

# LATE TRIASSIC PART OF NEWARK SUPERGROUP, DELAWARE RIVER SECTION, WEST-CENTRAL NEW JERSEY

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## Introduction

The Late Triassic part of the Newark Supergroup exposed along the Delaware Valley (Van Houten, 1969) consists of as much as 6 km of nonmarine sedimentary rocks and an associated sill. Its strike generally parallels the northeasterly trend of the basin with a dip of 10-20°NW. Along the northwestern margin the sequence is bounded by Precambrian and Paleozoic rocks of the Reading Prong of the New England Upland. Most of this boundary is a system of high-angle faults (see Ratcliffe, this guidebook), but intermittently Newark border conglomerate overlaps on rocks of the upland terrane. Within the basin and along its southeastern margin Newark strata lie on Paleozoic and Precambrian rocks of the Blue Ridge and Piedmont provinces.

In the northeast (Fig. 3) the Newark Supergroup consists of a lower, locally conglomeratic Stockton Arkose (1840 m, 6000 ft), grading upward into reddish-brown Brunswick Mudstone (more than 1900 m and perhaps as much as 4000 m thick). Along the northwestern faulted border these deposits interfinger with the Hammer Creek Conglomerate. In the central part of the basin the widely-occurring Stockton and Brunswick formations are separated by and interfinger with the dark gray to reddish-brown Lockatong Formation (as much as 1145 m, 3750 ft thick). These major sedimentary rock types comprise rather uniform, widespread units. In the Delaware Valley area a diabase (dolerite) sill is intruded into Lockatong and lower Brunswick strata.

Across the central part of the basin, as seen along the Delaware River, the Newark formations are repeated in three large northwest-tilted blocks. The Flemington and Hopewell faults that bound them may be part of a transcurrent system involving those along the northwestern border as well. Geophysical and subsurface evidence of intrabasin faults near the present margin of the basin (Summer, 1977; Cloos and Pettijohn, 1973) indicates that it was not a simple half-graben.

The Newark Supergroup ranges in age from Karnian (Late Triassic, 215 my) to late Liassic (about 180 my), with Liassic sedimentation beginning about 100 m below the 1st Watchung basaltic lava flow in the middle of the Brunswick Formation (Cornet and Traverse, 1975; Olsen and others, 1980; Olsen, this guidebook). Along the terrane of extension in eastern North America basin development and igneous activity apparently peaked about 190 my ago. In the Delaware River section the Triassic-Liassic boundary presumably is above the preserved Brunswick strata.

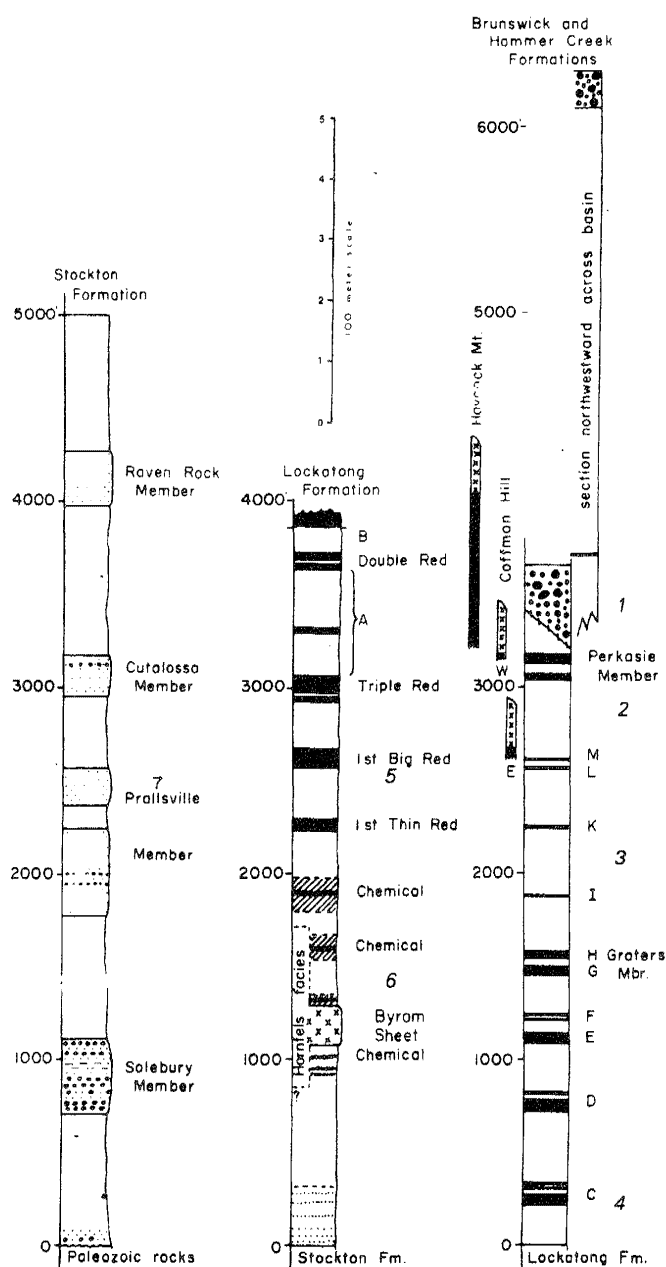
## Source Area

Soda-rich crystalline rocks in the faulted eastern and southeastern Piedmont upland were the source of most of the feldspathic Newark detritus. Its broad westerly paleoslope probably was broken by growth faults (Cloos and Pettijohn, 1973) covered by progressive outward spread of the proximal facies now stripped back from its original eastward extent. In contrast, northwestern highlands supplied mostly Paleozoic debris down a steep paleoslope to local fanglomerates and associated sandstones along the adjacent border of the basin.

## Stockton Formation

Along the Delaware River the Stockton Formation is about 1525 m thick in the northern fault block. Here it consists principally of yellowish-gray to pale reddish-brown fairly well-sorted arkose and subordinate poorly-sorted conglomerate and reddish-brown mudstone distributed in rather distinct units (Fig. 1). Commonly these are as much as 15-20 m thick and can be traced for several kilometers. Persistent groups of beds as much as 100 m thick have been defined as members.

Yellowish-gray conglomeratic deposits in the lower part contain moderately rounded clasts averaging about



**Figure 1.** Stratigraphic section of Newark Supergroup along the Delaware River from Stockton northward to 3 miles of Milford, N.J. Subordinate units in gray Locketong Formation are grayish-red to reddish-brown; those in reddish-brown Brunswick Formation are dark gray. Shows position of diabase sills, Locketong gray chemical cycles and hornfels, and field trip stops.

2-3 cm in diameter and only locally more than 6-8 cm long, set in a poorly-sorted arkosic matrix. Most of the clasts are quartz, some are quartzite, and a few are feldspar, metamorphic rock, and shale fragments.

In the northwestern part of the basin well-sorted medium-to fine-grained arkose occurs in thick beds only locally with stringers of conglomerate and mudstone. Stratification commonly is outlined by films of reddish-brown clay, or locally by abundant grains of specular

hematite (after magnetite). Planar bedding predominates. Cross-bedding and channeling are much more common in the eastern to southeastern proximal facies.

Most of the Stockton Arkose has a texture of interlocking grains produced by pressure solution presumably resulting from burial below an estimated 3000 m or more. Authigenic feldspar occurs locally as overgrowths and void fillings. In outcrop much of the well-sorted, fine-grained sandstone is speckled with yellowish-brown intergranular patches of limonite after iron-rich carbonate. Stockton Arkose contains 50-70 percent quartz, 15-40 percent feldspar which decreases in abundance stratigraphically upward and northward, and subordinate chert and metamorphic rock fragments, muscovite, biotite, and chlorite. Albite-oligoclase commonly is more abundant than K-feldspar.

Associated reddish-brown feldspathic mudstone is well-bedded, very micaceous, and burrowed. It contains abundant illite and muscovite, but very little kaolinite, and Na-feldspar predominates over K-feldspars.

**Locketong Formation**

In the northwestern fault-block the Locketong Formation is about 1145 m thick. It thins laterally to the northeast and southwest along the axis of the basin and toward the southeastern border. The lower 120-160 m consists of micaceous mudstone with subordinate ripple-bedded and mud-cracked fine-grained sandstone similar to that in the underlying Stockton Formation. Locketong deposits grade upward into the Brunswick Formation through a succession of rather regularly alternating reddish-brown and dark gray units (Fig. 1) recurring at about 100 m intervals. Gray units above the main body of the formation are successively thinner upward whereas reddish-brown ones are progressively thicker.

Throughout much of its extent the Locketong Formation is arranged in short “ detrital ” and “ chemical ” cycles averaging several metres thick (Fig. 2). Detrital cycles are most common in long gray intervals and at the northwestern and southwestern ends of the formation whereas chemical cycles are best-developed in the reddish-brown sequences recurring at about 100 m (300-325 ft) intervals. Short detrital cycles about 4-6 m thick comprise a lower black pyritic shale succeeded by platy dark gray carbonate-rich mudstone in the lower part, and tough, massive gray calcareous mudstone (argillite) in the upper. The argillite has a very small-scale contorted and disrupted fabric produced largely by crumpled shrinkage cracks and burrow casts. Some thicker detrital cycles contain a 0.5-1.5 m-thick lens of thin-bedded, ripple-bedded siltstone and fine-grained

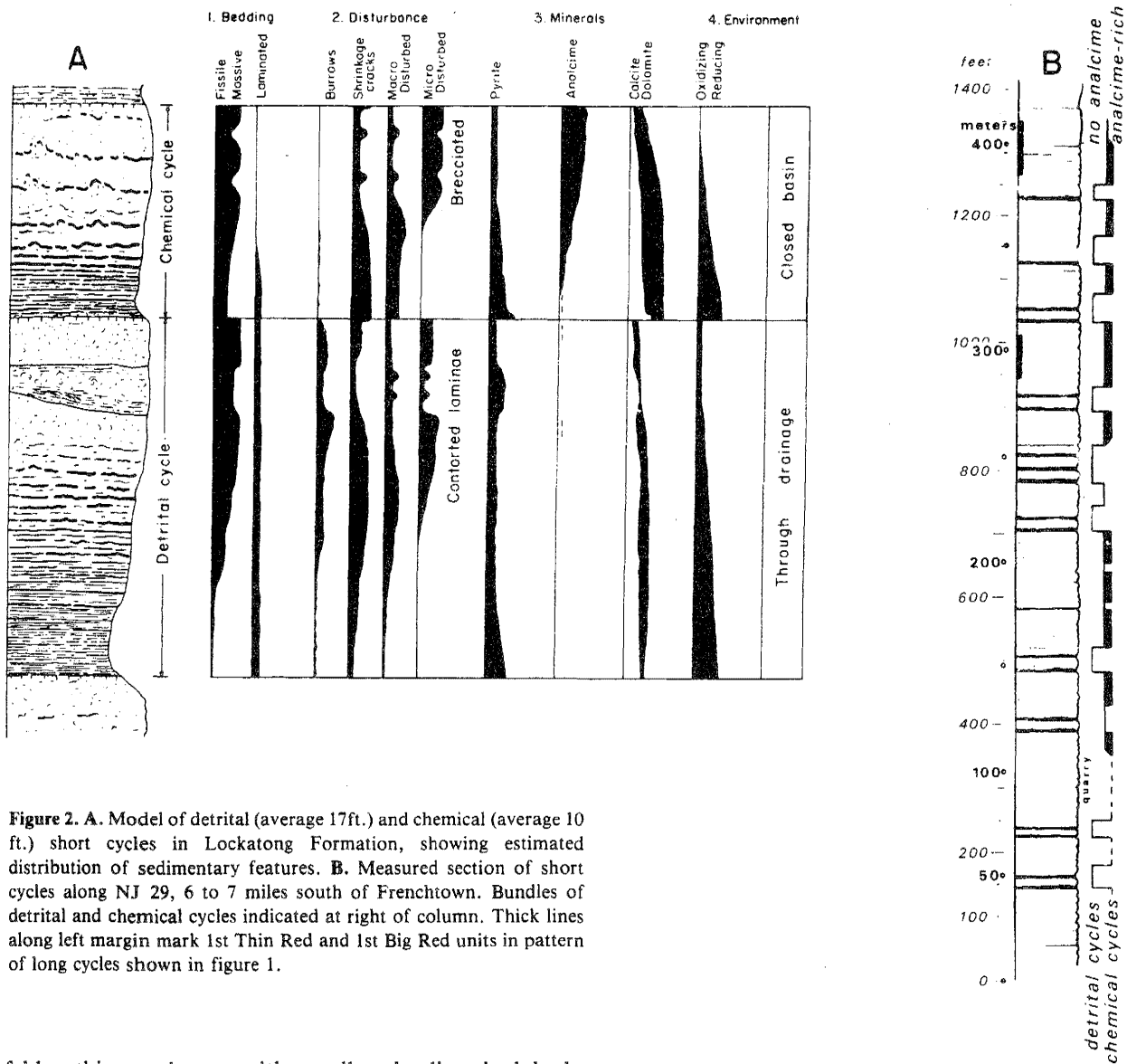


Figure 2. A. Model of detrital (average 17ft.) and chemical (average 10 ft.) short cycles in Lockatong Formation, showing estimated distribution of sedimentary features. B. Measured section of short cycles along NJ 29, 6 to 7 miles south of Frenchtown. Bundles of detrital and chemical cycles indicated at right of column. Thick lines along left margin mark 1st Thin Red and 1st Big Red units in pattern of long cycles shown in figure 1.

feldspathic sandstone with small-scale disturbed bedding. On average these deposits contain abundant Na-feldspar, illite and muscovite, some K-feldspar, chlorite and calcite, and a little quartz.

Short chemical cycles about 2-4 m thick are most common in the upper part of the formation and are limited to the central 100 km along the axis of the basin. Lower beds 1-8 cm thick are alternating dark gray to black platy dolomitic mudstone and marlstone disrupted by shrinkage cracks. Locally basal beds contain thin lenses of dolomite and pyrite. In the middle, more massive argillite encloses layers of the tan-weathering dolomitic marlstone extensively disrupted by shrinkage cracking. The middle part of many chemical cycles, as well as of reddish-brown ones in the lowest part of the Brunswick Formation, exhibit a pattern of upward-concave surfaces and thin zones of shearing in tent-like structures 15 to 30 cm high and recurring laterally in wave lengths of 0.5 to 1 m. The beds involved contain numerous small crumpled shrinkage cracks and

have been fractured and brecciated (Van Houten, 1964, p. 518, Fig. 14). These structures resemble gilgai (Hallworth and Beckmann, 1969) produced by repeated wetting and drying of carbonate-rich clayey soils. The upper part of a chemical cycle is tough gray analcime- and dolomite-rich argillite brecciated on a microscopic scale. Tiny slender crumpled shrinkage cracks filled with dolomite and analcime produce a "birdseye" fabric. Some thinner chemical cycles are grayish red to reddish brown. In these cycles thinner dark red layers are disrupted by shrinkage cracks and broken into mosaic intraformational breccia with patches of analcime and dolomite in the cracks. Thicker massive beds are speckled with tiny lozenge-shaped pseudomorphs of dolomite and analcime after gypsum? or glauberite? (Van Houten, 1965), and locally marked by long intricately crumpled crack filling. Argillite in the upper part of chemical cycles contains as much as 7 percent of  $\text{Na}_2\text{O}$  and as little as 47 percent  $\text{SiO}_2$ . It is com-

posed of a maximum of 35-40 percent analcime, together with albite, dolomite and calcite, and illite and minor chlorite.

### Brunswick Formation

Throughout the central part of the basin the Brunswick Formation consists of a rather uniform succession of reddish-brown mudstone and siltstone with subordinate claystone and fine-grained feldspathic sandstone. Unlike normal nonmarine basin deposits, this central facies has no well-developed coarse-grained channel fill. Commonly two kinds of mudstone occur in alternating sequences (Fig. 6). One is crumbly, bright reddish-brown homogeneous claystone only locally well bedded, with thin persistent layers of siltstone. The other is tougher bioturbated silty mudstone locally scoured by broad channels filled with a succession of 2-5 cm-thick overlapping layers of fine-grained sandstone and mudstone, many of which have been burrowed and have a mudcracked upper surface. Brunswick strata also record large and small tracks and trails. Molds of glauconite filled with calcite or barite are abundant locally in 5-20 cm-thick lenses. Calcite casts of incomplete glauconite crystals also form rosettes 10 cm in diameter.

Widespread units of dark gray pyritic mudstone and marlstone recur in the formation at 120-135 m (400-450 ft) intervals, matching those in the upper part of the Lockatong Formation (Fig. 1, 7). Eight such gray units have been identified in the Brunswick Formation in the northwestern fault block.

The common feldspathic mudstone and micaceous siltstone in the Brunswick Formation contain abundant illite and subordinate chlorite, abundant quartz (50-75 percent in siltstone, 10-30 percent in mudstone), less than 15 percent feldspar (Na-feldspar normally predominates), and relatively rare lithic fragments except near the northwestern border. Hematite is the pigment mineral coating grains and staining the clay fraction. It is also the common opaque mineral grain.

### Hammer Creek Conglomerate

Along the northwestern border of the basin very coarse conglomerate projects southward several kilometers (Fig. 1, 4, 5). Most of it as now exposed interfingers with Brunswick mudstone; some interfingers with the Stockton and Lockatong formations as well. Throughout its lateral extent the Hammer Creek Formation varies from common poorly-sorted, rather well-rounded conglomerate to local angular breccia. In west-central New Jersey Hammer Creek deposits are arranged in lenticular, crudely fining-upward units (Fig. 5), with caliche-like carbonate concentrated in the sandy

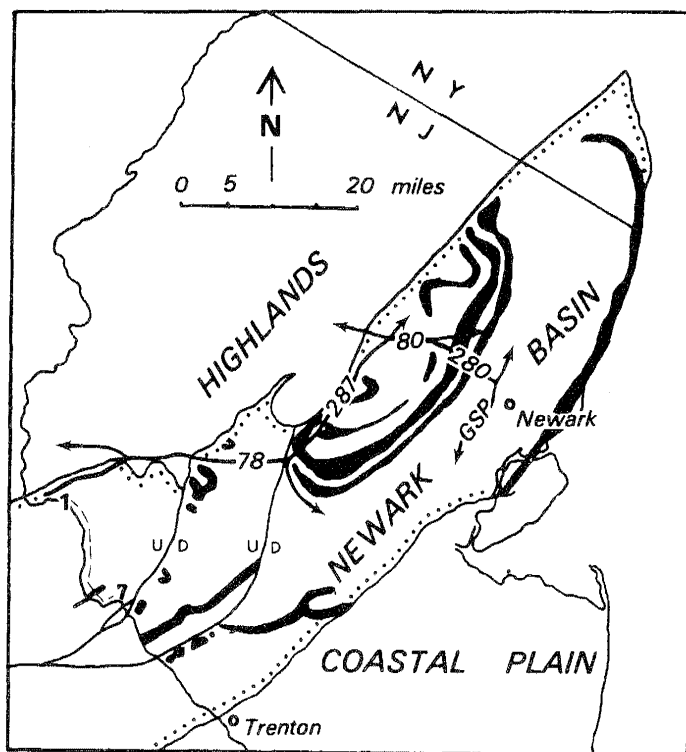


Figure 3. Route of one-day field trip from Newark, N.J. to Delaware River section of the Newark Supergroup. Sills and flows are black. Field trip stops are 1-7.

upper part. Clasts range in size from 10-20 cm cobbles to rare blocks 30 cm long. Most of them are Paleozoic quartzite, with fewer, smaller clasts of dolomite. The dark reddish-brown finer-grained fraction is very poorly-sorted lithic-rich sandstone containing abundant shreds of greenish-gray Paleozoic shale.

### Newark Hornfels

Thermally metamorphosed rock produced by intrusion of diabase reflects both composition of the host deposit and distance from the contact (Van Houten, 1971). In west-central New Jersey hornfels developed in Brunswick hematitic mudstone and micaceous siltstone near the Lambertville Sill (Fig. 4). The least altered mudstone a few hundred metres from the contact contains nodules of epidote and chlorite. Nearer the sill the matrix is chlorite-sericite with patches of coarsely crystalline chlorite and sericite or epidote and magnetite pseudomorphic after cordierite. The characteristic pale lavender color is due largely to conversion of aphanitic hematite pigment to fine-grained specularite. Dark gray pelitic hornfels with magnetite developed no more than 15-20 m from the intrusion. This inner facies contains phaneritic patches and isolated crystals of tourmaline and cordierite. High-grade hornfels of calcareous and sandy deposits is a grossularite-diopside-prehnite-muscovite or chlorite-calcisilicate rock.

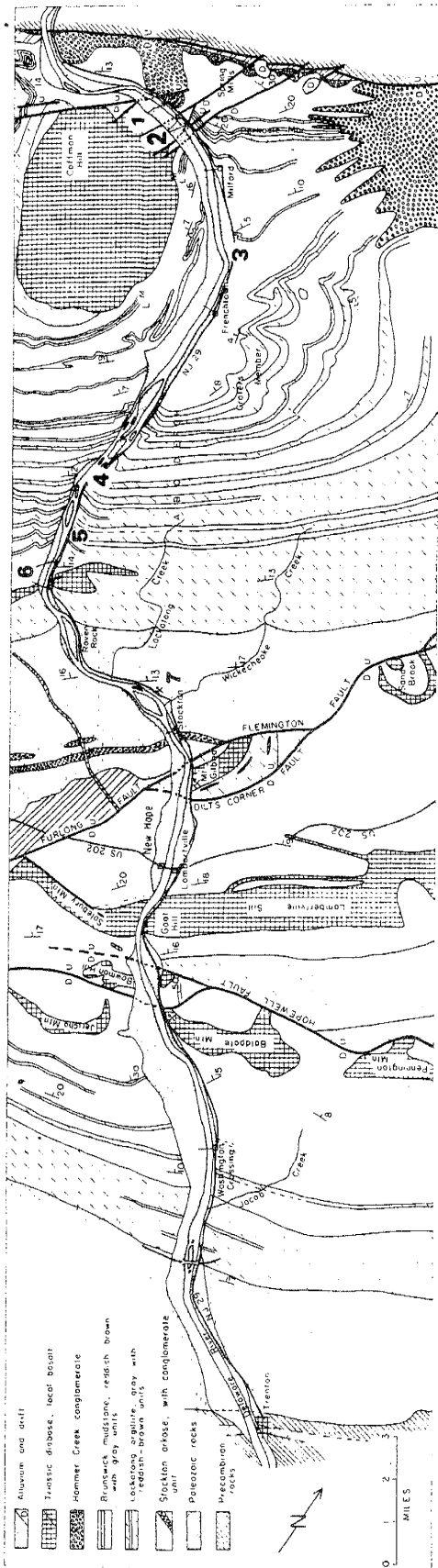


Figure 4. Geologic map of Newark Supergroup along Delaware River, west-central New Jersey and Pennsylvania. Shows field trip stops 1-7.

The Locketong Formation was most susceptible to thermal metamorphism, and converted to varieties of very fine-grained calcitic biotite and Na-feldspar hornfels marked by an absence of quartz, a paucity of SiO<sub>2</sub>, and an abundance of Na<sub>2</sub>O. In spite of extensive mineralogical alteration these rocks still exhibit their characteristic sedimentary structures. The middle carbonate-rich mudstone of Locketong short cycles within 100 m of the sill commonly contains analcime, grossularite, andradite, diopside, datolite, prehnite, sphene, calcite, biotite, and feldspar. The upper massive argillite of detrital cycles contains scapolite, aegirine, diopside, clinozoisite, K-feldspar, Na-feldspar, calcite, chlorite and biotite. The unique upper argillite of short chemical cycles (Fig. 8) contains nepheline, sodalite, cancrinite, thompsonite, calcite, biotite, and albite within 25 m of the sill; 25 m to 100 m from the sill cancrinite, thompsonite and increasing unaltered analcime predominate. In the uppermost part of the coarse-grained diabase at Mt. Gilboa (Brookville) a block of phaneritic nepheline and analcime syenites apparently was produced by reaction of a soda-rich Locketong xenolith with the granophyre differentiate of the basic intrusion (Barker and Long, 1969).

**Igneous Rocks**

Intrusive and extrusive igneous rocks in the Newark Supergroup are olivine-poor quartz tholeiite characteristic of rift valley sequences on continental crust. In northeastern New Jersey a thick diabase (dolerite) sill intruded the lower part of the Newark Section. Along the Delaware River a sill in Locketong and lower Brunswick beds locally transects the enclosing strata (Fig. 4). Only the thick (550 m) Lambertville Sill exposed in the middle fault block developed an early-formed olivine layer (Hess, 1956). Multiple basaltic lava flows such as those interbedded with upper Brunswick (Liassic) strata in the northeastern half of the basin are not present along the Delaware River.

**Conditions of Deposition**

Deep dissection of the Appalachian orogen and a late Permian and early Triassic hiatus reflect 20 to 30 my of broad uplift and erosion in eastern North America. Then a new framework of extension and rifting in late Triassic time produced a swath of faulted basins and uplands along the orogen. Newark deposits in New Jersey, like those in late Triassic-early Jurassic sequences throughout the belt, comprise the major facies of a piedmont-valley flat complex in rift basins (Van Houten, 1977, p. 89-93; 1978). During this episode of basin filling much of the sediment transported from flanking highlands was dispersed longitudinally by axial

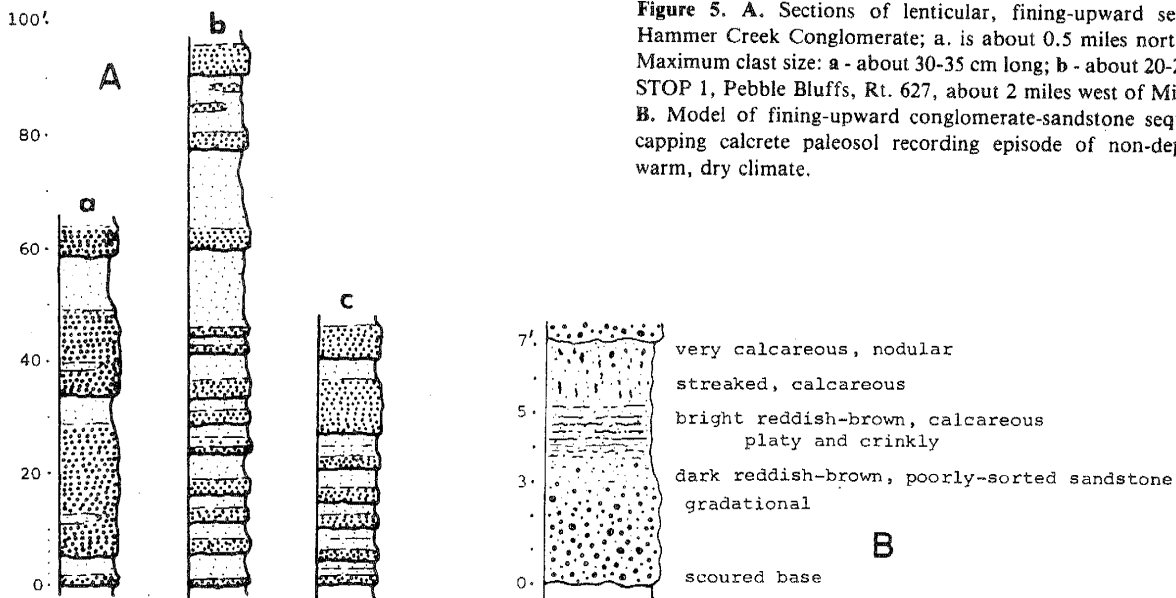
drainage. The path of exit of major through-flowing streams has not been determined, however.

In the principal eastern source area valleys incised in crystalline basement yielded a continuing supply of feldspar-rich detritus while deep weathering of the upland interfluvies produced abundant clay. Streams flowing westward on a long, gentle foothill slope spread Stockton gravel, sand and minor mud across much of the basin, forming extensive sheets of feldspar-rich alluvium. Most of the muddy fraction was carried beyond the known sandy deposits and perhaps beyond the Newark basin. Well-bedded, well-sorted upper Stockton Arkose in the northwestern interior of the basin may be a deltaic facies deposited along the shore of a narrow lake (Turner-Peterson, 1980). This facies lacks abundant cross-bedding, repeated fining-upward sequences, and paleosol caliche characteristic of fluvial deposits like the New Haven Arkose in the Newark Supergroup in Connecticut (Hubert, 1978).

Active faulting along the northwestern flank of the Newark Basin and repeated flash floods generated short, vigorous torrents in the highlands. These eroded the Paleozoic bedrock and fed local debris flows, sheets floods, and steep-gradient streams that built Hammer Creek alluvial fans which projected several kilometers into the basin. Although the roundness of tough Paleozoic quartzite clasts suggests prolonged abrasion, the character and distribution of the deposit point to derivation of debris from source perhaps 15 to 30 km away. Construction of these northwestern fans presumably occurred throughout the basin filling, renewed by successive faulting and relative uplift along the border faults. During lulls in aggradation paleosol caliche developed in the fan deposits.

**Widespread accumulation of Stockton sandy deposits** ended with waning of detrital influx and widespread ponding along the axial drainageway. Eventually this produced a huge Lockatong lake with narrow marginal Brunswick mudflats and small deltas supplied largely from the distant southeastern upland. Along its northern margin the lake was fringed by alluvial fans. The cause of ponding is not known, but it may have been partly the especially active building of fans at both ends of the basin (Van Houten, 1969, Fig. 8; Turner-Peterson, 1980, Fig. 2), combined with continued slow subsidence. Once established, conditions in the long lake varied only within narrow limits for several million years. In this stabilized setting cyclic variation in climate exerted a major control on the lacustrine sedimentation. This was expressed in a succession of short detrital cycles during times of through-flowing drainage, and of chemical cycles when the lake was closed. Among the early Mesozoic basins flanking the Atlantic Basin, the Newark Basin was unique in producing a thick soda-rich silicate facies. In its late stage the Lockatong lake became a carbonate-clay playa with salts crystallizing in the mud and repeated wetting and drying producing extensive cracking, brecciation, and upward-concave patterns of shearing (gilgai). Based on the counts of assumed varves Lockatong short cycles may be the result of expansion and waning of the lake during 21,000 year precession cycles. Clusters of 20 to 25 cycles (Fig. 2b), either predominantly detrital or chemical, suggest another climatic control of 400-500,000 years duration.

The long-lived Lockatong lacustrine facies gradually gave way to broad oxygenated Brunswick mudflats and ponds with shallow water-courses and weak external drainage. In the eastern source most of the mud



**Figure 5.** A. Sections of lenticular, fining-upward sequences in Hammer Creek Conglomerate; a is about 0.5 miles northwest of c. Maximum clast size: a - about 30-35 cm long; b - about 20-25 cm long. STOP 1, Pebble Bluffs, Rt. 627, about 2 miles west of Milford, N.J. B. Model of fining-upward conglomerate-sandstone sequence with capping calcrete paleosol recording episode of non-deposition in warm, dry climate.

weathering was intense enough to convert crystalline basement in the upland into a continuing supply of ferric oxide-rich feldspathic mud. Along the northwestern border of the basin Brunswick mud interfingered directly with the fringing alluvial fans. Much of the basin regime may have been that of ephemeral clay-flat playas where sedimentation was largely from suspension (Friend and Moody-Stuart, 1972; Turner-Peterson, 1980). Here and there glauberite formed as scattered crystals in dried-out mud abundantly broken by shrinkage cracks, and both large and small reptile and small crustaceans left their tracks and trails on the mudflats.

Long (400-500,000 year) climatic cycles, in phase with those recorded in upper Lockatong deposits, produced prolonged periods of dry, oxidizing environment and thick sequences of ferric oxide-rich mud alternating with briefer, moist intervals and accumulation of thin units of pyritic dark gray mud and minor carbonate.

## FIELD TRIP

### Route and Objective

This one-day field trip (Fig. 3) crosses the Newark Basin and Watchung lava flows northwestward from Newark to the border fault, then turns southwestward to the Delaware River section of the Newark Supergroup in the northernmost of three major fault blocks in the central part of the basin. Stops along the 33 km (20 mi.) traverse southward down the section afford study of 1) the Hammer Creek Conglomerate near the northern border fault, composed of Paleozoic carbonate and quartzite clasts in fining-upward sequences marked by calcrete paleosols; 2) the lower part of the Brunswick Mudstone arranged in repeated alternations of reddish-brown silty mudstone and claystone mudflat deposits; 3) the cyclic lacustrine facies of the analcime-dolomite-rich Lockatong Argillite and its hornfels; 4) the small Byram diabase sill; and 5) the Stockton Arkose with a predominance of Na-feldspar, confirming derivation of

most of the Newark basin fill from an eastern or southeastern source. This thick (6 km) sequence is the record of interior basin sedimentation in a major rift valley developed during the early stage of post-Appalachian-Variscan opening of the central Atlantic Basin. The return trip to Newark crosses the Brunswick mudflat lowland in the middle fault block (Fig. 3, 4), then continues northeastward along the south flank of the Watchung lava flows.

The focus of the field trip is on the principal sedimentary facies and the successive changes in sedimentation displayed in the Newark Basin. In this review particular significance is attributed 1) to the eastern upland as the source of the distinctive soda-rich basin fill, 2) to relatively intense weathering in the upland terrane required to produce the large supply of clay in the Lockatong and Brunswick formations, in contrast to the evidence of aridity in the basin reflected in many of the sedimentary features, 3) to a long interval of stability during development of the graben documented by the Lockatong lacustrine deposits, and 4) to several patterns of allocyclic sedimentation recorded in the Lockatong and Brunswick deposits.

## ROAD LOG

### Mileage

0.0 Enter I 280 at intersection with Garden State Parkway (exit 145). Head NW. Interbedded Brunswick (Passaic) reddish-brown arkosic sandstone and mudstone with thin layers of dark gray micaceous mudstone. Local exposures of fining-upward fluvial sequences. See Olsen, this guidebook for revised stratigraphic nomenclature.

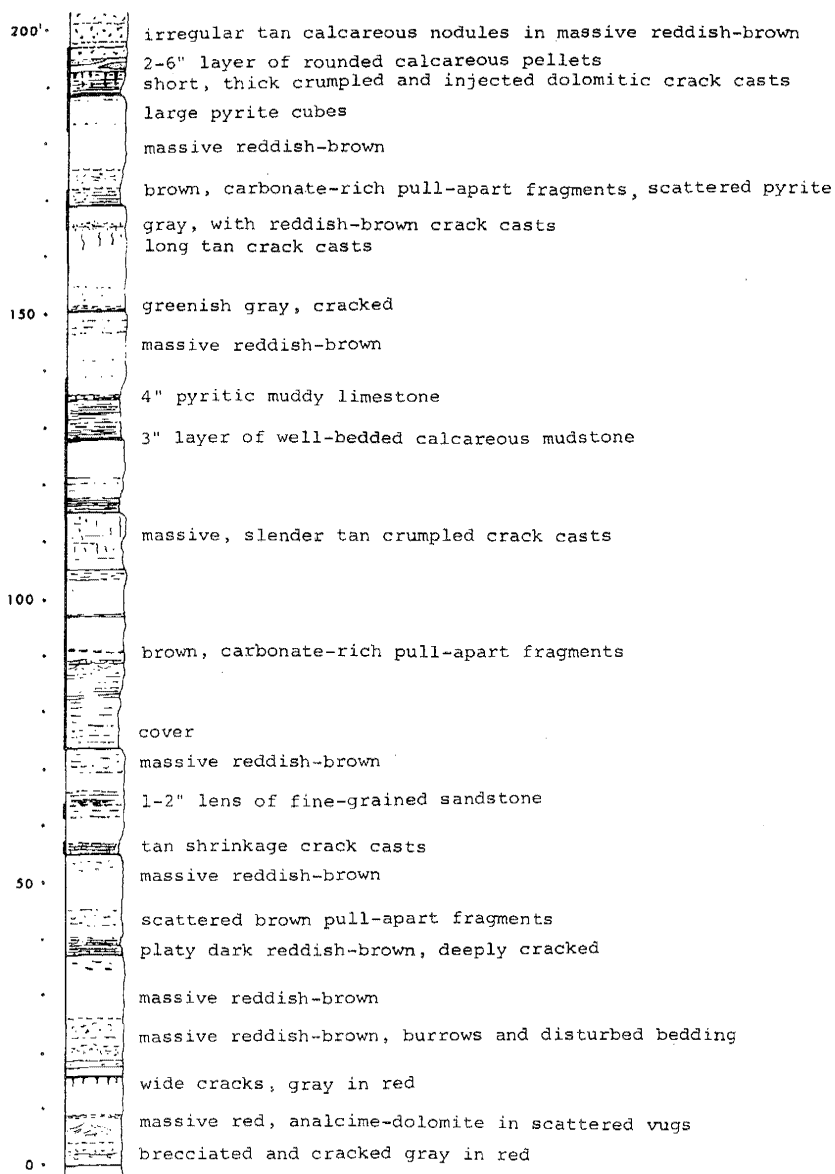
Samples across this traverse to the border fault reveal that the 1250m section of Late Triassic Brunswick beds below the 1st Watchung lava flow contains many zones of reversed magnetic polarity. All of the Liassic strata (1750m) above the 1st flow are normally magnetized (McIntosh and Hargraves, 1980, ms; Cornet and Tr averse, 1975).

3.5 1st Watchung lava flow (Orange Mountain Basalt) 50-65m thick. Basal contact covered. Very thin hornfels facies with small patches of copper minerals. Lower part displays well-developed colonnade with vertical columnar joints. Main



Figure 6. Sketch of rhythmic reddish-brown alternations in Brunswick Formation. Each consists of a more massive, resistant silty mudstone member and a less resistant hackly clay-rich member. Channel is filled with successive overlapping beds 2-8 cm thick, commonly grading

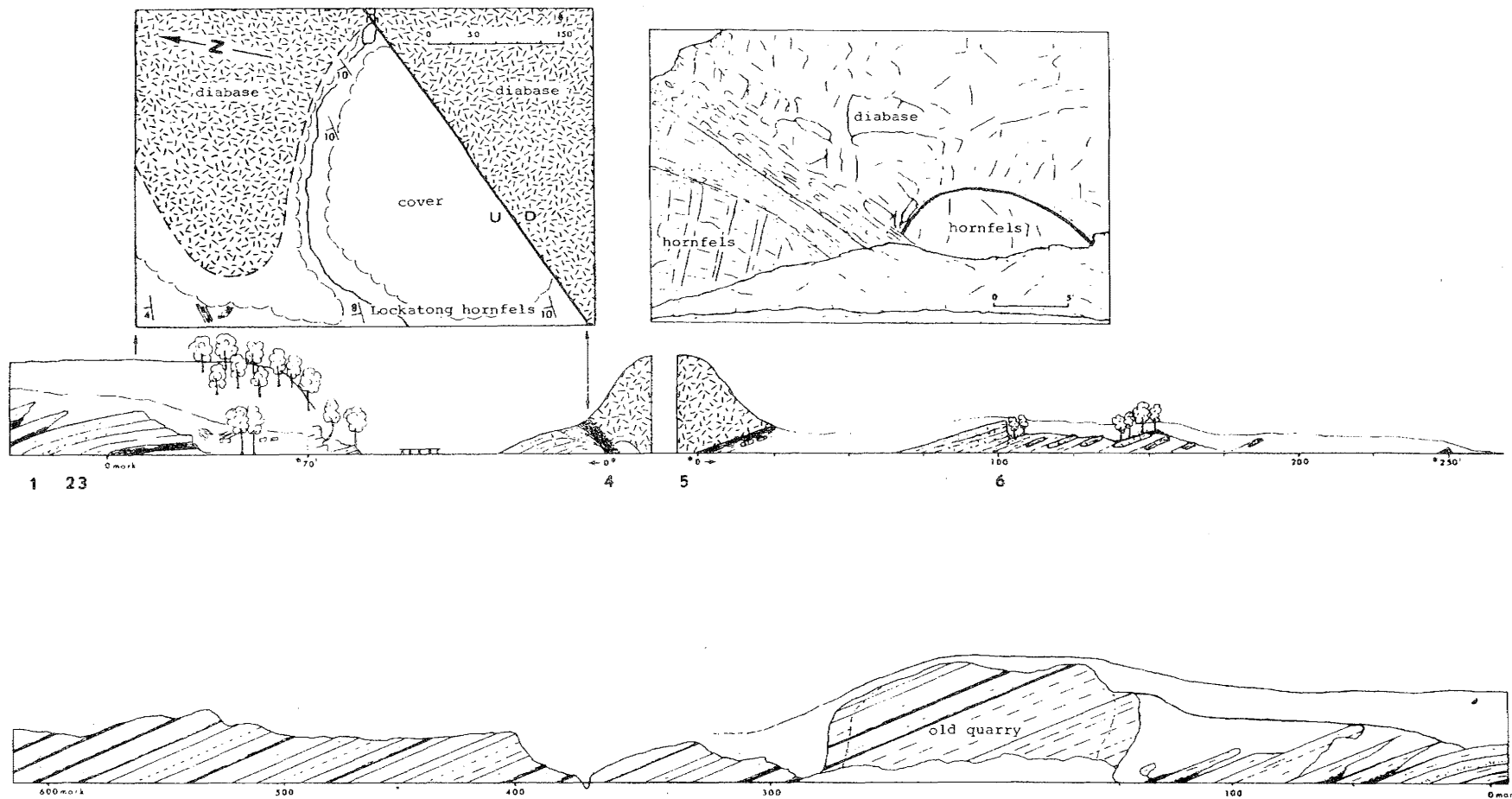
upward from fine-grained feldspathic sandstone into mudstone. Tongue of dark reddish-brown poorly-sorted lithic-rich Hammer Creek Formation derived from the northwest. STOP 2, Rt. 627, about 1 mile west of Milford, N.J.



**Figure 7.** Section of upper 75 ft (20 m) of lowest reddish-brown unit in Brunswick Formation and overlying lowest gray unit C (see Fig. 1). STOP 4, Rt. 29, 5 miles south of Frenchtown, N.J.

- |  |      |   |
|--|------|---|
| body of flow is curvi-columnar zone with closely-spaced radiating joints. (See Manspeizer, this guidebook). Roadcut is 38m deep, said to be the deepest east of the Mississippi River.   | 8.4  | Crossing 3rd Watchung lava flow (Hook Mountain Basalt). Each Watchung flow was extruded somewhat later than renewed faulting and differential uplift of the flanking highlands that produced fanglomerates (Faust, 1978). |
| 4.5 Crossing Pleasant Valley Way in mudflat and lacustrine facies of Brunswick (Feltville) Formation between 1st and 2nd Watchung Mts.   | 11.3 | Join I 80 W to I 287.   |
| 4.75 2nd Watchung lava flow (Preakness Mountain Basalt).   | 14.0 | SW on I 287: Continue past Morristown.  |
| 7.2 Crossing lowland in reddish-brown fluvial and dark gray lacustrine Towaco Formation (37m). Rikers Hill (Roseland) Nat. Mon. (dinosaur tracks) to SW. Locally some of these lacustrine deposits contain traces of hydrocarbons. | 21.5 | North horn of New Vernon anticline in 3rd Watchung flow to S.   |





**Figure 8.** Sketch of roadcut through middle part of Lokatong Formation and Byram diabase sill. STOP 6, Rt. 29, Byram, N.J. 0\*.\*70 ft. and \*0.\*250 ft.- Lokatong hornfels above and below diabase. 0 mark about 70 ft above the sill is base of continuous section to north measured in feet. Lower profile - Lokatong Formation 70 to 715 ft (0-645 ft marks in measured section) STOP 6A. Heavy lines at

base of detrital cycles (see Fig. 2B). Well-displayed analcime-rich chemical cycles between 450 and 550 ft marks. Cancrinite occurs as much as 425 ft (134 m) above sill. Upper profile - Lokatong hornfels. Enlargement (upper right) of upper faulted contact; sketch map (upper left) of diabase east of road. 1-6: items listed in road log.

- 23.5 Patch of Hammer Creek Conglomerate in low hill to SE.
- 24.5 Narrow gap between Ramapo border fault and west end of New Vernon anticline in 3rd Watchung flow. The fault continues for about 50 miles to the NE end of the basin (see Ratcliffe, this guidebook).
- 25.5 Crossing Passaic River. In its last stage Glacial Lake Passaic drained northeastward through gaps in the Watchung flows at Little Falls and Paterson. Great Swamp National Wildlife Refuge to S is a swampy remnant in broad syncline above the 3rd Watchung flow.
- 28.6 Narrow gap between 2nd and 3rd Watchung ridges.
- 30.5 Moggy Hollow (Mine Brook Road) between recurved 2nd Watchung Mt. to NW and 3rd Watchung (Long Hill) Mt. to ESE. Early drainage of Glacial Lake Passaic flowed westward through this notch to the North Branch of the Raritan River. West scarp of 2nd Watchung faulted against Brunswick Formation (Adams, 1980).
- 34.3 Intersection of I 287 and I 78. Watchung Mts. on skyline to E. Continue W on I 78.
- 40.7 Syncline in New Germantown flow in low hills a mile N.
- 44.7 Crossing NE end of Flemington Fault at junction with the border fault (near Lebanon). To S Cushetunk Mt. (diabase) encloses Round Valley Reservoir.
- 45.7 Complexly faulted Cambro-Ordovician strata and Precambrian gneiss that project S into the Newark Basin are limited on E by the Flemington Fault.
- 49.7 Reddish-brown and gray Early and Middle Ordovician shale with thin beds of chert and limestone. Apparently a remnant of a Taconic klippe (Perrisoratis, 1974).
- 51.2 Ordovician shale overlapped by Hammer Creek Conglomerate.
- 52.7 Leave I 78(22), SW to Pattenburg (1.1 mi) on northern edge of Hammer Creek Conglomerate covering Cambro-Ordovician strata faulted against Precambrian gneiss.
- 55.3 Cross Rt. 579 on border fault. Large fan of quartzite-rich conglomerate interfingers with Brunswick, Lockatong, and Stockton formations to E and SE. Evidence that movement on border fault occurred throughout episode of basin-filling.
- 57.7 Little York on border fault. Turn S (0.3 mi.) then SW (1.0 mi), then W in Brunswick Formation S of narrow belt of limestone-pebble conglomerate.
- 60.4 Spring Mills on Brunswick Mudstone between fanglomerates. Jog N then continue W on Church Road along border fault.
- 62.0 Quarry in Hammer Creek (Silurian quartzite clasts) Conglomerate to S. Clasts shattered by crushing in fault zone. Detailed map of Musconetcong Mt. to N and Newark Supergroup S to Frenchtown by Drake and others, 1961, 1967.
- 63.4 S on Phillips Road. Traverse crosses narrow belt of Cambrian limestone and border conglomerate, and the Brunswick Mudstone between lobes of Hammer Creek Conglomerate. Good exposures of border fault relations across the Delaware River at Monroe (0.5 mi S of Durham Furnace on PA 611).
- 64.3 S on Rt. 627 (River Road). Cliff on far side of river above power station shows patterned sequence of middle Brunswick deposits seen at Stop 2. Plateau capped by Coffman Hill diabase sheet (165 m) above gray Brunswick hornfels. The sill is estimated to be about 1400 m below the 1st Watchung lava flow.
- 65.6
- Local Traverse**
- 0.0 **STOP 1** Hammer Creek Conglomerate, Pebble Bluffs at culvert.
- 0.5 **Stop 1B** Conglomerate in steep roadcut at RR milepost 37 (0.5 mi S). Southward projecting lobe of quartzite-rich fanglomerate dipping 10-15 NW. Most clasts are less than 8 cm in diameter, a few are 13 cm long, the largest are 25 cm long. Some clasts are imbricated. Bedding is very poorly developed; cross-bedding is virtually absent.
- The poorly sorted detritus is arranged in crudely fining-upward sequences about 7-9 m thick (Fig. 5) with a scoured base, multi-storied units of conglomerate, and calcareous patches and nodules (calcrete paleosol) in the upper sandier part.
- Significant items:
1. Outcrop less than 5 mi from border fault.
  2. Source probably less than 25-30 mi to N.
  3. Clasts and matrix derived from Paleozoic rocks now stripped from the uplands.
  4. Fining-upward sequence and calcrete common in alluvial fans.
  5. Lensing and channeling well-displayed at south end of bluffs.
  6. Rapid gradation southward into distal, finer-grained facies.
  7. Fault in ravine between two major outcrops.
- 1.1 **STOP 2** Long roadcut in essentially horizontal middle Brunswick Mudstone south of Spring Valley Road. Bright reddish-brown mudstone in patterned sequences about 950 m above base of formation (Picard and High, 1963).
- Items along 0.2 mi traverse:
1. Normal fault at E end of exposure down to E. Conspicuous jointing.
  2. Succession of about 30 massive mudstone and hackly claystone alternations averaging 1.5-3 m thick (Picard and High, 1963). Few units with persistent 1-2 cm beds of siltstone.
  3. Abundant burrowing has destroyed lamination in mudstone. Absence of bedding in claystone may be result of small-scale physical disruption.
  4. Distinct 2-6 cm layers filling abandoned channel (Fig. 6). Fine-to-medium grained feldspathic sandstone in lower part of each layer derived from southeastern Na-feldspar-rich source area. Some layers are graded. Tops

are marked by burrows and shrinkage cracks. Abandoned channel may have been part of interfluvial drainage of extensive alluvial plain (Allen and Williams, 1979) or a shallow waterway in a clay-flat playa.

5. Hammer Creek tongue of dark reddish-brown Paleozoic quartzite-clast lithic-rich sandstone 3 m above road E and W of ravine and culvert.
- 1.8 Dark gray Perkasio and L and M members of Brunswick Formation 930 m above Lockatong Formation. These are highest of 8 recurring gray units in the Delaware Valley region, centered at 120-137 m intervals (Fig. 1). Several have been traced to NE into Hammer Creek Conglomerate (Fig. 4), as well as 25 km to SW where they interfinger with reddish-brown mudstone. Gray units consist of black, pyritic platy muddy limestone and calcareous mudstone. The Perkasio Member apparently is about 1400 m below the 1st Watchung flow. Intervals of reversed magnetic polarization have been identified below both the Perkasio and L and M units, as well as just below and above the Graters Member lower in the formation (W.C. McIntosh and R.B. Hargraves, 1980, Ms).
- 2.5 Milford. Turn E on Main Street, then S at traffic light on Rt. 627.
- 4.5 **STOP 3** Middle Brunswick Mudstone, roadside excavation. Well-displayed bedding surface markings, including several sizes of shrinkage crack-patterns, burrows, and small tracks and trails, many probably made by small crustaceans (Boyer, 1979).
- 6.1 Frenchtown. Turn E on Main Street, then S on NJ 29.
- 9.5 Gray units E and F exposed in ravine and along side road. Gray units G and H above 100 m higher in section constitute the Graters Member (40 m thick).
- 10.05 Gray unit D exposed in ravine of Warford Creek.
- 10.7 **STOP 4** Lowermost Brunswick Formation, Tumble Falls. Ravine and high roadcut in lowest reddish-brown unit and lowest gray unit C (40 m thick) about 75 m above base of formation (Fig. 1, 7). Reddish-brown mudstone units exhibit three distinctive disruption features:

1. Thin greenish-gray beds with scattered shrinkage wafers.
2. Layers of light brown-weathering dolomitic mudstone 1-3 cm thick, in both pull-apart structures and widely dispersed fragments.
3. Upward-concave surfaces of shearing in tent-like structures 15 to 30 cm high suggestive of gilgai formed in soils by repeated wetting and drying.

The uppermost platy part of gray unit C consists of:

1. Black pyritic mudstone layers 2-3 cm thick with wide, completely crumpled composite and injected shrinkage crack casts of brown-weathering muddy dolomite and minor calcite.
2. Lenses of pyritic peloidal dolomite 10-20 cm thick, with silty round and flattened burrow casts and thin arcuate calcitic skeletal debris (ostracodes?) in the upper part. Many of the peloids are crudely concretionary dolomite with internal shrinkage cracks filled with sparry calcite. They may be algal oncolites.

The overlying massive reddish-brown mudstone contains tiny flecks of pyrite and irregular tan calcareous nodules 1-5 cm long that may be algal structures. Many of them have irregular patches of sparry calcite or are crudely concretionary.

- 11.1 Top of Lockatong Formation (top of gray unit B). Base of Brunswick Formation has been placed arbitrarily below the lowest thick reddish-brown unit (Fig. 1) even though its lower part is more like upper Lockatong deposits than the upper part of the Brunswick Formation.
- 11.4 Double Red unit exposed in creek to E is uppermost reddish-brown sequence of analcime-rich chemical cycles assigned to the Lockatong Formation. Thin reddish-brown intervals of this sort are the most analcime-rich and recur in a 105-120 m pattern of long cycles in phase with thick reddish-brown units in the Brunswick Formation (Fig. 1).
- 12.0 Triple Red unit in abandoned building-stone quarry to E about 1000 m above base of Lockatong Formation. Red units were favored for building blocks because of their more interesting variegated colors.
- 12.25 **STOP 5A** First Big Red unit about 35 m thick, Lockatong Formation, roadside outcrop, north end of Byram road cut. Short chemical cycles consist of lower platy dark lavender analcime-rich argillite with intraformational breccia and conspicuous shrinkage cracks with large white patches of analcime and dolomite. Upper massive part is reddish-brown, and spotted with tiny specks of analcime and dolomite locally arranged in rosettes of radiating skeletal crystal casts.
- Profile of ledges in long Byram roadcut to S (395-730 m above base of Lockatong Formation) outlines succession of short cycles (Fig. 2B).
- 12.4 **STOP 5B** Short detrital cycles in gray sequence of Lockatong Formation. Easily eroded black shale in lowest part and feldspathic (Na-feldspar predominates) siltstone and fine-grained sandstone in the upper part (Fig. 2A). Essentially a very fine-grained distal facies of Stockton Arkose.
- 12.5 First thin Red unit in Lockatong Formation. Lowest of the several red units in the Newark section (Fig. 1).
- 12.8 **STOP 6A** Short chemical cycles in gray unit of Lockatong Formation between 450-550 ft marks (Fig. 8). Gray analcime-rich chemical cycles 2-4 m thick (Fig. 2) are characterized by:

1. Platy lower part of alternating black mudstone and tan-weathering dolomitic layers disrupted by shrinkage cracks and pull-aparts.
2. More massive middle part with extensively disrupted dolomitic layers.
3. Upper more homogeneous analcime-rich part,

- commonly speckled with tiny patches of analcime and dolomite distributed in a pattern of minute shrinkage cracks. Locally analcime and dolomite occur in sprays of skeletal crystal casts.
- 13.1 Large abandoned quarry in Locketong cancrinite-rich hornfels (chemical cycles; Fig. 8). Cancrinite is present 130 m (425 ft) stratigraphically above the faulted contact with the Byram diabase to the S. Two well-defined detrital cycles at top of quarry wall.
- 13.3 **STOP 6B** Locketong hornfels and Byram diabase sill, south end of roadcut (Fig. 8).
- 13.5
1. White sprays of cancrinite, albite, and calcite at 21 ft mark developed from analcime-dolomite crystals in a chemical cycle, as seen in First Big Red units (stop 5a).
  2. Nepheline developed in hornfels 25 m (11 ft mark) above Byram Sill.
  3. Metal disk 2 m above road at 10 ft mark records flood level in Sept. 1955.
  4. Faulted upper contact with diabase sill (Fig. 8) and essentially undisturbed contact with xenolith. Locketong chemical cycles metamorphosed to nepheline cancrinite, calcite, pyroxene and amphibole, biotite-albite hornfels (an aphanitic syenite!).
  5. Extensively fractured coarse-grained diabase with abundant joint minerals including calcite, epidote, prehnite, tourmaline, and amphibole. Conspicuous horizontal lineations marked by concentrations of joint minerals are not related to compositional layering in the sill.
  6. Vague cyclic pattern of ledges of albite-biotite hornfels S of sill. Nepheline occurs about 30 m (100 ft) below the sill.
- 13.6 Southernmost roadside outcrop of Locketong hornfels, about 80 m below Byram sill.
- 14.4 Crossing estimated Locketong-Stockton contact.
- 14.8 Well-bedded reddish-brown sandy mudstone and sandstone in uppermost Stockton Formation.
- 15.1 Raven Rock. Upper arkosic member 100 m thick (Fig. 1).
- 16.3 Locketong Creek. Quarry in Cutalossa Member of Stockton Formation (Fig. 1) high on west bank of river.
- 17.5 **STOP 7** Middle Stockton Arkose. Quarry 1 mi N of Stockton. Upper Prallsville Member (Fig. 1) 61 m thick, 760 m above base.
1. Yellowish-gray, well-sorted, medium-grained arkose with only minor reddish-brown micaceous mudstone.
  2. Horizontal bedding predominates, with local micoplacers of specular hematite (after magnetite) on bedding planes.
  3. Large- and small-scale cross-bedding rare.
  4. Intraformational mud-chip conglomerate common.
  5. Isolated burrows in arkose and on bedding planes. Micaceous mudstone extensively burrowed.
  6. Small yellowish-brown patches common in arkose are limonite after altered iron-rich carbonate cement.
  7. Na-feldspar almost twice as abundant as K-feldspar.
  8. Very coarse-grained, kaolinized arkose along upper rim of quarry with clasts of quartz, feldspar, quartzite, and gneiss.
- 17.8 Wichecheoke Creek. Bear right to Stockton on NJ 29.
- 18.65 Conglomeratic Solebury Member (115 m thick) of Stockton Formation in schoolyard to E.
- 19.1 Roadcut in arkosic conglomerate of Solebury Member. Clasts as large as 8 cm mostly quartzite, rare feldspar and gneiss.
- 19.2 Crossing Flemington Fault at Brookville (Fig. 4). To W in Pennsylvania uplifted Cambro-Ordovician limestone is overlain by conglomeratic limestone-clast facies of Stockton Formation.
- 19.5 Locketong nepheline-cancrinite hornfels above Mt. Gilboa diabase. Nepheline and analcime syenites at top of sill probably formed by reaction of a xenolith of Locketong chemical cycles with a granophyric differentiate of the coarse-grained diabase (Barker and Long, 1969).
- 20.1 Mt. Gilboa trap-rock quarry in unusually coarse-grained diabase (gabbro). Locketong hornfels along south edge of quarry.
- 20.3 Crossing southern branch of Flemington Fault (Dilts Corner Fault).
- 22.0 Join US 202 to NE across Brunswick Formation north of Lambertville sill.
- Return Trip**
- 6.0 Ringoes.
- 12.0 Flemington. Continue to US 202.
- 26.0 Somerville. Join US 22 to NE, south of Watchung lava flows.
- 46.0 Enter Garden State Parkway at exit 140. N to exit 145.
- 52.0 Exit 145 to Newark. End of trip.

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RAMAPO RIVER.

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