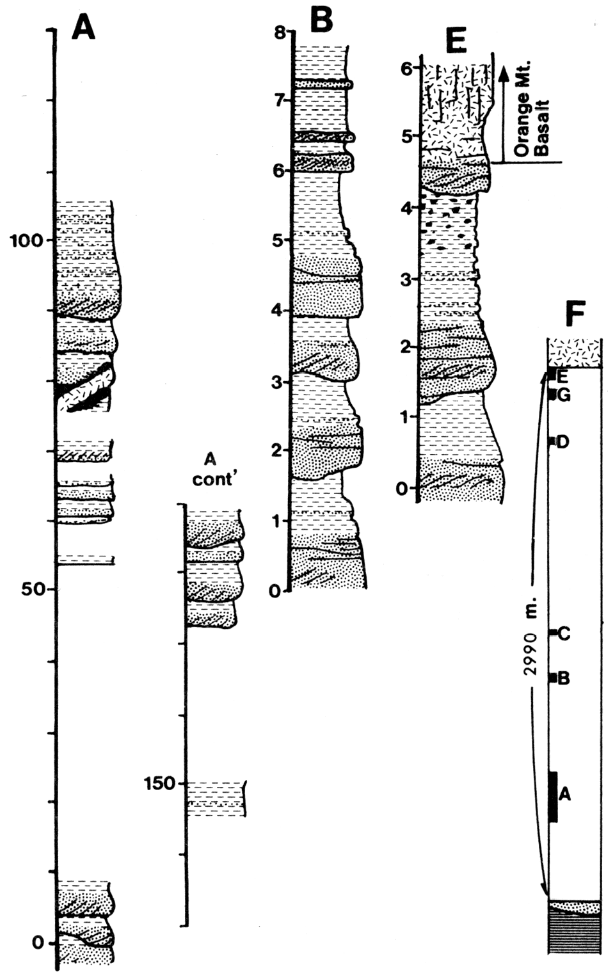


Fig. 4 A - E, type section of Passaic Formation (Table 5 for description); F, diagram showing positions of sections A - E in Passaic Formation.

the Newark Basin at Weehawken, the Lockatong is 150 m thick and consists of detrital cycle clusters separated by beds of buff arkosic sandstone. The large number of detrital cycles prevalent in the lower Lockatong in the central Newark Basin strongly suggests that the Lockatong outside of its thickest central portion comprises only the lower 500 m of the Lockatong or less (not including the lower 30 m of red siltstone grouped here in the Stockton).

The thickness of the Lockatong decreases away from the central Newark Basin not only by replacement of its upper beds by Passaic Formation but also by the thinning of individual detrital cycles. While the mean detrital cycle thickness is 5.2 m along the Delaware River, for example, it is 1.5 m along the Hudson River (see Olsen, this Fieldbook).

Beds along strike from the lower Lockatong at the northeastern, southeastern, and northwestern edges of the Newark Basin are indistinguishable from the Stockton Formation and are thus mapped (Figure 2).

PASSAIC FORMATION

The name Passaic Formation has recently been applied (Olsen, in press) to the predominantly red siltstones, sandstones, and conglomerate which conformably overlie the Lockatong Formation and which underlie the Orange Mountain and Jacksonwald Basalts. It is equivalent to the pre-basalt portion of Kümmel's Brunswick Formation (Table 2). The type section consists of intermittent exposures of red clastics along Interstate Route 80 near Passaic, New Jersey (Figure 3 and 7).

The Passaic Formation is the thickest coherent lithologic unit in the Newark Basin, reaching a maximum calculated thickness of over 6000 m (Jacksonwald Syncline — Figure 2). The formation outcrops throughout the Newark Basin, although its upper beds are preserved only in the Watchung Syncline (Figure 2), in the smaller synclines preserved along the eastern side of the Flemington Fault, and in the Jacksonwald Syncline (Figure 2). In all other areas, the upper Passaic has been removed by post-Newark erosion.

While in most areas the Passaic Formation rests conformably on Lockatong Formation or, where that is absent, Stockton Formation, in several areas on the western margin of the Newark Basin the Passaic directly overlaps the step-faulted basement without any intervening Stockton or Lockatong. In these areas (Figure 2) the thickness of Passaic Formation present below the Orange Mountain Basalt is comparatively slight.

Facies patterns of the Passaic Formation are a modified continuation of those of the Lockatong, and differ from all younger Newark Basin deposits. As in the Lockatong, periodically spaced clusters of detrital cycles occur through most of the thickness of Passaic Formation (Van Houten, 1969). The great majority of these non-red units, however, are not as laterally continuous as those of the Lockatong, and as a general trend, it is clear that the number of cycles involved in these clusters decrease in frequency upwards through the Passaic Formation (see Van Houten, this Fieldbook). The boundary between the Passaic Formation and the Lockatong can be operationally defined (both horizontally and vertically) as where the thicknesses of beds of red clastics dominate gray and black. It follows from this definition that where gray and black detrital cycles do not occur, as in Rockland County, New York, the Passaic Formation rests directly on Stockton Formation.

McLaughlin (1933, 1943, 1945, 1946, 1948) has succeeded in mapping out the distribution of Passaic Formation detrital cycle clusters over the Bucks-Hunterdon Fault Block and part of the Montgomery-Chester fault

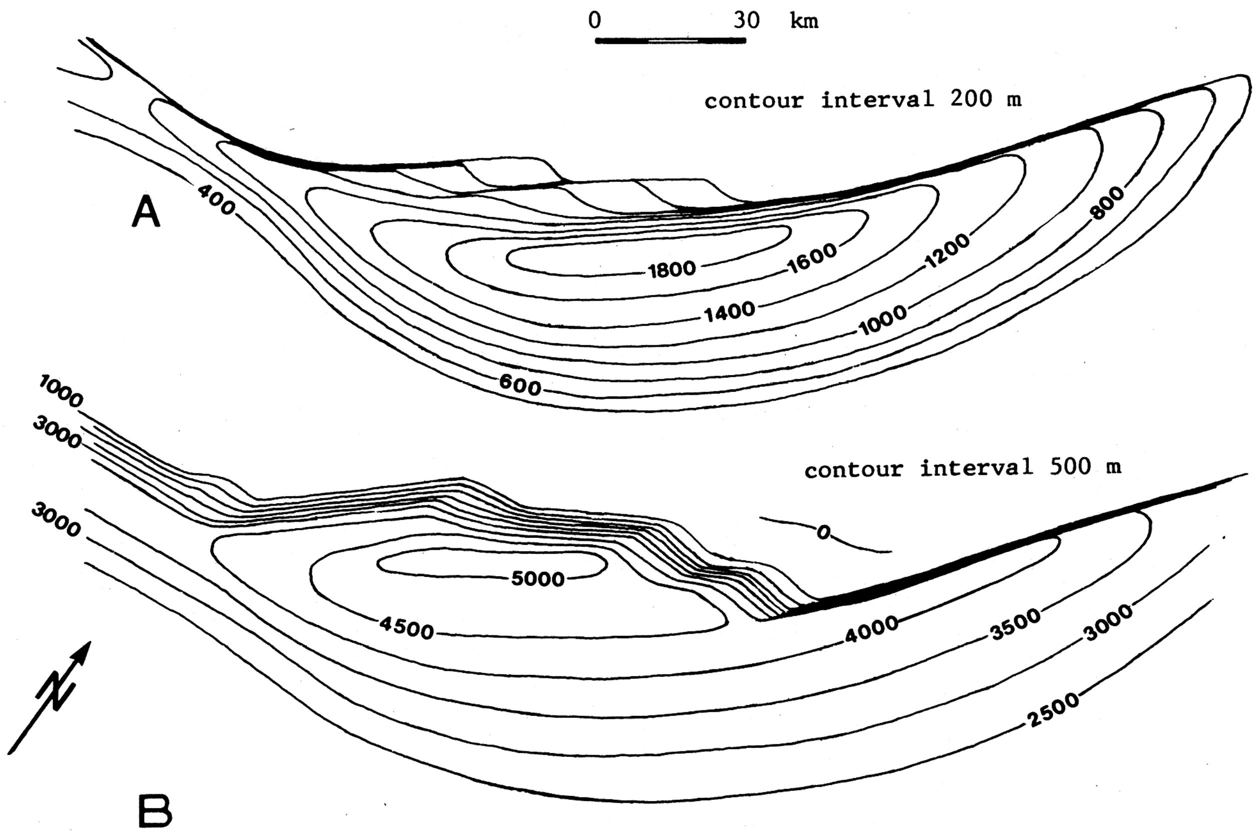
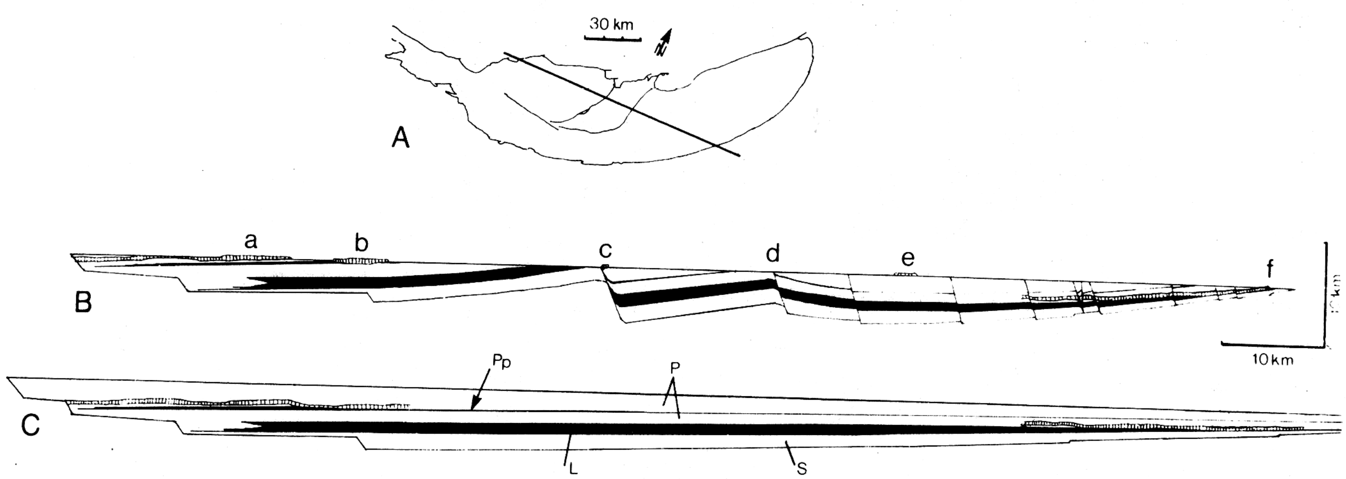


Fig. 5 Approximate predeformational shapes of Stockton Formation (A) and Lockatong-Passaic Formation (B) sediment bodies.

Fig. 6 Cross-section of the pre-Orange Mountain Basalt portion of the Newark Basin: A, position of section in Newark Basin; B, present cross section--note that the vertically ruled band represents diabase and gabbro sills and plutons; C, reconstructed section with Passaic Formation-Orange Mountain Basalt contact as horizontal--note thinning to east and ramping to west.
Abbreviations as follows: a, Haycock Mountain Pluton; b, Coffman Hill Pluton; c, Flemington syncline outlier of Orange Mountain Basalt and to the immediate left the Flemington Fault; d, Hopewell Fault; e, Orange Mountain Basalt of Watchung syncline; L, Lockatong Formation; P Passaic Formation; P;. Perkasie Member of Passaic Formation; S, Stockton Formation. Note that the trigonometrically calculated thickness of Passaic Formation east of the Watchung syncline has been reduced by 25% as a correction for dip slip faults.



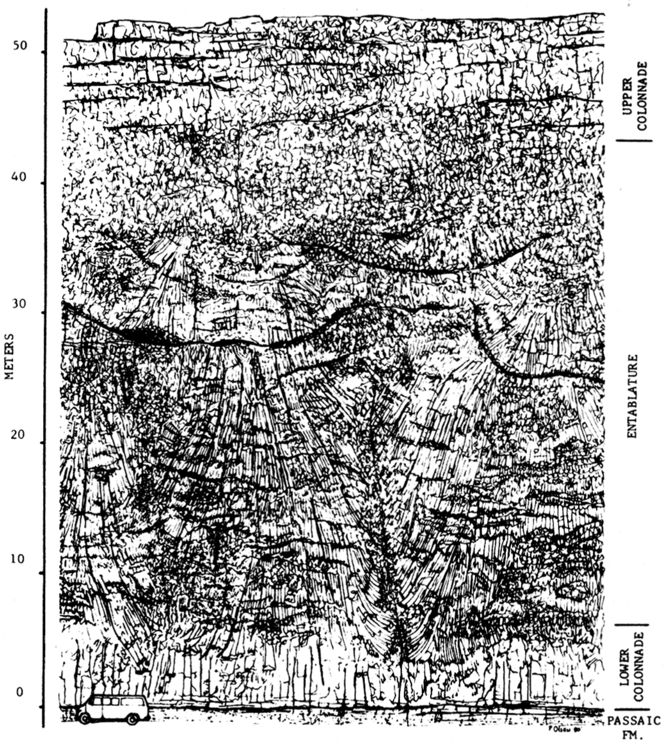


Fig. 7 Type section of the Orange Mountain Basalt; exposure along Interstate Route 280 in East Orange, New Jersey. Traced from a composite of a continuous series of photographs.

block. A detailed physical stratigraphy has developed around these mapped beds, each detrital cycle being designated by a letter (A,B,C,...). The extension of McLaughlin's units outside of the areas he mapped is a principal goal of ongoing field research (Figure 2). The highest of McLaughlin's mapped units (134 m above L and M) join with other cycles to the southwest to form a large body of black and gray siltstone called the Perkasie Member (McLaughlin, 1946). Unlike the Lockatong Formation, however, the thickest section of the Perkasie Member is in the southwestern portion of the Bucks-Hunterdon fault block. Due to repetition by the Hopewell, Flemington, and Chalfont Faults (Figure 2) and changes in strike along folds, the broader aspects of the three dimensional relationships of most Passaic dark clastic units can be observed. Looking over the bulk of the Passaic Formation (Figure 2), there is no evidence that the rest of the detrital cycle clusters of the Passaic (i.e., other than the lateral equivalents of the Lockatong or Perkasie Member) represent the remnants of a larger, now eroded, gray and black siltstone body as Glaeser (1963) has suggested.

There are major masses of red-matrix conglomerate at both the northern and southern ends of the Newark Basin (Figure 2). It is the southern body Glaeser (1966) has named the Hammer Creek Formation (= Robeson Conglomerate of McLaughlin, 1939). These masses of red conglomerate grade nearly imperceptively into the finer red clastics of the Passaic Formation. I would prefer to consider these units as facies of the Passaic. Other much smaller areas of conglomerate occur along the western border of the Newark Basin; these are especially prevalent where Passaic Formation onlaps basement rocks (Figure 2).

Because of the interfingering and inverse thickness relationships that are consequences of the definitions of the Passaic and Lockatong formations, the predeformational shape of each formation is very difficult to depict. Therefore, in Figure 5 the thicknesses of both formations are combined so that the lens shape of the Lockatong-Passaic lithosome is evident. Interestingly, the Lockatong-Passaic lithosome is thickest just to the west of the thickest portion of the Stockton. To the west and north of this thickest area, progressively higher Passaic beds lap onto a step-faulted basin margin, while to the east, the entire Lockatong-Passaic lithosome thins by the thinning of its individual components (see Figure 6).

ORANGE MOUNTAIN BASALT

Orange Mountain is the local name of the First Watchung Mountain in Essex County, New Jersey, long known for its spectacular exposures of columnar basalt (Cook, 1884). I have recently applied the name Orange Mountain Basalt to these multiple (at least two), tholeiitic, olivine-poor basalt flows and interbedded volcanoclastic units above the Passaic Formation and below the Feltville Formation (Olsen, in press). The type section (Figure 7), exposing about 40% (50 m) of the formation's total thickness, is along Interstate Route 280 at its cut through Orange Mountain in East Orange, New Jersey. The petrography and geochemistry of the Orange Mountain Basalt (as well as the two younger basalt formations of the Newark Basin) is reviewed by Faust (1975), and is therefore not discussed here.

The Orange Mountain Basalt is the oldest Newark Basin Formation thought to be wholly Early Jurassic in age, and like similarly aged beds in the Newark Basin, the main area in which the basalt is preserved is the Watchung Syncline (Figure 2). Smaller synclines preserve portions of the Orange Mountain Basalt in several other regions (Figure 2). In the New Germantown and Sand Brook Synclines, the overlying Feltville Formation is preserved above the basalt. Correlation by palynomorph assemblages and fossil fish of the overlying Feltville Formation (Cornet, 1977; Olsen, McCune, and Thomson, in press) demonstrate the identity of the underlying basalt. Between these two synclines is a newly identified, very small outlier of basalt, preserved in what can be called the Flemington Syncline (Figure 2). Unfortunately, the remnant is so small that no sedimentary rocks are preserved above the basalt. The simplest hypothesis identifies this basalt remnant as an additional portion of the Orange Mountain Basalt.The Jacksonwald Basalt crops out in a syncline near the southern terminus of the Newark Basin (Figure 2 and 3) over 100 km southwest of the Watchung Syncline. Palynomorph assemblages recovered from the overlying sediments indicate correlation with the Feltville Formation (Cornet, 1977). There is no evidence to contradict the hypothesis that this outlier too represents the Orange Mountain Basalt.Two other as yet poorly known probable outliers of Orange Mountain Basalt are the Union Hill and Ladentown basalts in Rockland County, New York (Ratcliffe, this Fieldbook), (Figure 2). Taken together, these remnants of Orange Mountain Basalt suggest that originally the basalt covered the entire Newark Basin, a minimum of over 7700 km². This is comparable to the extent of the Holyoke Basalt over the Hartford Basin and the North Mountain Basalt over the Fundy Basin.

The Orange Mountain Basalt appears thickest in the Watchung Syncline, varying between 100 and 200 m. At least 130 and 120 m are present in the New Germantown and Sand Brook Synclines, respectively, and + 100 m are present in the Jacksonwald Syncline. Potential error in measurement in these outliers is great. Existing exposures do not permit estimates of the thicknesses of the Flemington, Union Hill, or Ladentown outliers.

A minimum of two flows is evident in most sections of the Orange Mountain Basalt, at least in the Watchung, New Germantown, and Ladentown Synclines. The lower flow is exposed at the type section where it shows a nearly complete Tomkeieff structural sequence (Manspeizer, 1969). Other exposures of the lower flow are abundant. In most places the lower and upper flows are separated by a red volcanoclastic bed which is generally less than a meter thick (Bucher and Kerr, 1948; Johnson, 1957; Van Houten, 1969; Faust, 1975). In the New Germantown Syncline, however, the volcanoclastic bed is over 4 m thick and has numerous beds of purple, red, and gray ripple-bedded and mudcracked siltstone. The upper flow is extensively pillowed and pahoehoe-like near the type section (Fenner, 1908; Van Houten, 1969) and locally at isolated spots throughout the Watchung Syncline. Elsewhere, however, the upper flow resembles the lower in having a large columnar entablature. It is not clear whether these flows represent continuous sheets.

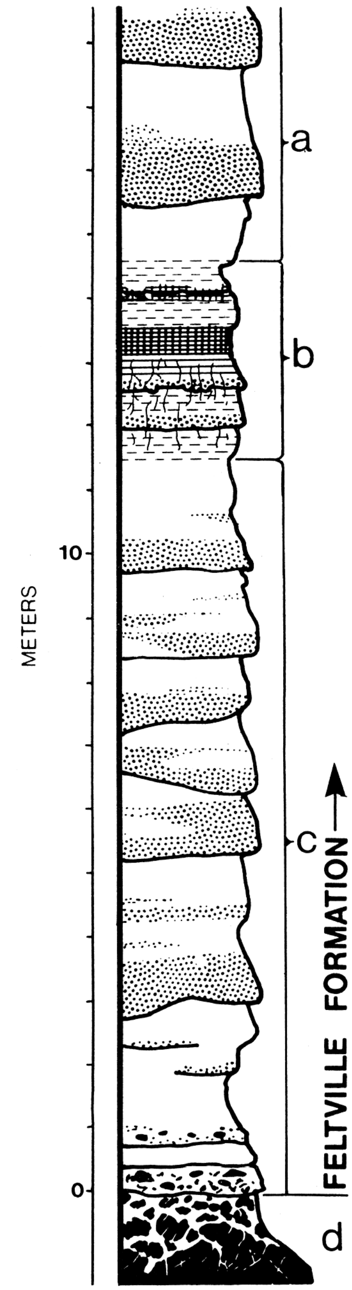


Fig. 8 Type section of the Feltville Formation; section exposed along ravine for Blue Brook about 1 km south of Lake Surprise in the Watchung Reservation. For key to individual units.

FELTVILLE FORMATION

The sedimentary rocks above the Orange Mountain Basalt and below the Preakness Basalt are termed the Feltville Formation (Olsen, in press). The Feltville consists of red siltstone and sandstone, buff, gray, and white feldspathic sandstone, and a thick, laterally continous non-red unit containing a unique laminated limestone. This formation is named for the old village of Feltville, Union County, New Jersey, where the type section is located (Figure 8).

Like the underlying Orange Mountain Basalt, the Feltville Formation is preserved in the Watchung, New Germantown, Sand Brook, and possibly the Jacksonwald Synclines (Figure 2). The formation averages about 170 m in the Watchung Syncline, apparently thickening to 300 m in the Sand Brook and 600 m in the Germantown Syncline. More than 200 m seems to be present in the Jacksonwald Syncline.

The Feltville Formation is distinguished from the underlying Passaic Formation and the younger Jurassic formations of the Newark Basin by the presence of abundant beds of buff, gray, or white feldspathic sandstone interbedded with red siltstone in fining-upwards sequences (Olsen, in press); thus, much of the Feltville superficially resembles the Stockton Formation. The lower half of the Feltville contains a black to white laminated limestone, calcarenite, and graded siltstone bed (0.4 - 3 m) containing abundant fossil fish. This is sandwiched between two beds (each 1-7 m) of gray, small- to large-scale crossbedded siltstone and sandstone. As is true for the formation as a whole, these beds are thickest in the New Germantown Syncline (+ 14 m).

Conglomerate occurs in the Feltville Formation at Oakland, New Jersey, about 15 m below the Preakness Basalt (Faust, 1975). This conglomerate contains as much as 30 % vesicular basalt clasts, in addition to cobbles and pebbles of phyllite and limestone. Very little of the section below this unit is exposed and at this point it is impossible to say how much additional conglomerate is present. Other beds of conglomerate crop out in the New Germantown Syncline in association with the non-red laminated beds. The available evidence suggests that the Feltville Formation, like the Orange Mountain Basalt, originally occupied the whole of the area of the Newark Basin; the predeformational shape of the Feltville lithosome seems to have been a wedge thickest along the western border of the basin. The data are not conclusive, however.

PREAKNESS BASALT

Preakness Basalt consists of the extrusive, tholeiitic basalt flows and interbedded volcanoclastic beds above the Feltville Formation and below the Towaco Formation (Olsen, in press). Preakness Mountain is the local name of the second Watchung Mountain near Franklin Lakes, New Jersey. The type section is located along Interstate Route 280 (Figure 9) about 2.25 km west of the type section of the Orange Mountain Basalt.

The Preakness Basalt is the thickest extrusive unit in the Newark Basin. The calculated thickness is 215 m at its northernmost outcrops at Pompton and Oakland, New Jersey. Judging from outcrop width alone, the formation thickens to as much as 500 m near the type section. This figure is questionable since in the area where the formation seems to be the thickest, the strike of the beds parallels a series of small faults, many of which have a strong normal component. That a figure of more than 300 m may be nearer to the truth is suggested by the persistence of a large outcrop width around the southern curve of the Watchung Syncline. The

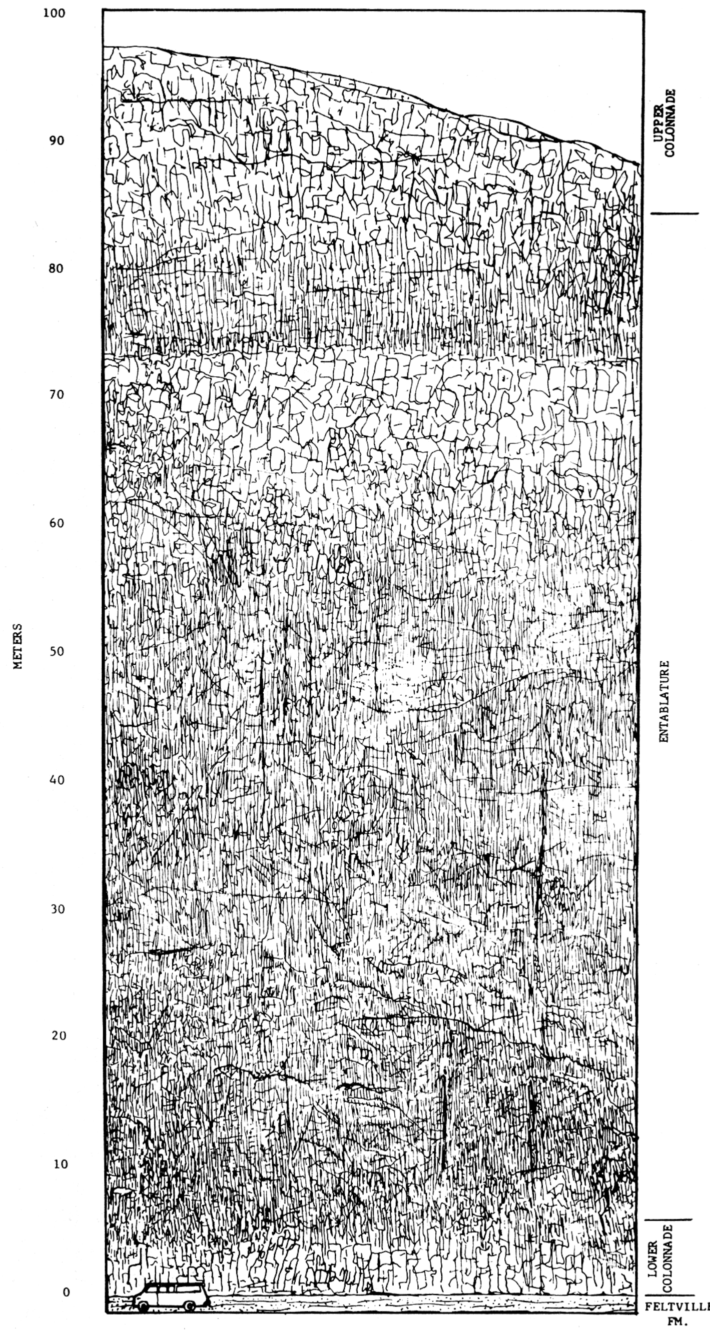


Fig. 9 Type section of the Preakness Mountain Basalt. Section located along Interstate 280, 2.25 km west of type section of the Orange Mountain Basalt. Section traced from composite of continuous photographs.

Preakness Basalt may be the youngest formation represented outside the Watchung Syncline. There are small masses of basalt at the northwestern edge of the New Germantown and Sand Brook Synclines, but it is unclear (because of poor exposure) whether these beds are lying stratigraphically above the Feltville or rare merely upthrown fault slices of the Orange Mountain Basalt (Olsen, in press). Some geochemical evidence supports the former hypothesis (Geiger, Puffer, and Lechler, 1980).

At its base, the Preakness Basalt is much more variable than the Orange Mountain Basalt. Locally, there are thick sequences of multiple basalt flows making up possible basalt foreset beds (Manspeizer, this Fieldbook). In other areas there are thick beds of angular and vesicular basalt breccia resembling aa. In still other areas the thick massive lower flow rests on the flat Feltville Formation surface (Lewis, 1908).

At least two or three thick individual flows make up the bulk of the Preakness Basalt. The lowest flow is the thickest (+100 m) and is exposed througout the Watchung Syncline usually showing a complete although modified Tomkeieff structural sequence (Figure 9). In most outcrops the entablature is coarsely grained and very densely jointed, forming high, irregularly jointed columns 0.1-1.0 m wide, in marked contrast to the hexagonally jointed Orange Mountain Basalt. This characteristic joint pattern, which Faust (1978) calls platy prismatic (in contrast to cooling joints), allows the Preakness Basalt to be identified at isolated outcrops (Olsen, in press). The first flow is separated from the second by a thin red siltstone, the distribution of which was mapped by Kümmel (1897) and Lewis (1907b) in the southern portion of the Watchung Syncline (but see Faust, 1975). The extent of the second flow outside this area is poorly known, although its extension into the northern Watchung Syncline is supported by some well data and known outcrop patterns (Darton, 1890;) Lewis, 1907b). There is at least one other flow present in the northern Watchung Syncline, separated by what I assume to be the second flow of the Preakness Basalt by a red and buff siltstone riddled with root casts. Faust, on the other hand (1975), feels this upper flow is the second. Darton (1890) presents evidence, partially confirmed by later field work (Olsen, in press), that the Preakness Basalt consists of three flows at Pompton, New Jersey. As with the Orange Mountain Basalt, more field work is required to clarify the number and distribution of flows in the Preakness Basalt.

TOWACO FORMATION

The name Towaco Formation is applied to the red, gray and black sedimentary (and minor volcanoclastic) rocks present below the Hook Mountain Basalt and

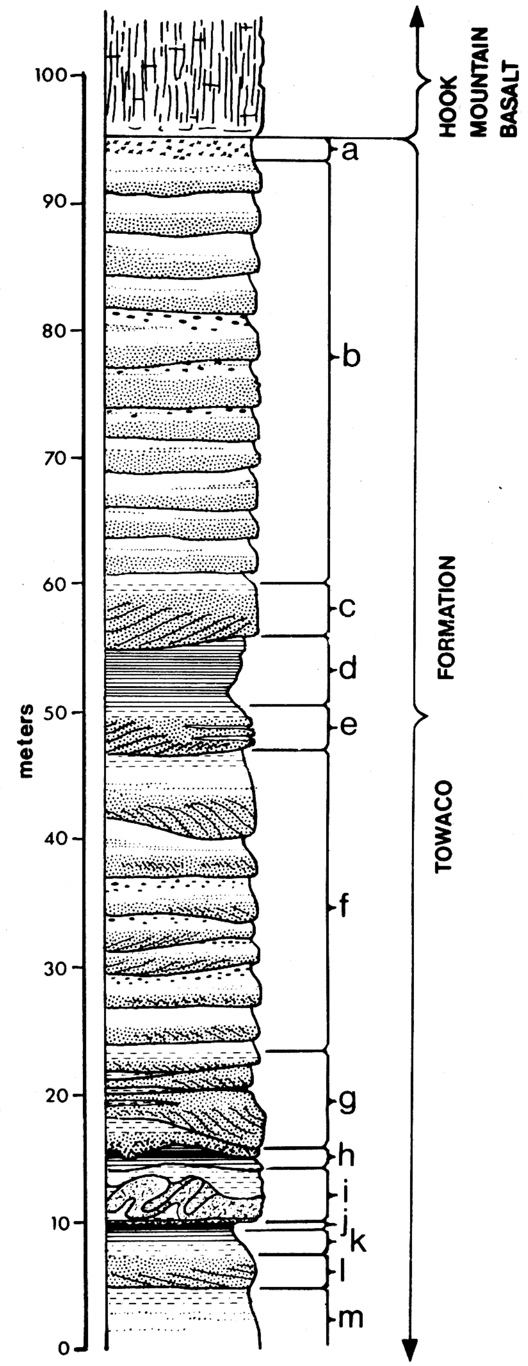


Fig. 10 Type section of the Towaco Formation in the Dinosaur Tract, Essex County Park Commission, Roseland, New Jersey. For key to individual units.

above the Preakness Basalt in the Watchung Syncline (Olsen, in press). The type section is the Essex County Department of Park Recreation and Cultural Affairs, Walter Kidde Dinosaur Park (Roseland or Riker Hill Quarry), Roseland, New Jersey, where 50 m of the uppermost Towaco Formation is exposed, making up 15% of 340 m present in that area (Figure 10, Table 7).

Laterally continuous symmetrical sedimentary cycles characterize most of the Towaco Formation. These consist of a central black or gray microlaminated calcareous siltstone bounded above and below by gray sandstone and siltstone beds arrange in fining-upwards cycles. These symmetrical cycles are a mean of 35 m thick and bear a close resemblance to the East Berlin Formation (Hartford Basin) cycles described by Hubert, Reed, and Carey (1976). Towaco cycles are an order of magnitude thicker than Lockatong or Passaic Formation detrital cycles and differ from the otherwise similar Feltville Formation non-red unit in containing a predominantly clastic rather than carbonate laminated portion (Figure 13). In total, six such cycles have been identified in the upper half of the Towaco Formation and most of these have been traced through the Watchung Syncline.

Beds of conglomerate occur at numerous horizons through the Towaco Formation at Pompton, New Jersey. Not only is conglomerate present directly below the Hook Mountain Basalt in this area (Faust, 1975), but thick conglomerate beds also occur at intervals of about 120-150 m. 160-170 m, 185-195 m, 205-220 m, and 270-280 m below the Hook Mountain Basalt. As a general comment, I see no special relationship between the position of any Passaic-Boonton conglomerate beds and lava flows (*contra* Faust, 1975). Clast composition, especially the inclusion of basalt fragments, may be important, however.

There is a thin brown volcanoclastic unit at the top of the Towaco Formation. It is about 1 m thick and occurs at most exposures of the upper Towaco Formation. It is especially well exposed at the type exposure. This volcanoclastic unit is in the same position as the flow-breccia described by Faust (1978) at Pompton. Lewis (1908) has been the only worker to study unweathered sections of this volcanoclastic unit and he described it as consisting of altered volcanic glass with inclusions of feldspar and augite and pseudomorphs after olivine in a matrix of brown radial natrolite.

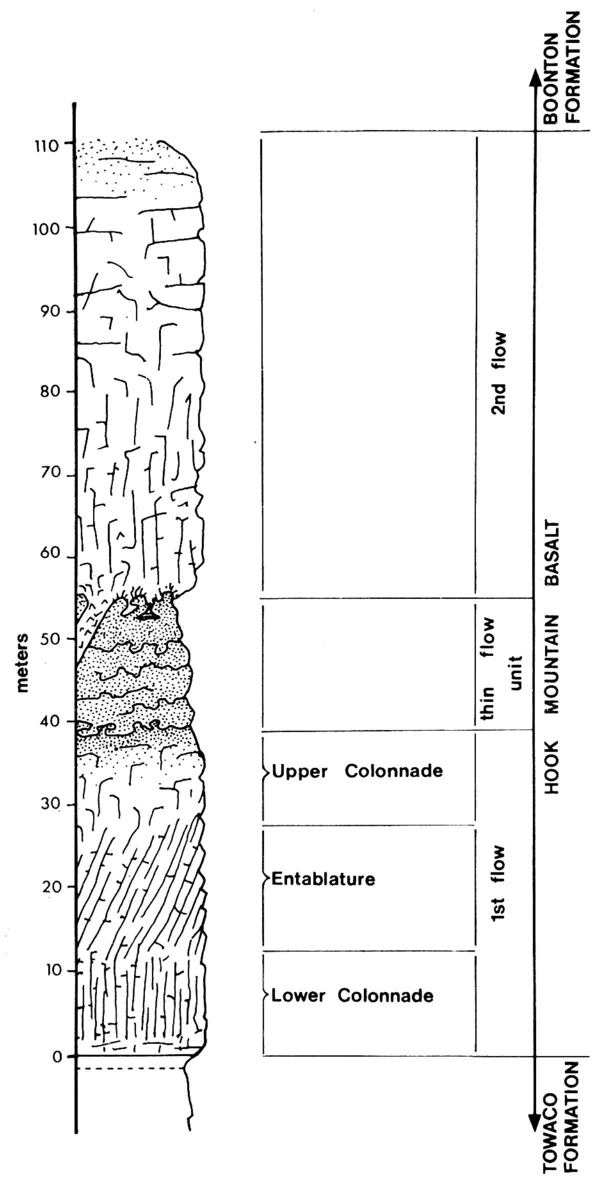


Fig. 11 Type section of the Hook Mountain Basalt. Note two major flow units and interbedded thin pahoehoe flows and possible feeder dike. Section exposed along Interstate 80 near Pine Brook, New Jersey.

HOOK MOUNTAIN BASALT

The uppermost extrusive unit in the Watchung Syncline is called the Hook Mountain Basalt (see Baird and Take, 1959). The name is taken from its type exposures (Figure 11) in cuts along Hook Mountain Road and Interstate Route 80 through the southern tip of Hook Mountain near Pine Brook, New Jersey. About 80% of the total formation is exposed there (Olsen, in press).

The Hook Mountain Basalt is the thinnest of the three major extrusive formations of the Newark Basin; at its type section, it is 110 m thick and it retains this thickness throughout the Watchung Syncline. That this basalt extends subsurface across the gaps between Hook Mountain and Riker Hill and between Riker Hill and Long Hill is shown by the bedrock topography maps of Nichols (1968) and the aeromagnetic data of Henderson, *et al.* (1966). In the area of Bernardsville, New Jersey, what has been mapped (Lewis and Kümmel, 1910-1912) as part of the Preakness Basalt is in fact Hook Mountain, as shown by unambiguous exposures of Towaco Formation between it and the underlying basalt. This portion of Hook Mountain Basalt I have traced nearly to the Long Hill portion. The remaining gap is probably due to a series of small faults.

Aeromagnetic data (Henderson, *et al.*, 1966) is no help in this area since the faults would probably run about N-S and thus be parallel with linears caused by errors in the alignment of flight paths. These newly mapped portions of the Hook Mountain Basalt are shown in Figure 2.

Two flows have been recognized through most of the Watchung Syncline. At the type section the lower flow is 57 m thick and shows a complete Tomkeieff structural sequence (Figure 11), while the upper flow is more massive, without clear columnar jointing. As is the case for the flows which make up the older two basalt formations of the Newark Basin, it is not definitely clear that the upper and lower flows of the Hook Mountain Basalt represent continuous sheets over the extent of the whole formation.

BOONTON FORMATION

Overlying the Hook Mountain Basalt are sedimentary rocks that Baird and Take (1959) termed the Boonton and Whitehall beds of the Brunswick Formation. I have proposed the formal name Boonton Formation for these beds, the type section being near Boonton, New Jersey along the Rockaway River (Figure 12) (Olsen, in press). The Boonton Formation is the youngest sedimentary unit in the Newark Supergroup sequence of the Newark Basin and consists of more than 500 m of red, brown, gray, and black fine to coarse clastics and minor evaporitic beds.

The stratigraphically lowest beds in the Boonton Formation are well exposed near Bernardsville, New Jersey. In this area, the formation consists of blocky to finely bedded red, gray, brown, and black, often dolomitic siltstone. Thin (1-4 m) beds riddled with hopper casts (pseudomorphs after gypsum, glauberite, and halite) are common in sequences of all colors. Similar beds are exposed along Packanack Brook, Wayne, New Jersey. The different colors or textures of these beds do not seem to be arranged in any obvious or consistent cyclic pattern and resemble no other units in the Newark Basin. Stratigraphically above these lower beds is a sequence of well-bedded red siltstones and sandstone beds (mean thickness 35 m) alternating with thinner beds of gray-green siltstones (mean thickness 2 m). The longest continuous section of these beds is the type section (Figure 13). The uppermost beds of the type section include a bearing fossil fish calcareous gray microlaminated siltstone at least one meter thick (Smith, 1900). This is the famous Boonton Fish Bed (Newberry, 1888; Schaeffer and McDonald, 1978). Also in this section are gray and brown conglomerate units up to 0.5 m thick. Along the western edge of the Watchung Syncline, northeast of Morristown, New Jersey are thick sequences of red-, gray-, and brown-matrix

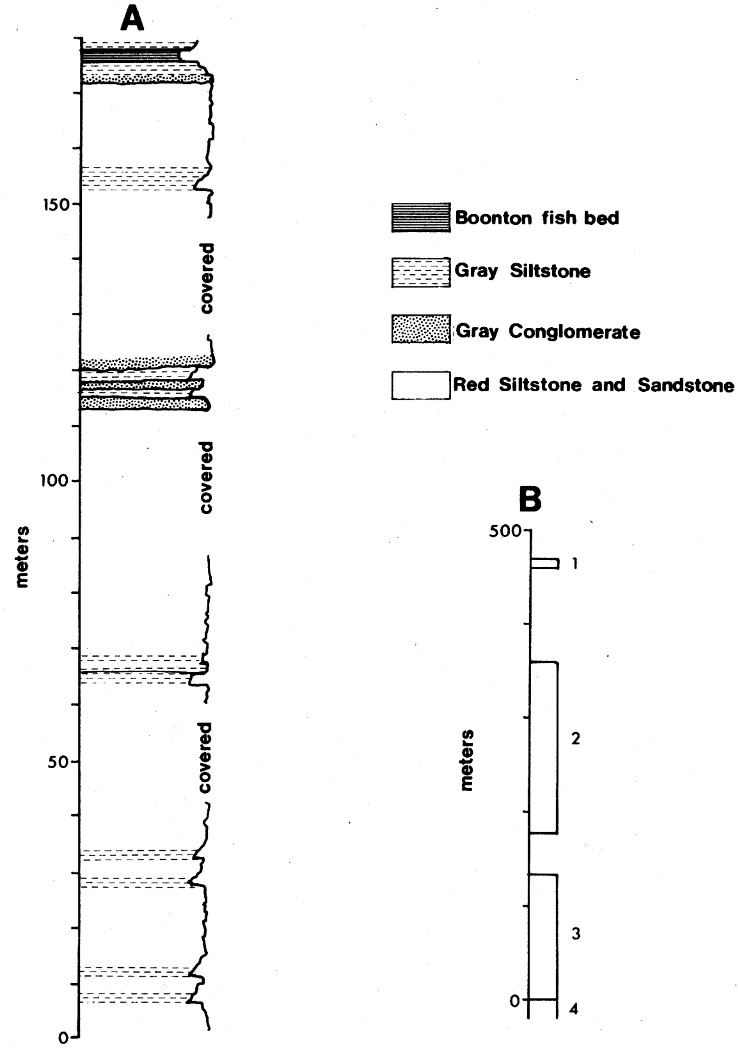
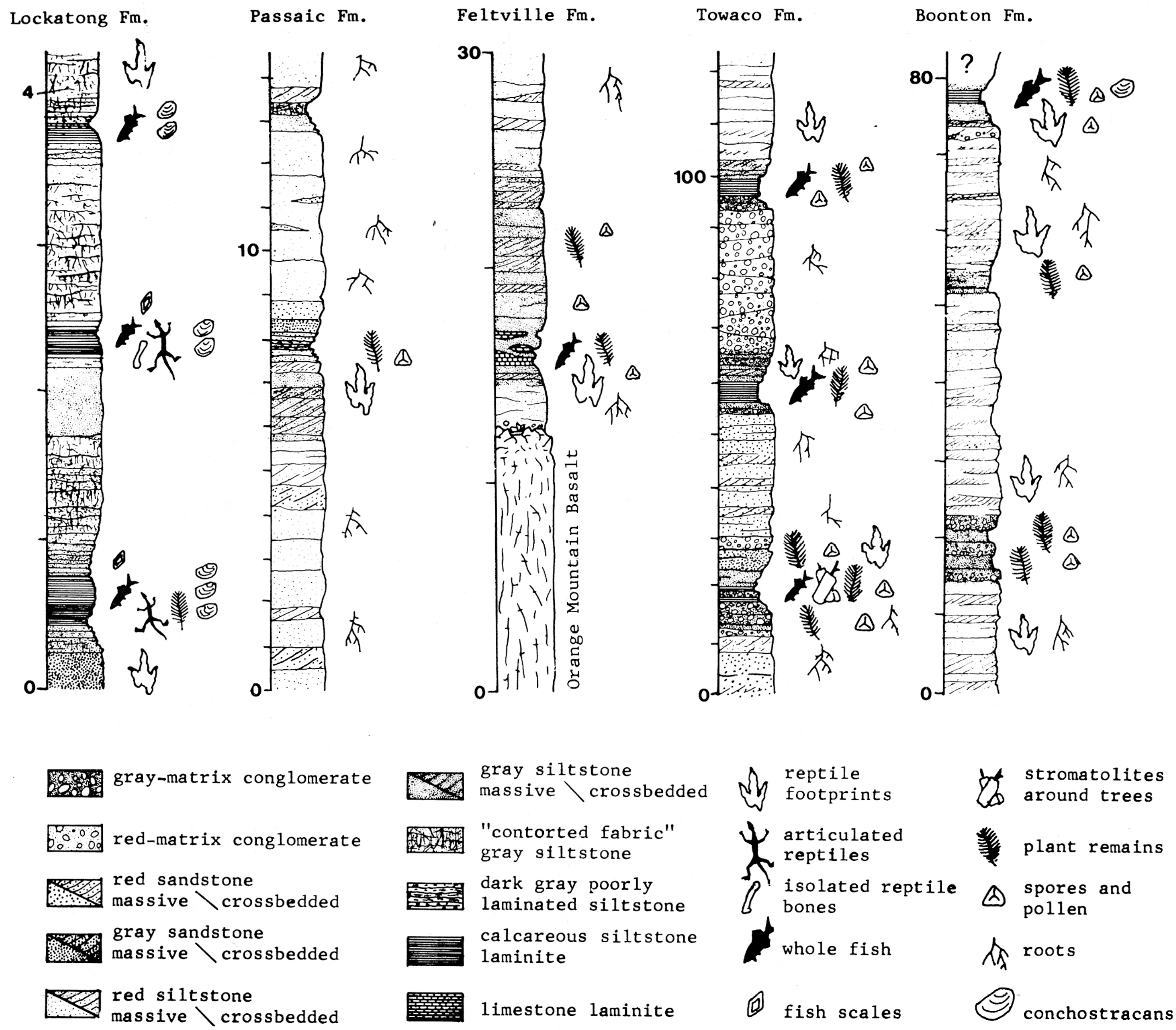


Fig. 12 Type section of the Boonton Formation: A, section exposed along Rockaway River in Boonton, New Jersey; B, composite section of entire preserved Boonton Formation; red matrix conglomerate exposed at Chestnut Hill, Morristown, New Jersey; 2, beds making up the type section; 3, gray, black, brown, and red siltstones exposed near Bernardsville, New Jersey; 4, Hook Mountain Basalt.

conglomerate and breccia. The relationships of these units to the finer portions of the formation are unclear.

DIABASE INTRUSIONS

Large diabase and gabbro plutons and sills are emplaced through various portions of the pre-Orange Mountain Basalt section of the Newark Basin sequence. The areal extent, petrography, and contact relationships of these masses are, for the most part, well known (Darton, 1890; Kümmel, 1897, 1898; Lewis, 1908; Lewis and Kümmel, 1910-1912; Willard, *et al.*, 1959; Hotz, 1952) and will not be described in detail here. These bodies



Major types of sedimentary cycles of the formations of the Newark Basin. Note that the approximate center of the symbols for the major types of fossils found is placed about where they occur in the section to the left. Note the change in scale (in meters) from section to section.

Lockatong Formation section measured at Kings Bluff, Weehawken, New Jersey and represents three detrital cycles. The Passaic Formation section measured along Nishisakawick Creek and Little Nishisakawick Creek, northeast of Frenchtown, New Jersey; the two cycles shown represent the lower portion of McLaughlin's Graters Member (i.e., Member G) and are characteristic of most of the detrital cycles of the Passaic Formation. The upper cycle develops a dark gray siltstone a kilometer to the south. Feltville Formation section measured along East Branch of Middle Brook, Martinsville, New Jersey--there is only one such "cycle" in the Feltville Formation. Towaco Formation section measured along stream 2 km southwest of Oakland, New Jersey; three cycles are shown. Boonton Formation section is upper part of type section (see Figure 12); section not clearly cyclic.

generally parallel the distribution of major bodies of gray and black siltstones; thus the largest intrusives are broadly concordant (but locally discordant) to the Lockatong Formation (i.e., Palisade, Rocky Hill, and Sourland Mountain sills) or the Perkasie Member of the Passaic Formation (Haycock Mountain, Coffman Hill, and possibly the Cushetunk Plutons). The general pattern is for these intrusions to be emplaced progressively higher in the Newark Basin section viewed along an east to west section (Figure 6).

Like most Newark Supergroup deposits, Newark Basin beds are cut by a number of narrow, often straight and vertical diabase dikes which, in this area, trend north and northeast. The mapping of the distribution of these dikes is still very incomplete (see King, 1971, and May, 1971, for reviews).

PALEONTOLOGY AND BIOSTRATIGRAPHY

In contrast to the famous Triassic and Jurassic deposits of Europe, China, southern Africa, and southwestern United States, Newark Basin beds have been traditionally regarded as fossil-poor. Recently, however, this opinion has changed; it is now clear that every major sedimentary unit of the Newark Basin has its own suite of abundant fossils. Pollen and spores, megafossil plants, clams, arthropods, fish, reptile footprints, and even reptile skeletons are abundant in certain units through the Newark. Considering the very large number, high diversity, and excellent quality of Newark fossils and the very long (ca. 35 million years) time span represented by the fossiliferous beds, the Newark Basin section is certain to be a key factor in understanding the larger aspects of Early Mesozoic historical geology. Detailed descriptions of some individual sites are presented in Olsen, (this Fieldbook). Here the sediment-fossil relationships and the biostratigraphic framework of the Newark Basin section will be outlined.

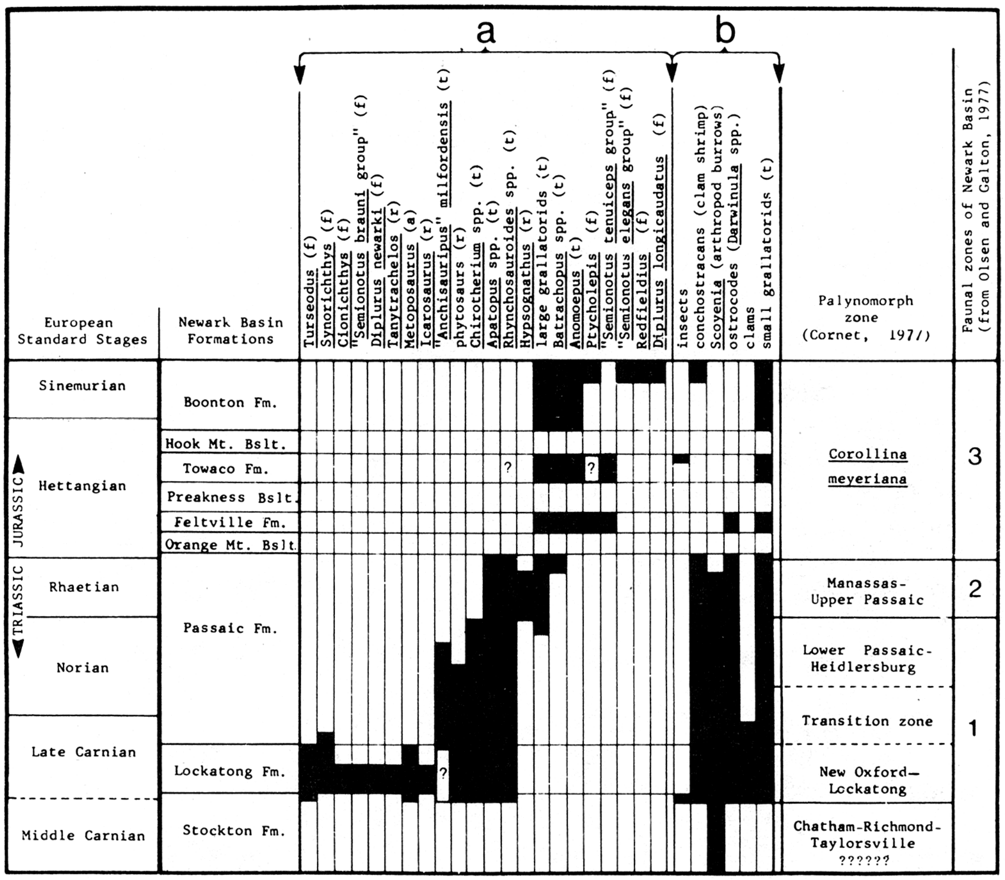
The bulk of Newark Basin sediments are red clastics. Throughout the basin, these beds are riddled with roots and burrows. As a general trend, bioturbation of all kinds is more intense in the older red beds (Stockton-Passaic) than in the younger. The arthropod burrow *Scoyenia* (see Olsen, 1977) is the most common trace of macro-bioturbation in the pre-basalt red clastics. Reptile footprints are abundant throughout the red beds in association with gray and black sedimentary cycles, and locally in red beds along the basin edge where bioturbation is not intense. Claystone-replaced megafossil plants occur in thin belts of red and purple siltstone near the base of the Stockton. Common plants include cycadeoids, conifers, and equisetalians. Newark Basin red sandstones have yielded a series of reptile skeletons, especially in the area of Passaic, New Jersey in the upper Passaic Formation (Colbert, 1946). Despite a notable lack of good exposures in this area, skulls and skeletons of the procolophonid reptile *Hypsognathus* show up at a rate of more than one per decade. Systematic collection in Newark Basin red beds would probably yield many more vertebrate remains. Most kinds of fossils, however, are more abundant in the gray and black facies of the Newark Basin, especially in the sedimentary cycles which characterize the Lockatong, Passaic, and Towaco formations. The distribution of characteristic fossils in these sequences is given in Figure 13. The discovery of large numbers of fossils in the Newark Basin (as well as throughout the Newark Supergroup) has prompted a restudy of the biostratigraphic relationships of the sequence as a whole.

The basic biostratigraphic framework for Newark Basin deposits has been outlined by Olsen and Galton (1977) and by Cornet (1977), and the details of this correlation will be given elsewhere (Olsen, McCune, Thomson, in press; Olsen, Baird, Salvia, MS; Colbert and Olsen, MS). Here I will simply outline the distribution of taxa within the Stockton through Boonton Formations and tie these in with the regional correlation (Table 8, Figure 14).

For regional correlation, relatively heavy emphasis has been placed on the distribution of palynomorph taxa (Cornet, 1977, and pers. comm.), especially for correlation between the upper Newark and the European type Early Jurassic (Figure 14). Tetrapod data, both in the form of skeletal remains and footprints, parallel the palynomorph data, and have been essential in correlating regions from which floral data is not available, such as the upper Stormberg (J.M. Anderson, pers. comm.). For fine internal correlation of the Early Jurassic portions of the Newark, however, the biostratigraphic subdivisions based on pollen and spores have proved too broad (Cornet, 1977). In these areas, fossil fish have provided a means of correlation (Olsen, McCune, and Thomson, in press).

The broad aspects of this biostratigraphic correlation agrees with most geophysical data, particularly the paleomagnetic work of McIntosh (1976) and Reeve and Helsley (1972) on the Newark Basin section and on the Chinle Formation (southwestern United States). In addition, radiometric dates of Newark Basin basalts suggest a Jurassic age for these units (Armstrong and Besancon, 1970; Dallmeyer, 1975; Sutter and Smith, 1979; K.K. Turekian, pers. comm.) It must be noted, however, that current geophysical techniques are too inconsistent for the data to be used in fine-scale correlation of individual formations of the Newark Supergroup.

A



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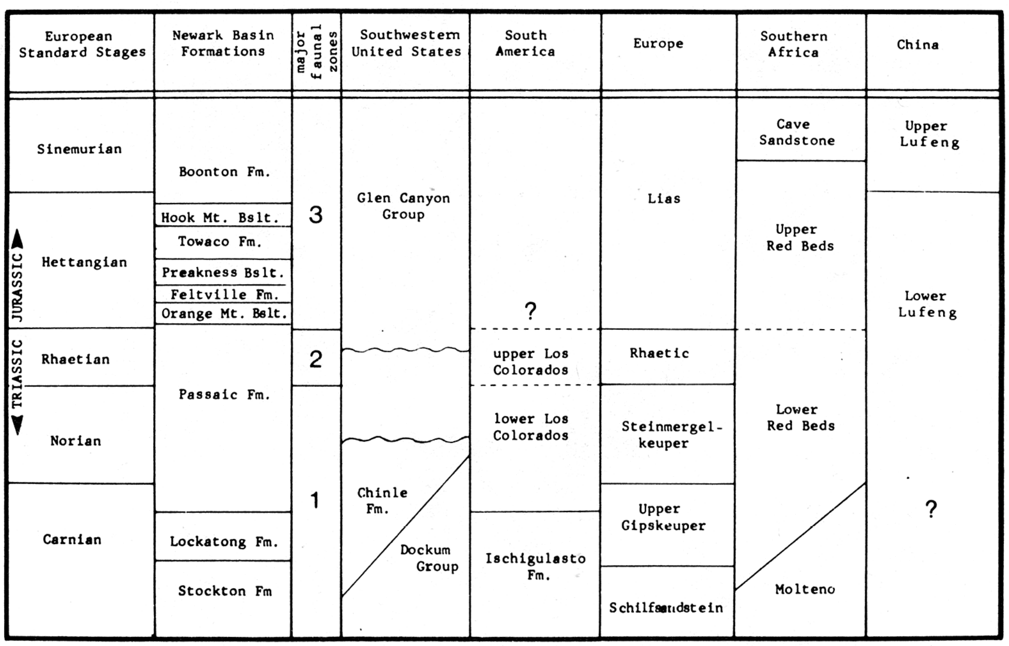

Fig. 14

A. Distribution of most abundant vertebrate and invertebrate fossils in the Newark Basin; a, taxa thought to be biostratigraphically important; b, taxa thought to be of little or no stratigraphic value. Letters in parenthesis--(f), (r), (a), (t)--indicate nature of fossils: (a) amphibians; (f) fish; (r) reptiles; (t) reptile footprints.

B. Correlation of the formations of the Newark Basin with other Mesozoic sequences.

Data for A and B from: Cornet (1977); Olsen (in press; Olsen and Galton (1977); Olsen, McCune, and Thomson (in press); Olsen, Baird, and Salvia (MS); and Olsen and Colbert (MS).

Thickness (meters)	Description
30.5	purplish, gray, reddish brown, and red hard siltstone
250.0	red and brown siltstone and sandstone with minor beds of gray sandstone
46.3	RAVEN ROCK MEMBER, massive white, gray, and buff, medium and coarse arkose
298.9	white, gray, buff, and red sandstone, (soft) and medium to coarse arkose with minor beds of red siltstone
106.1	CUTALOSSA MEMBER, hard white, gray, buff, and red sandstone and medium and coarse arkose
95.8	poorly exposed red sandstone and siltstone
231.0	PRALLSVILLE MEMBER, white, gray, buff, yellow, and some red sandstone and medium and coarse arkose with some quartz complomerate
137.6	gray and red sandstone and medium arkose
172.8	SOLEBURY MEMBER, white and gray arkosic conglomerate with minor beds of red siltstone and sandstone
217.2	interbedded gray, white, and buff coarse arkose, quartz conglomeratem and red sandstone and siltstone

BASE OF NEWARK BASIN SECTION

Table 3, B

Bucks-Hunterdon fault block (McLaughlin, 1945, 1946)	Montgomery-Chester fault block (Rima, Meisler, and Longwill, 1962)
mostly red siltstone and sandstone above Raven Rock Member	Upper Shale Member
beds above Prallsville Member to top of Raven Rock Member also includes Cutalossa Member	Middle Arkose Member
beds from basement contact to top of Prallsville Member also includes Solebury Member	Lower Arkose Member

Table 3

A. composite type section of the Stockton Formation; adapted from McLaughlin (1945). Exposures occur in ravines, roadside exposures, and quarries on both shores of the Delaware River near Stockton, New Jersey.

B. equivalence of McLaughlin (1945) and Rima, Meisler, and Longwill's (1962) members of the Stockton Formation.

Designation of member	Thickness (meters)	Description
base of Passaic Formation		
"Transition"	7.6	interbedded red, gray, and brown hard siltstone
B	48.8	gray and black siltstone
"Double Red"	30.2	two beds of red hard siltstone sandwiching a bed of gray and black siltstone
A_2	81.2	black hard siltstone
"Smith's Corner"	3.4	red hard siltstone
A_1	87.2	black hard siltstone
"Triple Red"	45.5	three thick beds of hard red siltstone alternating with two beds of gray and black siltstone
no name	75.3	hard black siltstone
"First Big Red"	33.5	red hard siltstone
no name	84.1	hard black siltstone
"First Thin Red"	4.6	red hard siltstone
no name	305.0	black and gray hard siltstone
Byram Diabase	64.1	
no name	18.3	hornfels of hard black siltstone
no name	91.5	massive, hard, black siltstone with much interbedded light gray hard calcareous siltstone and impure limestone
no name	80.8	thick bedded hard black siltstone
no name	22.9	thick bedded hard black siltstone with interbedded hard brown siltstone
no name	33.6	interbedded red, purple, and black hard siltstone
base of Lockatong Formation		

Table 4

Composite type section of the Lockatong Formation, adapted from McLaughlin (1944, 1945). Measured sections exposed along the east and west banks of the Delaware River. The actual type section as designated by Kümmel is the bed of Lockatong Creek; these exposures have never been measured in detail.

Section E.

+10 m	massive basalt, base of Orange Mountain Basalt
.9 m	brown massive sandstone
4.2 m	red sandstone beds fining-upwards into beds of red siltstone with numerous carbonate nodules

Section D.

+ 3 m	red, cross-bedded sandstone

Section C.

3 m	2 fining-upwards sequences consisting of beds of red, irregularly cross-bedded sandstone grading upwards into beds of red siltstone. Laminated, carbonate-rich oblong chips and concentric carbonate accretions at base of sandstones.

Section B.

3.2 m	red, fissile siltstone beds sandwiching three beds of yellow-orange, coarse siltstone and sandstone.
2.6 m	red fissile to blocky siltstone
2.2 m	2 fining-upwards sequences of red sandstone and siltstone
+1.5 m	red blocky siltstone

Section A.

14.2 m	4 fining-upwards sequences of red feldspathic sandstone grading upwards into red blocky siltstone
26.0 m	covered
4.6 m	red siltstone
41.0 m	covered
16.4 m	fining-upwards sequences of red feldspathic sandstone grading into red fissile to blocky siltstone
2.0 m	diabase dike surrounded by .3 m zone of black hornfels
+3.0 m	red blocky siltstone
5.0 m	covered
1.7 m	red cross and planer bedded sandstone and siltstone
4.0 m	covered
4.6 m	red sandstone and siltstone beds
2.0 m	covered
1.2 m	red sandstone and siltstone, Scoyenia abundant
48.0 m	covered
8.7 m	3 fining-upwards sequences of red feldspathic sandstone with strongly down cutting bases, grading up into red blocky siltstone.

Table 5

Type section of the Passaic Formation and key to Figure 4. Section exposed at intervals along Interstate Route 80, from Ridgefield to Paterson, New Jersey. Details of section in Olsen, in press. Sections measured from top down.

Unit a	
+4.0	buff to red-purple feldspathic sandstone and siltstone
Unit b	
.5 m	green and red ripple-bedded siltstone
1.0 m	gray and red limestone and siltstone beds, laminated at the base. Fossil fish abundant. In other near-by sections, this unit is black.
1.54m	beds of gray and red siltstone and fine ripple-bedded sandstone with abundant roots and reptile footprints.
Unit c	
11.0 m	-1 m thick beds of buff and red sandstone grading up into beds of blocky red siltstone with roots. Lower beds contain breccia of upper Orange Mountain Basalt.

Table 6

Type section of the Feltville Formation and key to Figure 8. Section exposed in bluff on west side of Blue Brook about 1 km south of the dam for Lake Surprise in the Watchung Reservation, Union County, New Jersey (Details in Olsen, in press). Section measured from top down.

Table 7. Type section of the Towaco Formation

Unit a	
.9	brown, badly weathered, palgonitic unit
Unit b	
32.3	11 red fining-upwards cycles, each a mean of 2.9 m thick and composed of thick beds of red sandstone or coarse siltstone grading up into beds of red ripple-bedded or blocky siltstone. Uppermost cycle is lavender in color and the lowest cycle contains a buff intraformational breccia with scattered vertebrate remains. Dolomitic concretions, root casts, and reptile footprints common.
Unit c	
3.4	Gray, buff, and lavender fining-upward sequences of sandstone and siltstone, plant fragments, reptile footprints, and roots common.
Unit d	
2.6	fine gray to black siltstone base with prominent black, microlaminiated, calcareous siltstone. Upper parts of black unit contain chert nodules. Very fragmentary fish and insects present along with well preserved plant fragments.
Unit e	
2.5	Gray-buff, well-bedded, upwards-fining siltstone and sandstone with dinosaur footprints and abundant roots.
Unit f	
21.0	7 upwards-fining cycles similar to those of unit b. Upper-most cycle very thick (4.2 m) with extremely good reptile footprints. The uppermost beds of this cycle are gray-green.
Unit g	
5.2	2 or 3 upward-fining cycles of gray sandstone and siltstone. Upper-most cycle grades into red siltstones. Plant fragments and reptile footprints locally abundant. Siltstones palyniferous.
Unit h	
.8	black, microlaminated, calcareous siltstone grading upwards into gray, graded sandstones. Fossil fish and plant stems abundant.
5.1	olive, massive, convoluted, poorly sorted siltstone grading up into beds of poorly sorted gray and black siltstone. Some recumbant folds over 1 m between limbs.
Unit j	
.5	black laminated, calcareous siltstone similar to unit h, but without fossil fish.
Unit k	
.6	very fine, gray siltstone grading upwards into j.
Unit l	
3.0	gray fining-upwards sequence grading into fissile siltstone. Plant remains common.
Unit m	
5.3	red, ripple-bedded siltstone, upper 1 m gray.

Table 7

Type section of the Towaco Formation in the Dinosaur Tract of the Essex County Park Commission, Roseland, New Jersey (key to Figure 10). Lower beds of unit f and all beds below are now covered. Details of section in Olsen, in press. Section measured from top down.

Table 8. Distribution of Taxa within the Stockton through Boonton Formations.

STOCKTON FORMATION		
Plants		
Equisetales (scouring rushes)		
Neocalamites sp.	lower - upper Stockton	Willard, et al., 1959; Bascom, et al., 1938; Brown, 1911, Bock, 1969
Coniferales (conifers)		
Pagiophyllum diffusum	upper Stockton	Cornet, 1977; Bock, 1969
P. simpsonii	" "	" " " "
Glyptolepis spp.+	" "	" " " "
Rotundolepis intermedia	" "	" " " "
Araucarioxylon spp.+	lower - ?upper Stockton	Wherry, 1912
Podozamites spp.	upper Stockton	Willard, et al., 1959; Bascom, et al., 1938
Bennettitales (cycad-like seed plants)		
Zamites spp.	lower - upper Stockton	Brown, 1911; Bascom, et al., 1938; Willard, et al., 1959
Pterophyllum spp.	" " "	Willard, et al., 1959; Bascom, et al., 1938; Lyman, 1902
seed plants of uncertain affinities		
Eoginkoites	upper Stockton	Bock, 1969; Cornet, 1977
Invertebrates		
Mollusks		
Unionid clams		Lewis, 1884; Richards, 1944
Arthropods		
Darwinula spp.	" "	YPM (IP) 28805
Cyzicus	" "	Kummel, 1897; YPM (IP) 28804
Scoyenia (burrows)*	" "	YPM (IP) 28806
Koophichnium sp.* (limulid tracks)	" "	Caster, 1939

Table 8. (cont'd.)

Insects		
beetle elytron	" "	YPM (IP) 28803
Vertebrates		
Amphibians		
Calamops paludosus	lower Stockton	Sinclair, 1917; Olsen, et al., MS
Metoposaurus sp.	upper Stockton	Olsen, et al., MS.
Reptiles		
{cf. Rutiodon (Phytosaurus) manhattanensis}	" "	Von Huene, 1913
phytosaur teeth	" "	Olsen, et al., MS
LOCKATONG FORMATION AND STOCKTON LATERAL EQUIVALENT		
Plants		
Equisetales (scouring rushes)		
Equisetites sp.	lower Lockatong	Bock, 1969
Coniferales (conifers)		
Pagiophyllum spp.	" "	" "
Glyptolepis spp.	" "	" "
Invertebrates		
Mollusks		
Unionid clams	lower Lockatong	Conrad, 1858, 1870

Table 8. (cont'd.)

Arthropods		
Darwinula spp.	through Lockatong	YPM (IP) 28809
Cyzicus spp.	" "	Jones, 1862; Bock, 1953
cf. *Palaeolimnadia*	" "	YPM (IP) 28802
*Scoyenia**	through Lockatong and Stockton lateral equivalent	YPM (IP) 28810, YPM 8262
Vertebrates		
Fishes		
Carinacanthus jepseni	lower Lockatong	Bryant, 1934
Turseodus spp.	through Lockatong	Schaeffer, 1952b; Olsen, McCune, and Thomson, in press
Synorichthys sp.	" "	Schaeffer and Mangus, 1970; Olsen, McCune, and Thomson, in press
Cionichthys sp.	lower Lockatong	Bock, 1959; Olsen, McCune, and Thomson, in press
Semionotus brauni sp.	" "	Newberry, 1888; Olsen, McCune, and Thomson, in press
Diplurus newarki	" "	Bryant, 1934; Schaeffer, 1952a; Olsen, McCune, and Thomson, in press
Amphibians		
Metoposaurus durus	" "	Cope, 1866; Colbert and Imbrie, 1956; Olsen, *et al.*, MS
Reptiles		
"deep tailed swimmer"	" "	Colbert and Olsen, MS.
Tanytrachelos ahynis	" "	Olsen, 1979
Icarosaurus seifkeri	" "	Colbert, 1966
Rutiodon spp.	through Lockatong	Cope, 1869; Colbert, 1965
phytosaur bones and teeth	through Lockatong and Stockton equivalent	Colbert, 1965; Olsen, *et al.*, MS.
Rhynchosauroides spp.*	" "	Bock, 1969; Olsen, *et al.*, MS.
*Gwyneddichnium**	lower Lockatong	Bock, 1969
*Apatopus lineatus**	through Lockatong and Stockton equivalent	Olsen, *et al.*, MS.

Table 8. (cont'd.)

Chirotherium cf. eyermani*	Stockton equivalent	Olsen, et al., MS.
"Anchisauripus" cf. milfordensis*	lower Lockatong	Bock, 1969; Baird, 1957
Grallator spp.*	through Lockatong and Stockton equivalent	Bock, 1969; Olsen, et al., MS.
PASSAIC FORMATION AND LOCKATONG LATERAL EQUIVALENT		
Plants		
Equisetales (scouring rushes)		
Neocalamites sp.	lower to middle Passaic	Newberry, 1888
Filicales (ferns)		
Clathropteris sp.	middle Passaic	Newberry, 1888
Coniferales (conifers)		
Pagiophyllum spp.	lower to uppermost Passaic	Cornet, 1977; Bock, 1969
Brachyphyllum spp.	uppermost Passaic	Cornet, 1977
Glyptolepis platysperma+	middle Passaic	Cornet, 1977; Bock, 1969
G. keuperiana+	" "	" " " "
Bennettitales (cycad-like seed plants)		
?Zamites (Dioötes) sp.	" "	Newberry, 1888
?Pterophyllum (Brunswickia dubium)	" "	Wherry, 1959
Cycadales (cycads)		
Otozamites sp.	uppermost Passaic	Cornet, 1977
Invertebrates		
Arthropods		
Kouphichnium	lower Passaic	PU 22002

Table 8 (cont'd.)

Cyzicus sp.	lower Passaic	Cornet, 1977; YPM
*Scoyenia**	lower through upper Passaic	PU 21517
Vertebrates		
Fishes		
Semionotus sp.	lower Passaic	Olsen, McCune, and Thomson, in press
Synorichthys	" "	" " " "
Reptiles		
Hypsognathus fenneri	upper Passaic	Colbert, 1946
Sphodrosaurus pennsylvanicus	middle Passaic	Colbert, 1960
Stegomus arcuatus		Jepson, 1948
Clepsysaurus pennsylvanicus	upper Passaic	Lea, 1851; Colbert and Chaffee, 1941
phytosaur maxilla	middle Passaic	UPM 3772
*Rhynchosauriodes brunswicki**	lower and middle Passaic	Ryan and Willard, 1947; PU 21520; Baird, 1957
R. hyperbates *	middle Passaic	Baird, 1957
cf. *Rhynchosauroides* sp.*	uppermost Passaic	PU 222140; 22204
Gwynnedichnium sp.*	lower Passaic	YPM 7556
*Apatopus lineatus**	lower through upper Passaic	Baird, 1957
*Apatopus lineatus**	upper Passaic	PU 21235
*Chirotherium lulli**	middle Passaic	Baird, 1953
*C. parvum**	" "	Baird, 1957
*C. eyermani**	" "	" "
Chirotherium sp.*	lower Passaic	YPM 7555
"*Grallator*" *sulcatus**	middle Passaic	Baird, 1957
"*Anchisauripus*" milfordensis	lower and middle Passaic	Baird, 1957; YPM 7554
small *Grallator* spp.*	lower through upper Passaic	Baird, 1957; PU21517
large *Grallator* spp.*	upper and uppermost Passaic	PU 21900; 21901; 21519
Batrachopus sp.*	uppermost Passaic	PU 22214b

Table 8 (cont'd.)

FELTVILLE FORMATION		
Plants		
Equisetales (scouring rushes)		
Equisetites spp.	lower Feltville	Cornet, 1977
Filicales (ferns)		
Clathropteris meniscoides	lower and middle Feltville	Newberry, 1888; Cornet, 1977
Coniferales (conifers)		
Brachyphyllum scottii	lower Feltville	Cornet, 1977
Brachyphyllum spp.	lower and middle Feltville	" "
Pagiophyllum spp.	lower Feltville	" "
Hirmerella cf. *muensteri*+	" "	" "
Masculostrobus spp.+	" "	" "
Cycadales (cycads)		
Otozamites sp.	" "	Cornet, 1977
Invertebrates		
Arthropods		
Darwinula sp.	" "	YPM (IP) 28807
Vertebrates		
Fishes		
Ptycholepis cf. marshi	" "	Schaeffer, Dunkle, and McDonald, 1977
"*Semionotus tenuiceps* group"	" "	Olsen, McCune, and Thomson, in press

Table 8 (cont'd.)

Reptiles		
small *Grallator* spp.	lower through upper Feltville	YPM 6636
large *Grallator* spp.	" " " "	YPM 8666
Anomoepus sp.	upper Feltville	AMNH 3639
Batrachopus cf. *deweyi*	" "	PU 18564
TOWACO FORMATION		
Plants		
Equisetales (scouring rushes)		
Equisetites sp.	through Towaco	Cornet, 1977
Filicales (ferns)		
cf. *Phelbopteris* sp.	middle Towaco	YPM (PB) 3771
Coniferales (conifers)		
Brachyphyllum spp.	through Towaco	Cornet, 1977
Pagiophyllum spp.	" "	" "
Invertebrates		
Insects		
beetle elytron	upper Towaco	YPM (IP) 28808
Vertebrates		
Fishes		
"*Semionotus tenuiceps* group"	through Towaco	[Olsen, McCune, and Thomson, in press]
Semionotus spp.	" "	" " " "

Table 8 (cont'd.)

Reptiles		
cf. Rhynchosauroides sp.*	upper Towaco	PU 18563
Batrachopus sp.*	through Towaco	PU 19911
small Grallator spp.*	" "	RU main display slab
large Grallator spp.*	" "	RU " "
Anomoepus spp.*	" "	RU " "
BOONTON FORMATION		
Plants		
Equisetales (scouring rushes)		
Equisetites sp.	through Boonton	YPM (PB) 3769
Coniferales (conifers)		
Brachyphyllum spp.	"" "	YPM (PB) 3770
Invertebrates		
Arthropods		
cf. Palaeolimnadia sp.	middle Boonton	YPM 6567
Vertebrates		
Fishes		
Ptycholepis sp.	" "	Schaeffer, Dunkle, and McDonald, 1977
Redfieldius cf. gracilis	" "	Schaeffer and McDonald, 1978
Redfieldius spp.	" "	Olsen, McCune, and Thomson, in press
"Semionotus elegans group"	" "	" " " "
Diplurus longicaudatus	" "	Newberry, 1888
Reptiles		
Batrachopus sp.*	" "	YPM 7558
small Grallator spp.*	" "	" "
large Grallator spp.*	" "	AMNH uncatalogued specimen in Cope collection
Anomoepus sp.*	" "	I. C. Russell (N.D.)

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ROAD LOG

This field trip is a traverse along Route 80 which intersects all of the sedimentary and extrusive formations of the Newark Basin portion of the Newark Supergroup (fig. 3). The road log commences at the Fort Lee entrance to Route 80 off Cross Street (see Olsen, this Fieldbook, for directions to this entrance).

Mileage

0.0 Entrance ramp for Route 95-80 off Cross Street, Fort Lee, New Jersey. Veer left onto entrance ramp, proceed on Route 95S.

To the east about one mile is the west portal of the George Washington Bridge, Fort Lee, New Jersey. The west abutments of the bridge rest on Stockton and Lockatong formations and Palisade Diabase. Roads along the east face of the Palisade Escarpment in the Fort Lee portion of Palisades Interstate Park have excellent exposures of nine individual detrital cycles of the lower Lockatong, each of which has been traced 15 km. to the south (Olsen, this Fieldbook). Three of these cycles are especially fossiliferous; the lowest of these (called cycle 6) has produced articulated remains of *Semionotus brauni* and disarticulated remains of the little reptile *Tanytrachelos.* The middle fossiliferous cycle (cycle 5) contains abundant disarticulated remains of *Diplurus newarki* and articulated remains of *Turseodus*. The upper cycle (cycle 2) has produced abundant articulated *Turseodus* and disarticulated large *Diplurus*. Clam shrimp (conchastracans) and ostracods are also common in cycles 5 and 2. These and other Lockatong cycles exposed here were deposited in shallower water than their more southern extensions.

In this area the trigonometrically computed thickness of both the Stockton Formation and the Lockatong Formation is less than 200 m. This is almost an order of magnitude thinner than the same formations along the Delaware River (Van Houten, this Fieldbook). While part of this thinning is due to the lateral replacement of Lockatong facies by Passaic Formation, most of the thinning is due to the thinning of individual cycles of the Lockatong Formation and thinning of the whole of the Stockton.

Numerous small, predominantly normal, faults striking north and northeast and down-dropping to the east characterize this portion of the Newark Basin. The reentrant in the Palisade Escarpment just south of here is an erosional result of some of the larger of these faults.

0.5 Crossing large normal fault cutting the Palisade Diabase and overlying the Lockatong Formation. This fault nearly doubles the outcrop width of the Palisade Diabase in this area. Just north of here the upper contact of the sill and the Lockatong is duplicated by this fault.

In marked contrast to faults is the northwestern portion of the Newark Basin, many of which have slickensides showing lateral (both synestral and dextral) movement, those examined to date in the area along the Palisades show only vertical slickensides (both those dropping down to the east and to the west) (personal observation and Manspeizer, pers. comm.).

1.0 Excellent outcrops of the Lockatong—Palisade Sill contact and overlying detrital cycles of the Lockatong. Here the upper surface of the Palisade Sill is smoothly concordant with the Lockatong. I believe the cycles exposed here tie in with those exposed in Granton Quarry to the south, although it is far from certain. Articulated *Turseodus* and conchostracans, at least, are common at this outcrop.

According to Van Houten (1969), these Lockatong hornfels include grossularite-andradite, prehnite, and diopside varieties.

1.5 Hill at this point is underlain by a tongue of Stockton Formation (Van Houten, 1969). Presumably this is the same unit exposed about 1 km. north of Granton Quarry. There good exposures reveal Stockton Formation with a thin bed of *Synorichthys* — bearing green and gray siltstone with overlying beds of gray-buff arkose containing what I interpret as very well-developed limestone caliche paleosols. Tongues of Stockton such as this may correspond to clusters of chemical cycles prevalent in similar positions in the central Newark Basin.

1.7 Approximate contact with Passaic Formation. Lowermost Passaic is very poorly exposed in the vicinity of Ridgefield and consists of mottled red-buff feldspathic sandstone and red siltstone.

2.3 Hackensack Meadows.

Broad belt of relatively soft red siltstone and minor gray siltstone and arkose correlating with upper Lockatong and lower Passaic Formation of Delaware River area (Van Houten, this Fieldbook).

2.6 Veer right onto exit for Route 80.

3.1 Beginning of the type section of the Passaic Formation (see Table 2, fig. 4, this paper) (Olsen, In Press). The type section of the Passaic consists of intermittent exposures along Route 80. These exposures show interbedded red feldspathic sandstone and siltstone with small-to-large-scale cross-bedding, abundant bioturbation structures (including roots and *Scoyenia*) and some beds of caliche. Section A (fig. 4) of the type section begins here.

6.2 Section B of the type section of the Passaic Formation.

7.3 Section C of the type section of the Passaic Formation.

11.1 Section D of the type section of the Passaic Formation.

12.8 Garrett Mountain is 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.

Just south of this point, along Route 20 are exposures of Passaic Formation red conglomerates. The frequency of beds such as these increase to the northeast and decrease to the southwest. These conglomerate beds are crucial to tests of the "Broad Terrain Hypothesis" (Sanders, 1963, 1974). Cross beds consistently yield paleocurrent directions indicating transport from northeast to southwest (personal observation and Manspeizer, pers. comm.) in line with the mean paleocurrent vector for this portion of the Passaic Formation. Clasts consist primarily of Paleozoic sedimentary rocks, including quartzite, quartzite conglomerate, limestone, and minor phyllite. Such rocks are not known to be present to the east of the Newark Basin. Clast composition is very similar to beds found in the northernmost part of the Newark Basin, beds thought to have a northwestern provenance. The clasts are very different from those of the contemporary New Haven Arkose of the Hartford Basin. The "Broad Terrain Hypothesis" predicts that these beds of the Passaic should be western equivalents of the New Haven Arkose. Two alternative explanations come to mind.

1. The provenance of these Passaic conglomerates was to the east of the Newark Basin; presumably these source rocks are completely eroded. Either the Newark and Hartford Basins were with the Paleozoic sedimentary rocks intervening or the Paleozoic rocks were exposed to the east of a southern continuation of the Hartford Basin and contributed to New Haven Arkose bed no longer exposed.

2. The provenance of these Passaic conglomerates was to the west or north but the sediments were redeposited by southwest moving streams.

Detailed studies of these conglomerates are clearly needed.

15.3 Contact of Passaic Formation with overlying Orange Mountain Basalt on left (south). This is section E of the type section of the Passaic Formation (fig. 7). A series of faults cut the ridge made up of Orange Mountain Basalt here; some of these faults are visible in the cut on the left, just west of the Passaic-Orange Mountain contact.

Uppermost few meters of Passaic Formation, exposed to the south of here (Montclair State College) has produced a reptile footprint assemblage consisting of a mixture of taxa common to older beds of the Passaic and younger beds of the Feltville, Towaco, and Boonton Formations. The oldest North American occurences of *Batrachopus,* and grullatorid footprints of the *Anchisauripus minuscolus*-type have been discovered at this locality (Olsen and Galton, 1977).

This assemblage is nearly identical to a suite of footprints found in the Rhaeto-Liassic of France. It is unclear whether these uppermost Passaic beds are latest Triassic or earliest Jurassic (the French workers are unsure of their footprint bearing beds, as well). The Triassic-Jurassic boundary probably lies within a few meters of the Orange Mountain in the Route 80 area.

15.4 Exposures of Orange Mountain Basalt. Upper flow units of Orange Mountain Basalt are exposed in quarries near here. A diverse suite of zeolite minerals has made some of these quarries famous (Manspeizer, this Fieldbook; Van Houten, 1969).

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

The Feltville Formation is very poorly exposed in this area; the lower Feltville is not exposed at all.Exposures in bluffs just north and south of here consist of gray and buff arkose and sandstone, often cross-bedded and containing coalified plant remains, and red feldspathic siltstone and sandstone with roots and reptile footprints.

18.0 Position of Preakness Basalt: not exposed.

A confluence of a series of faults, densely spaced joint systems, and the low dip of the bedding are probably responsible for the low profile of the Preakness Basalt in this area. The outcrops of the main lower flow in this area (such as along Route 46 to the south) show the flow's characteristic splintery joint pattern.

18.9 Approximate position of Preakness Basalt — Towaco Formation contact.

The large outcrop width of Towaco Formation here is due to the Hook Mountain Anticline. Toward the west, along the axis of the anticline, the dip of the Towaco Formation steadily decreases.

24.2 About 4.4 miles north is the abandoned Vreeland Quarry which produced the superb reptile footprints on display at the Rutgers University Geological Museum. Just to the northeast is Tom's Point, an area which produced hundreds of reptile footprints in the 1960's. Exposures still extant include much of the non-red portion of the second-from-the-top Towaco Formation cycle. Exposures of the upper two Towaco Formation cycles occur sporadically in surrounding areas.

25.4 Type section of Hook Mountain Basalt.

Two flows and the contact between them are exposed along the highway (fig. 11). The entablature and lower colonnade of the lower flow are exposed on Hook Mountain Road just north of the Route 80 overpass.

25.6 Approximate position of Boonton-Hook Mountain Basalt contact.

29.1 The Boonton Formation is not exposed along Route 80 but 2 miles to the north are the excellent exposures along the Rockaway River (fig. 12). These exposures begin at the dam at the north end of Boonton (Jersey City) Reservoir and extend for over 1 mile along the river bluffs. The dam footing rests on the Boonton Fish Bed which during the

1800's and early 1900's produced thousands of fish of the "*Semionotus elegans* group," *Redfieldius* spp., several specimens of the large coelacanth *Diplurus longicaudadus,* and a single specimen of *Ptycholepis.*

Only the underlying beds are exposed now, by these beds produce abundant plant remains and reptile footprints.

31.1 Approximate position of the Ramapo Fault: end of the Newark Basin.

A prominent bluff of metamorphics marks the west wall of the fault (see Ratcliffe, this Fieldbook).

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