TRIP C: THE TRIASSIC ROCKS OF THE NORTHERN NEWARK BASIN

By E. Lynn Savage, Brooklyn College of The City University of New York

INTRODUCTION

Objectives of the Field Trip.

Outcrops to be visited on this trip have been selected to illustrate some of the problems involved in the interpretation of Triassic rock units and facies in the northern Newark Basin. (Figure 1). Where possible emphasis is directed toward general Triassic problems, as well as to those which are unique to the northernmost area of this basin.

Although it is generally accepted that much of the Triassic has been removed by erosion, there are two contrasting ideas as to whether the present northeastern end of the Newark Basin marks the former extent of the sediments:

(1) The present outcrop area is almost the same as the original extent (McLaughlin, 1957, p. 1498; Glaeser, 1966, p. 101).

(2) The sediments were once much more extensive, covering the area between the New Jersey-New York Trough and the Connecticut Trough (Sanders, 1963, 1960; MacLachlan, 1957, p. 13; Wheeler, 1938).

Nomenclature.

Currently there is need for reevaluation of the use of the formational names, Stockton, Lockatong, and Brunswick. These units were originally believed to represent a time sequence. Subsequently they were found to be "interfingering facies..... the Stockton in part contemporaneous with the lower portion of the Brunswick. The Lockatong is entirely contemporaneous with a part of the Brunswick" (Reeside, 1957, p. 1459).

Attempts to avoid the time significance which had been assumed for the three formations have led to different proposals. Reeside (1957, p. 1459), Perlmutter (1959, p. 7) and Van Houten (1965, pp. 832-833) use formation for the three rock units; Glaeser (1966, pp. 6-11) uses lithosome for Brunswick and Lockatong, but formation for Stockton; and Savage (1967, p. 3) uses lithosome for all three units.

The most recent evidence, as illustrated on this trip, indicates that in Bergen County, New Jersey, the Lockatong unit interfingers with the Stockton arkose. (Figure 2). This reemphasizes the need to eliminate time significance from the names Stockton, Lockatong and Brunswick before alternative designations can be evaluated. For example, lithosome, which refers to "masses of essentially uniform lithologic character that interfinger with adjacent masses of different lithologies" (Krumbein and Sloss, 1963, p. 301) is applicable, but its use is deferred until the downdip relationships of the units are better understood. In the present report the term with priority, formation, is applied to all three units and used properly as a rock stratigraphic unit without time significance.

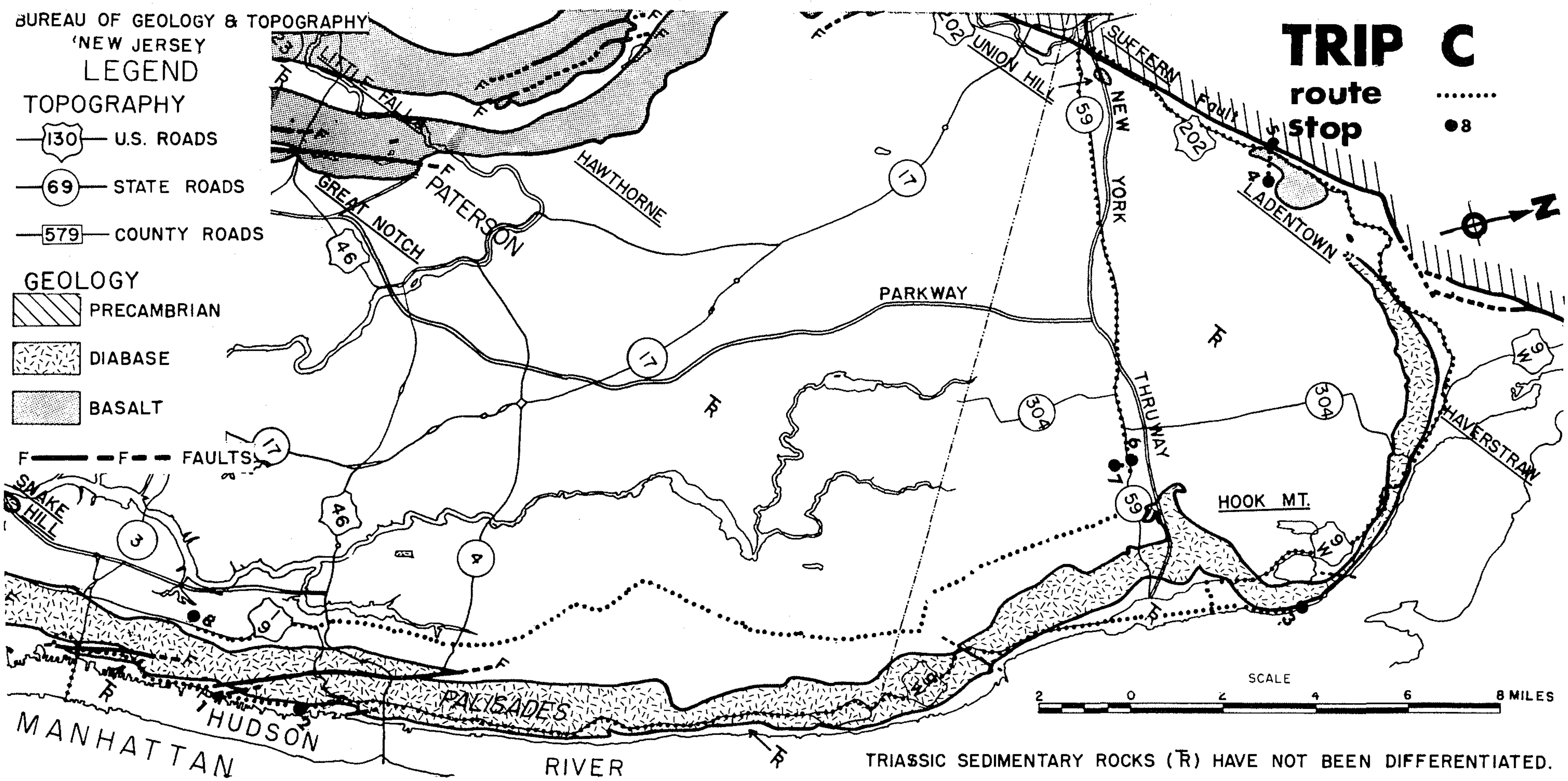


FIG. 1 NORTHERN NEWARK BASIN: TRIP C, ROUTE AND LOCATION OF STOPS

Acknowledgements.

All recent information related to the Lockatong Formation, including stratigraphy, petrology, sections, and interpretation, and Figure 2, is credited to Dr. F. B. Van Houten. He also made a few petrographic studies of the Brunswick rocks in Rockland County, N. Y., and pointed out certain aspects of the geology that had not been evident to the writer.

Much of the information for Rockland County, N. Y., including stratigraphy, petrology, sections and interpretation, is from the writer's Ph. D. dissertation (Savage, 1967).

Special thanks are also due to the writer's students and those of Dr. F. B. Van Houten who helped with the preliminary field work for this trip.

Geographic Setting.

The field trip route is located in the northernmost part of the Newark Basin and generally delineates a figure 1. It starts in the vicinity of Edgewater, Bergen County, New Jersey, at the base of the Palisades, continues to the north across the Rockland County, N. Y. boundary to Nyack, then turns westerly along the north rim of the Palisades to the western boundary of the Basin, then southwesterly near the foot of the Ramapo Mountains to Suffern, then turns east until the backslope of the Palisades is reached. Here, the route again turns south to the vicinity of North Bergen (Granton). (See Figure 1.).

Topography.

As in other eastern Triassic intermontane basins, the basalts, diabase, sandstones, argillites (Argillite: "an unusually tough mudstone" Van Houten, 1965, p. 828), and conglomerates generally form northeast trending rolling hills and ridges. At Nyack, however, the Palisades arc into a sickle-shaped ridge trending westward across the basin (see Figure 3).

The valleys which commonly are 150-200 feet below the nearby hills, are underlain by rocks composed mostly of clay and silt, called mudstone in this paper. (Mudstone: "a massive aphanitic rock composed of an unspecified mixture of silt and clay. Shale - a fissile mudstone." (ibid).)

In the area west of the Palisades, thick accumulation of drift covers much of the area, concealing bedrock in the valleys and adding to the problems of correlation. Kümmel (1897, p. 17) reports that the relief under the drift is more rugged than that of the present topography.

The width of the Palisade Sill outcrop varies, but generally is from less than 1/2 mile to 1 mile wide. It is widest at West Nyack where it is 2 miles in width. In New Jersey, the ridge has a very even crest, generally devoid of gaps, that becomes higher in elevation northward from sea level at Staten Island to 333 ft. at Ft. Lee, 433 ft. at Englewood, to its maximum height of about 550 ft. 1-3/4 miles south of the New York border (Kümmel 1897, p. 61). In contrast to that crest-line, the Palisades ridge in New York is cut by many gaps, the deepest of which is the 200-foot gap at Sparkill which nearly reaches sea level. Four gaps east of Rockland Lake between Nyack

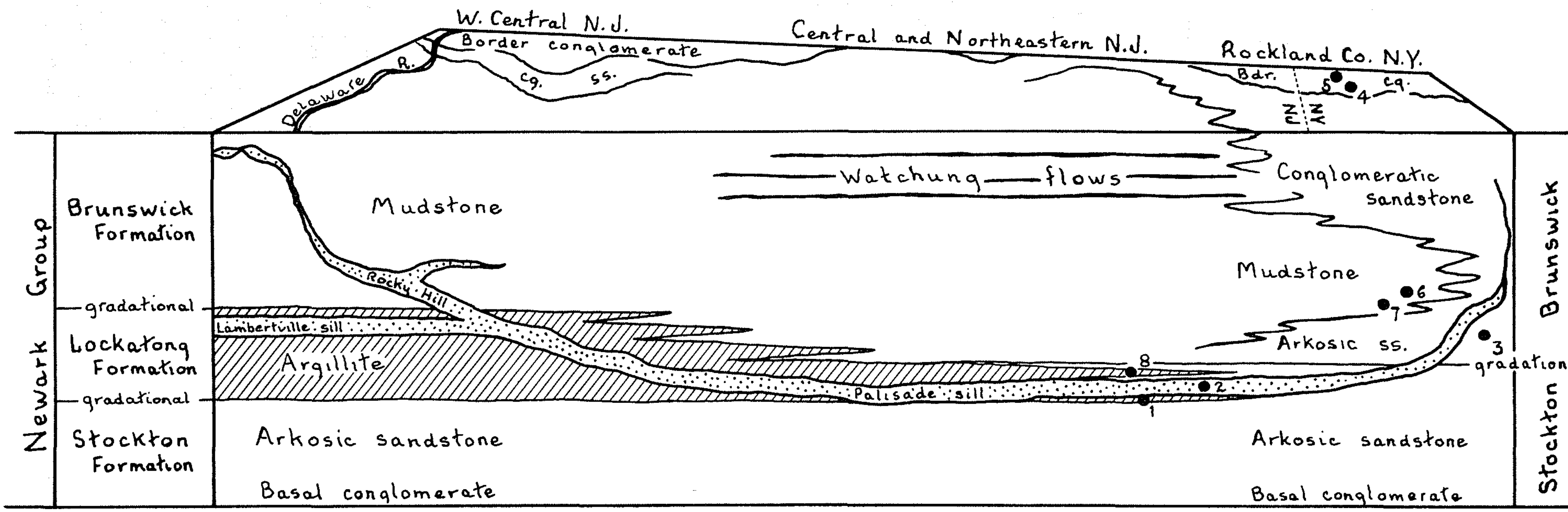


Figure 2. Schematic block diagram of Triassic Formations and lithofacies in Newark Basin, New Jersey and adjacent New York. Restored as before faulting, warping and tilting. Looking northwestward toward northwest border of the basin. Thicknesses relative. 0_1 - stops.

and Haverstraw, range from 190 to 230 ft. in elevation. Most of the knobs that make up the rest of the ridge in New York are from 600-700 ft. above sea level. Little Tor reaches 710 ft. and Verdreitege Hook (Hook Mountain, STOP 3) reaches 730 ft. From High Tor, where the ridge has its maximum elevation (832 ft; Kümmel, 1897, pp. 22-23), the crest again descends and finally disappears below the glacial cover.

ROCK UNITS

The Triassic Sedimentary Rocks.

The Stockton Formation which is about 5000 feet thick in eastern Pennsylvania and western New Jersey, is much thinner in Bergen and Rockland Counties where it is found near the Palisade Sill, and mainly between the lower contact of the sill and the Hudson River which conceals the base of the formation. It apparently does not crop out north or west of Piermont for here it is overlain by a sequence gradational between the uppermost Stockton and the lowest Brunswick Formations (Savage, 1967, p. 34).

In eastern Pennsylvania and western New Jersey the Lockatong Formation is up to 3750 ft. thick. In northeastern New Jersey it has only recently been recognized in drill core at Newark where it is about 500 ft. thick, in a 90-foot thick section in the Granton Quarry, Bergen County (STOP 8) (Van Houten, 1964, p. 500) and in a section that is about 60 ft. thick near Edgewater (STOP 1). At the latter localities, it apparently interfingers with the upper part of the Stockton Formation. The Lockatong has not been found elsewhere in northern Bergen County or in Rockland County.

The Brunswick Formation (7000 ft. thick in western Pennsylvania and central New Jersey) underlies most of the northern Newark Basin. In Rockland County it consists of a very coarse lithofacies. Figure 2 illustrates the relationships between these rocks prior to tectonic disturbance and erosion.

1. The Stockton Formation. In the field trip area the Stockton Formation is exposed only above and below the Palisade Sill in a narrow outcrop belt. Its base is concealed by the Hudson River. The Stockton Formation here consists mainly of fairly well-sorted fine-to coarse grained yellowish-gray to pale orange, thick-bedded arkose, interbedded with reddish-brown and pale lavender silty and shaly mudstones. The latter are commonly altered to hornfels many feet from the Palisade Sill whereas the arkoses only a few feet from the contact are relatively unaffected.

Mudstone-arkose contacts, such as are found at Sneden's Landing, New York, are usually irregular, showing local erosion and scouring.

Scattered pebbles at Sneden's Landing include angular grains of quartz and of fresh pink orthoclase up to 1 inch in diameter. Feldspar in the sand and silt size fractions appears to be fresher, and the quartz mainly clearer, without strain and with fewer inclusions than that in stratigraphically higher arkoses northwest of Piermont. In addition, an abundance of zircon, rutile, and authigenic anatase, a paucity of tourmaline and garnet and an absence of metamorphic fragments, contrasts with mineral frequencies in Brunswick arkoses (Figures 5-10; Savage 1967, pp. 104-121).

Clepysaurus (Rutiodon), a phytosaur, was found in the arkose just south of the base of the George Washington Bridge and is now on display at the American Museum of Natural History.

2. The Lockatong Formation. A thin extension of hornfelsed Lockatong argillite into Bergen County, New Jersey is well exposed in the Granton Quarry (STOP 8), where it is preserved between the top of the Palisade Sill and a smaller sill above it. This hornfels facies also occurs under the Palisade Sill from Weehawken to Edgewater. The Lockatong Formation apparently is absent farther north in the Newark Basin.

In western New Jersey and eastern Pennsylvania these rocks reach a total thickness of about 3750 ft. and conformably overlie the Stockton Formation (Van Houten 1965, p. 826), and interfinger extensively with the Brunswick Formation. In northeastern New Jersey exposures, they are interbedded with the Stockton Formation; the contact with the Brunswick is concealed by glacial drifts.

Where the Lockatong Formation is absent in Rockland County, New York, the Stockton arkose grades up into the Brunswick Formation.

Readily distinguished from the other formations by its distinctive bedding and dark color, the Lockatong Formation consists of asymmetrical chemical and detrital cyclic units, usually occurring as bundles of similar cycles. A generalized single chemical cycle, from oldest to youngest, consists of dark gray to black shaly feldspathic limy mudstone, thin limy and dolomitic laminae, platy limy layers typified by syneresis brecciation, and an overlying analcime-rich argillite. Such cycles are found at Edgewater, New Jersey (STOP 1). A detrital cycle consists successively of black shale, platy dark gray carbonate-rich mudstone, and an upper tough gray massive calcareous silty mudstones, as seen in the Granton Quarry (STOP 8). Average thickness of cycles in western New Jersey is about 15 feet, but detrital cycles are somewhat thicker. Both have yielded readily to thermal metamorphism, the analcime-rich layers being particularly susceptible, (Van Houten 1964, p. 497). The conspicuous hornfelsing of the sequence at Granton was no doubt due in part to its being sandwiched between two sills.

Varve counts of the chemical cycles suggest that short cycles (15 ft. thick) average 21,000 years and seem to correlate with cycles of precession, as do cycles in the Green River Shale (Eocene) of the Rocky Mountain region. These short cycles appear to be grouped into larger cycles of 100,000 years duration and these into even larger clusters spanning 500,000 years (Van Houten 1964, p. 529).

The cycles are believed to record climatic variation resulting from precession of the equinox. Apparently the changes in the pattern of rainfall were imposed on deposits of a sinking lake basin of which the sediments of the field trip area represent a minor part. During moister periods, detrital cycles (similar to the finest Stockton facies), accumulated in open lakes of low salinity. The chemical cycles accumulated in closed lakes reflecting a change to drier climates (Van Houten 1964).

Cyzicus (Estheria) ovata, a branchiopod, and fish are common at Granton and at Weehawken (Nason 1888, p. 26). Icarosaurus, a gliding reptile, was recently collected in the Granton Quarry which has also yielded other reptiles now being studied.

(See Road Log, STOPS 1 and 8, for detailed mineralogy of this formation.)

3. The Brunswick Formation. The Brunswick Formation, which is a max-

imum of 8000 ft. thick, is exposed extensively in the Newark Basin. Typically it consists of soft reddish-brown shaly mudstone and interbedded red-brown sandstone which grade into coarse cobble conglomerates to the west near the Ramapo Fault that delimit the Triassic basin.

Except for a small triangle of Stockton deposits between the New York State border and the Piermont-Sparkill area, all of the Triassic sedimentary rocks of Rockland County comprise the Brunswick Formation. Here, the formation is generally coarser than anywhere else in the basin.

The Brunswick Formation has been divided into 4 lithofacies with subdivisions. In general, each lithofacies coarsens upwards. On the basis of heavy mineral and lithic content the lowest lithofacies is more closely related to the Brunswick than the Stockton deposits to which it was previously assigned. (Savage 1967, pp. 34-35). However, the lowest feldspathic Brunswick unit is different from the overlying coarser layers of the Brunswick as well. This will be discussed further in the section below on dispersal.

Figure 3 illustrates the 4 lithofacies which are modified after Savage (1967, p. 35). These are as follows, from oldest to youngest (east to west):

1. Arkosic lithofacies:

   a. Reddish-brown, massive, well-sorted, medium to fine-grained, feldspathic sandstone, and red shaly silty mudstone. Rare coarser layers include quartz and feldspar clasts up to 1 inch in diameter.

   b. Massive red and lavender micaceous siltstone, shaly and limy mudstone, and micaceous reddish-brown sandstone, interbedded with, and underlying, pale light gray to yellow-and greenish-gray arkose. Rare pebbly layers in the arkose include angular quartz (mainly 1 inch, but as much as 2-1/2 inches in diameter), angular pink orthoclase clasts up to 2 inches in diameter, and rare (1 inch) gray limestone clasts, pegmatite with book mica, schist (to 1 inch), quartzite, and red mudstone clasts. (STOP 3.) There is also a unique greenish-gray bed of pellets and clasts of silty mud, many of which contain a carbonate core. Burrowing is common in mudstone layers.

2. Red-brown silty shaly mudstone interbedded with red-brown and buff finely banded feldspathic sandstone, the latter with scattered quartz clasts 1/2 to 1 inch in diameter. Near the Palisade Sill the shaly mudstones are altered to hornfels. Rootlike structures and burrows occur in these deposits.

3. Red-brown gravelly sandstone and pebbly quartz conglomerate with rare lithic clasts (up to 1 foot in diameter). Among the clasts which consist mainly of (1 inch) quartz, quartzite, shale and Green Pond Conglomerate (Silurian), there are rounded pieces of fine to medium-grained dark red-brown fossiliferous sandstones (Devonian?). Just south of the Palisade Sill near Lake Lucille, granite gneiss and gabbro clasts were noted by the writer.

4. Cobble Conglomerates: There are two areas of cobble conglomerates: in each, limestone fragments predominate. The more northerly Stony Point outcrop may be somewhat lower stratigraphically than the westerly one. The Stony Point cobble conglomerates consist of shaly to silty gray limestone and quartzite clasts (up to 10 inches in diameter) in a matrix of red shaly limestone. The western cobble conglomerates consist mainly of light tan to gray cherty limestone and dolomite cobbles. The largest clasts presently exposed are over 4 feet in diameter; a 12 foot cobble has been reported, but most of the cobbles are less than about 1 or 2 feet in diameter. The cobbles also include pink and gray quartzite, purple-red quartz conglomerate (Green Pond, Silurian) and in vicinity of Suffern, amygdaloidal basalt. Along the eastern margin of outcrop of this conglomeratic lithofacies dark reddish-brown fossiliferous sandstone clasts (Devonian?) are found. These have not been found to the west where the highest strata of the unit are exposed. Apparently most of the Devonian(?) rocks had been stripped from the source area by the time the youngest conglomerate was deposited.

From southeast to northwest these surface outcrops provide a succession of changing facies deposited at different times. It is not known whether these facies also continue very far down dip of each unit, or whether the same rock types were continuous eastward in any deposit now eroded from the updip portions of the units. Moreover, interfingering relationships along strike are difficult to decipher because soil, glacial drift and urban development conceal basic data. Subsurface information is needed to determine the detailed stratigraphic relations of these facies.

The great variability of these nonmarine facies makes it very difficult to reach meaningful conclusions from the limited data, no matter how rigorously they are analyzed.

Note on Pebbles and Distribution.

The composition and distribution of clasts of pebble size and larger are illustrated in Figure 4. The sizes of the pebbles increases to a maximum between Suffern and the Ladentown area to the north. Rare clasts up to 1 foot in diameter occur as far east as the position of Spring Valley.

Note on Minerals and Distribution.

Quartz in the Brunswick Formation has more inclusions than that in the Stockton and is more strained. In addition, the angularity of grains increases (markedly to the north, at Stony Point the grains are shard-like). The quartz at Tomkins Cove appears strained.

Feldspars are increasingly weathered in the younger rocks from southeast to northwest in the lowest Brunswick facies. At Cherry Hill (STOP 6) the potash feldspar is weathered but the sodium feldspar is rather fresh. In general the Stockton has more fresh feldspar than the Brunswick.

The distribution of heavy minerals are illustrated in Figures 5, 6, 7, 8, and 9.

The varieties of heavy minerals in the Brunswick Formation include mainly

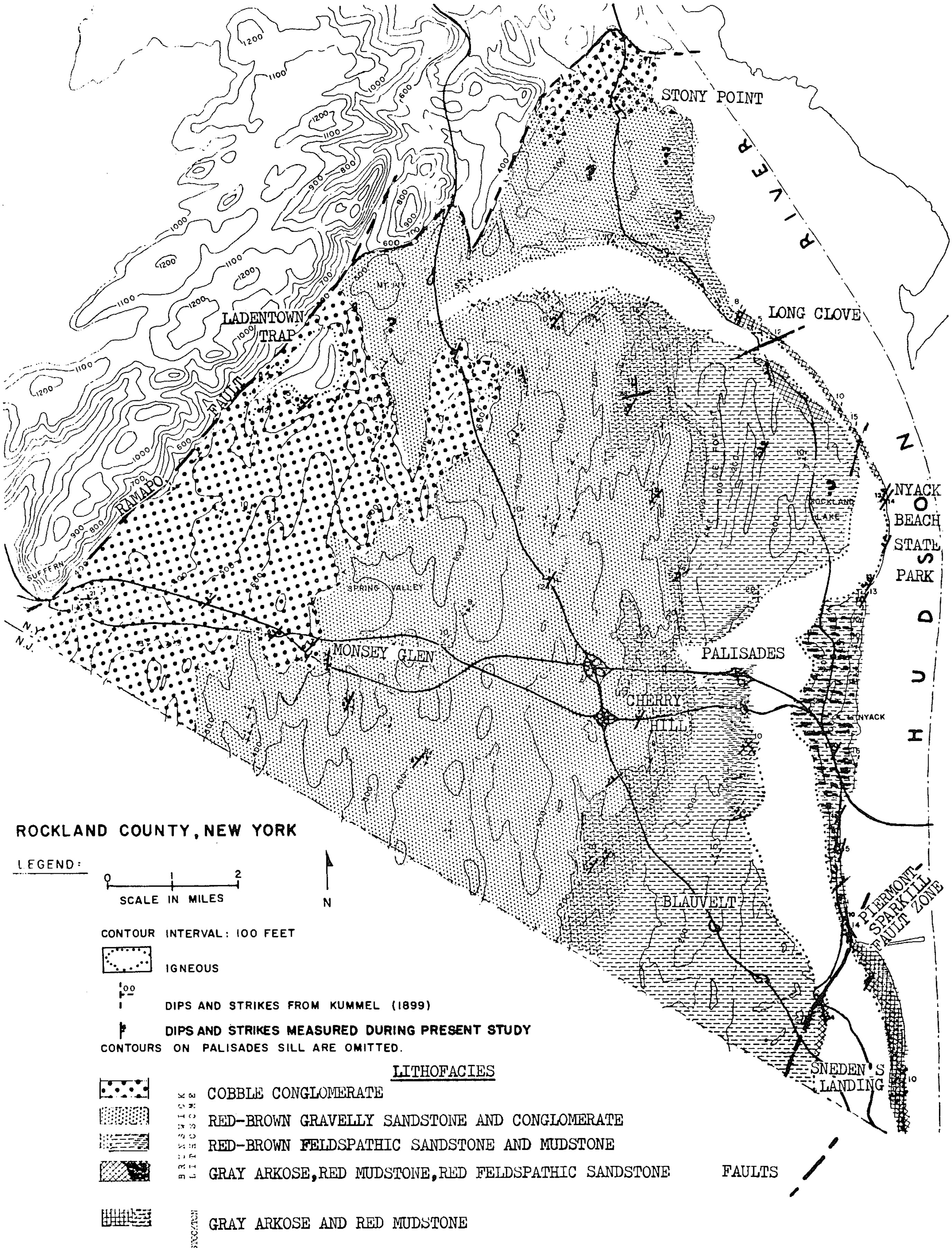


FIG. 3 GEOLOGIC MAP ILLUSTRATING DISTRIBUTION OF LITHOFACIES OF THE STOCKTON AND BRUNSWICK FORMATIONS (UPPER TRIASSIC) IN ROCKLAND COUNTY, NEW YORK

apatite, garnet, rutile, authigenic anatase, tourmaline and zircon, as well as hematite and magnetite. Rarer varieties included biotite, chlorite, very rare epidote and hornblende, muscovite, sillimanite(?), tremolite, and pyrite. Leucoxene with (?)ilmenite cores frequently make up 15% of the fraction. (Savage 1967, pp. 104-115).

Garnet, never exceeding 18%, frequently is almandite found as dodecahedrons, as at Nyack (STOP 3). In general garnet appears to be more common to the north and northwest and at Nyack.

Rutile which is also abundant in the Stockton, is frequently found along with authigenic anatase in the Brunswick Formation. It often occurs as prismatic crystals.

Tourmaline varies from brown to green to indigo-blue indicolite. Green tourmaline is common in the Stockton; and in the Brunswick, it increases to the northwest. Brown tourmaline apparently is restricted to the Brunswick and is widespread throughout the formation. This common variety consists of prisms and broken fragments of larger grains. Indicolite, present in only minor amounts, is scattered throughout the Brunswick. Total percentages appear to increase in a northerly direction.

Zircon, which comprises as much as 16% of the Stockton heavy minerals, does not exceed 6% in the Brunswick Formation, but it appears to be somewhat more abundant in higher Brunswick strata to the west.

The ratio of sedimentary rock fragments to metamorphic rock is illustrated in Figure 10. The sedimentary varieties include red and brown shales, red shaly siltstones, pale siltstones. The metamorphic varieties include low-grade phyllite(?) frequently replaced by chlorite, quartzite with mosaics of strained quartz, both red and pale muscovite schists, schists with streaks of (?)magnetite, gneiss with streaks of magnetite, and possibly granite gneiss. Sedimentary rock fragments apparently are more common to the north whereas metamorphic rock fragments increase to the southwest (Savage, 1967, p. 115).

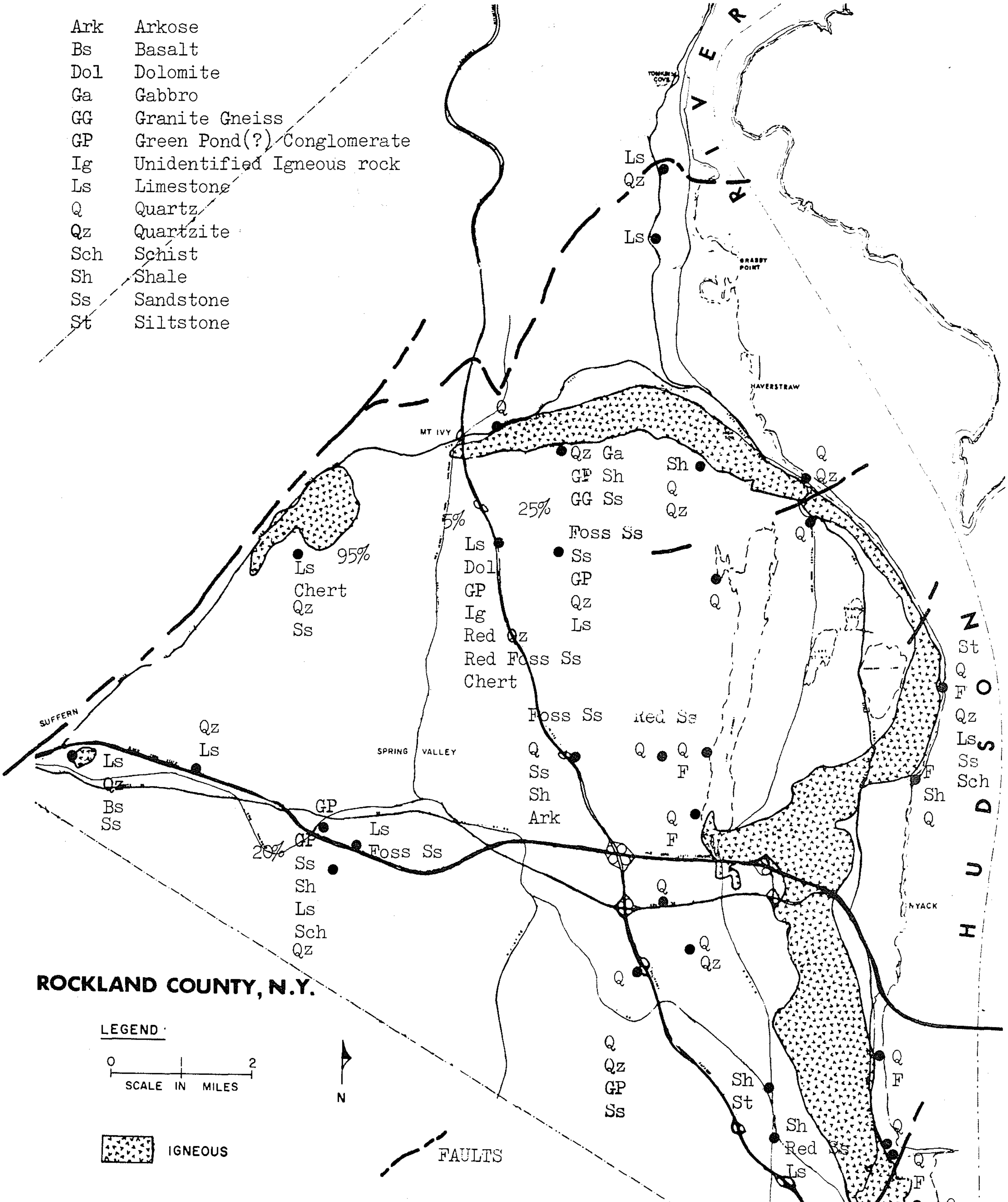
According to these data the heavy mineral content changes laterally within units, rather than vertically from unit to unit, except for zircon and possibly lithic fragments. Except for the Stockton and lowest Brunswick Formations where apparently some correlation may be possible, correlation by heavy mineral content appears to fail in the higher stratigraphic units.

IGNEOUS ROCKS

The igneous rocks of the Newark Basin include three lava flows in central New Jersey which may be synchronous with those of the Connecticut Valley. These flows apparently did not extend to the north in Rockland County, New York.

The Palisade intrusion is a sill throughout most of the Newark Basin but may be a dike in the Rockland County, New York area according to Lowe (1959). The rock type of the Palisade intrusion varies from basalt at its chilled borders to diabase in its interior. Gabbro has also been noted at Casper Hill, New York.

Within the field trip area, a zone of olivine diabase is present south of the Piermont-Sparkill area. The accumulation of the olivine by gravitational differentiation has recently been questioned and several theories have been proposed to explain its



Rock types are listed above.

Percentages shown refer to percentage of rock made up of cobble-sized material.

FIGURE 4 COMPOSITION OF PEBBLES FOUND IN THE TRIASSIC SEDIMENTS

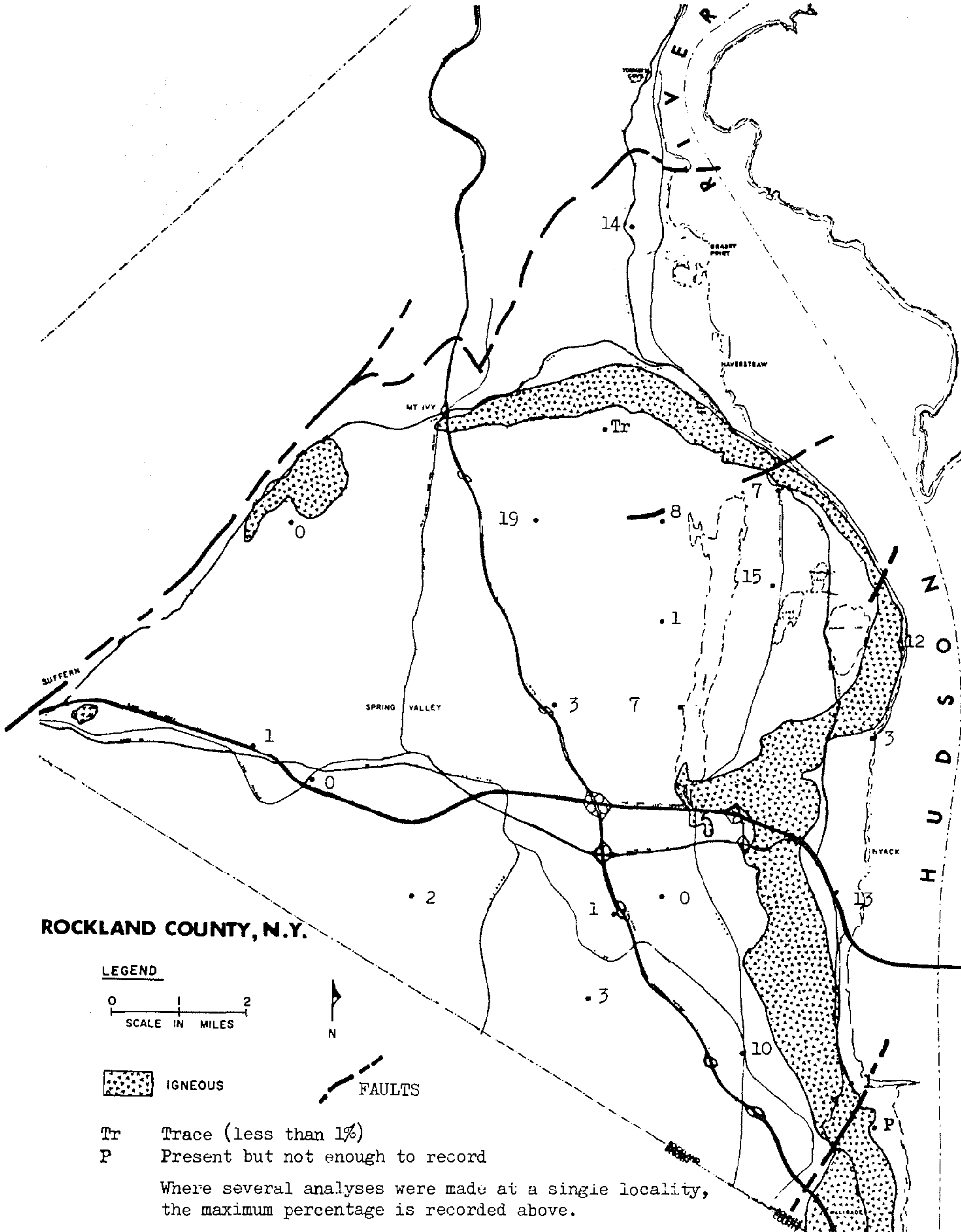


FIGURE 5 GEOGRAPHIC DISTRIBUTION OF PERCENTAGE FREQUENCY OF APATITE

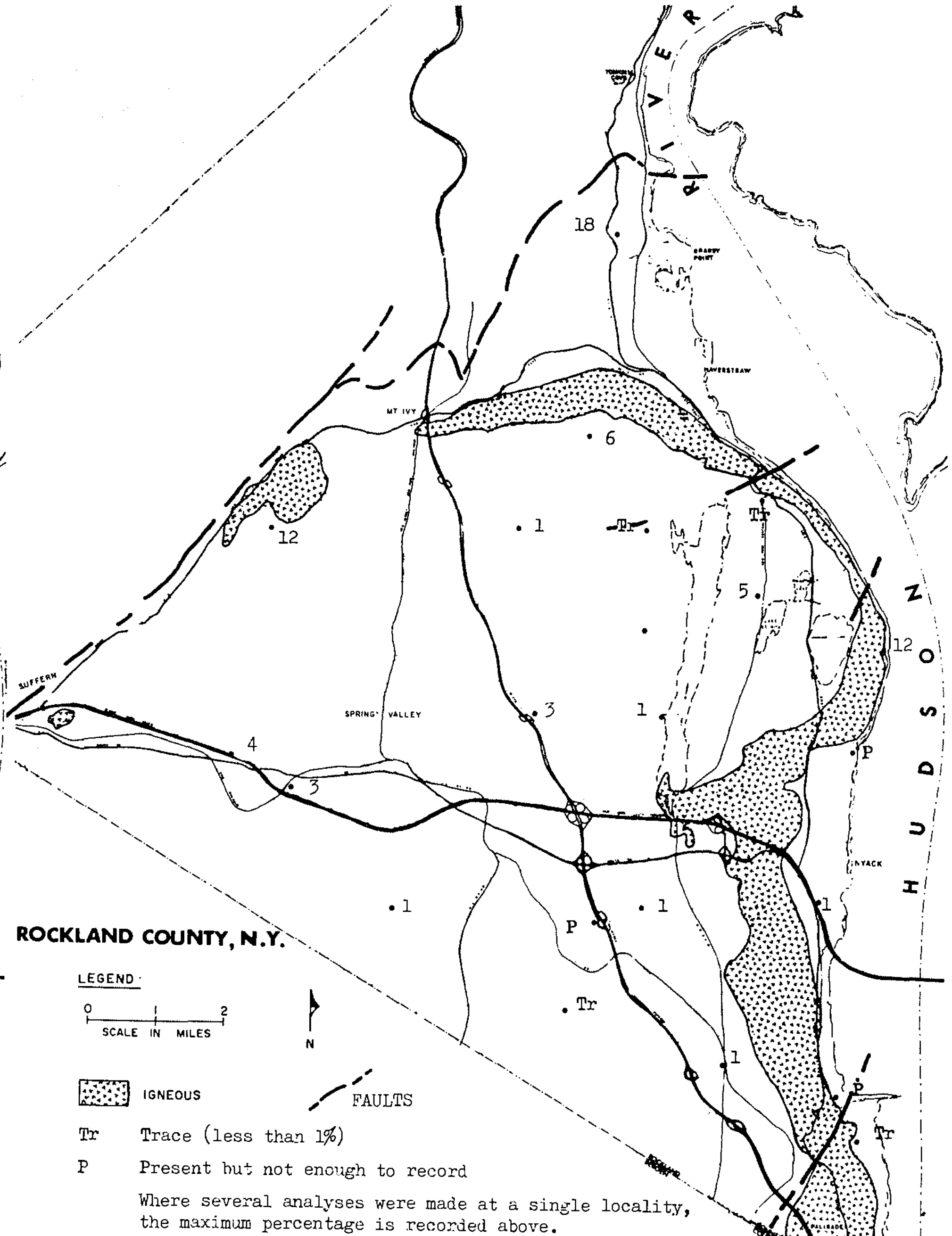


FIGURE 6 GEOGRAPHIC DISTRIBUTION OF PERCENTAGE FREQUENCY OF GARNET

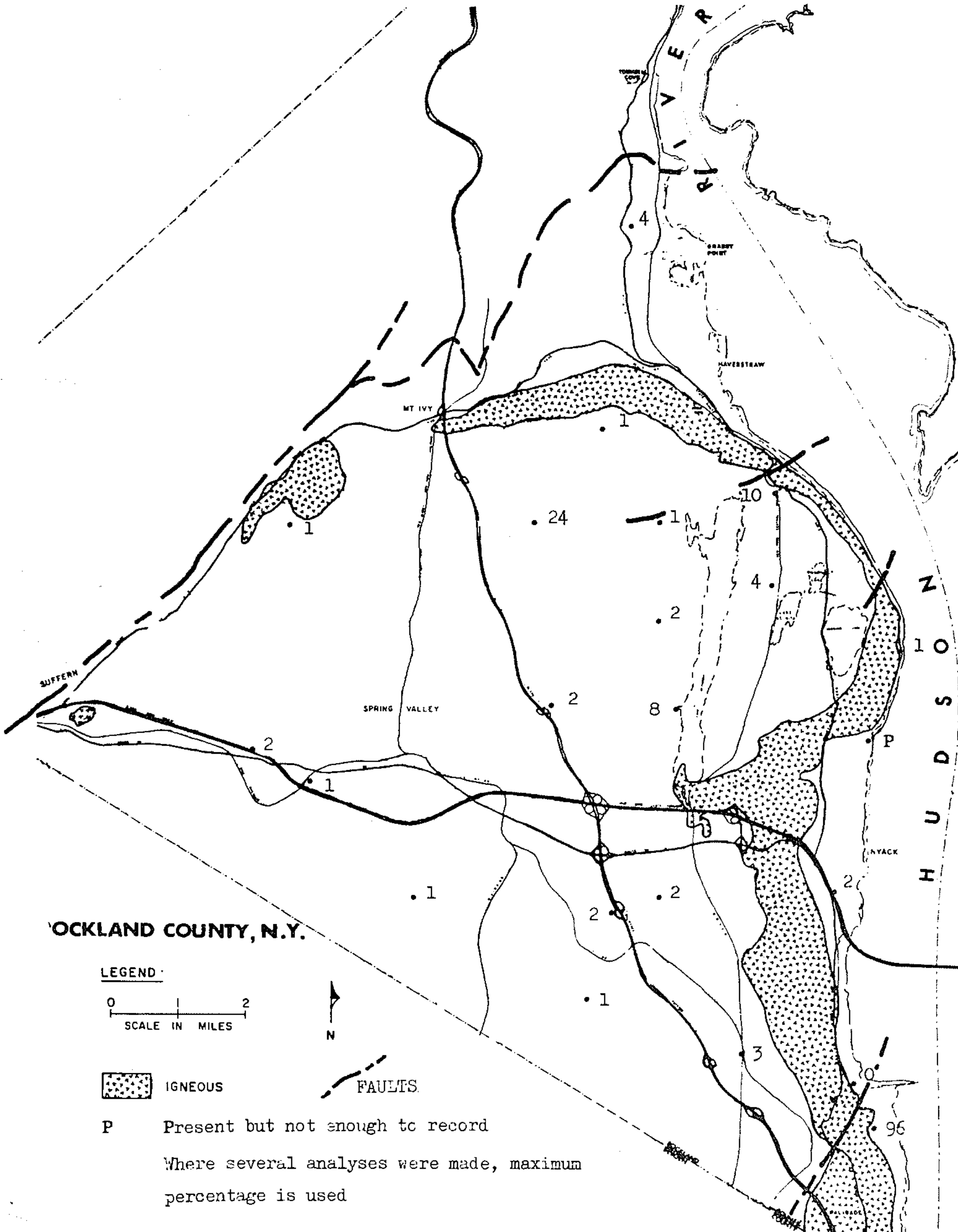


FIGURE 7 GEOGRAPHIC DISTRIBUTION OF COMBINED PERCENTAGE FREQUENCIES OF RUTILE AND ANATASE

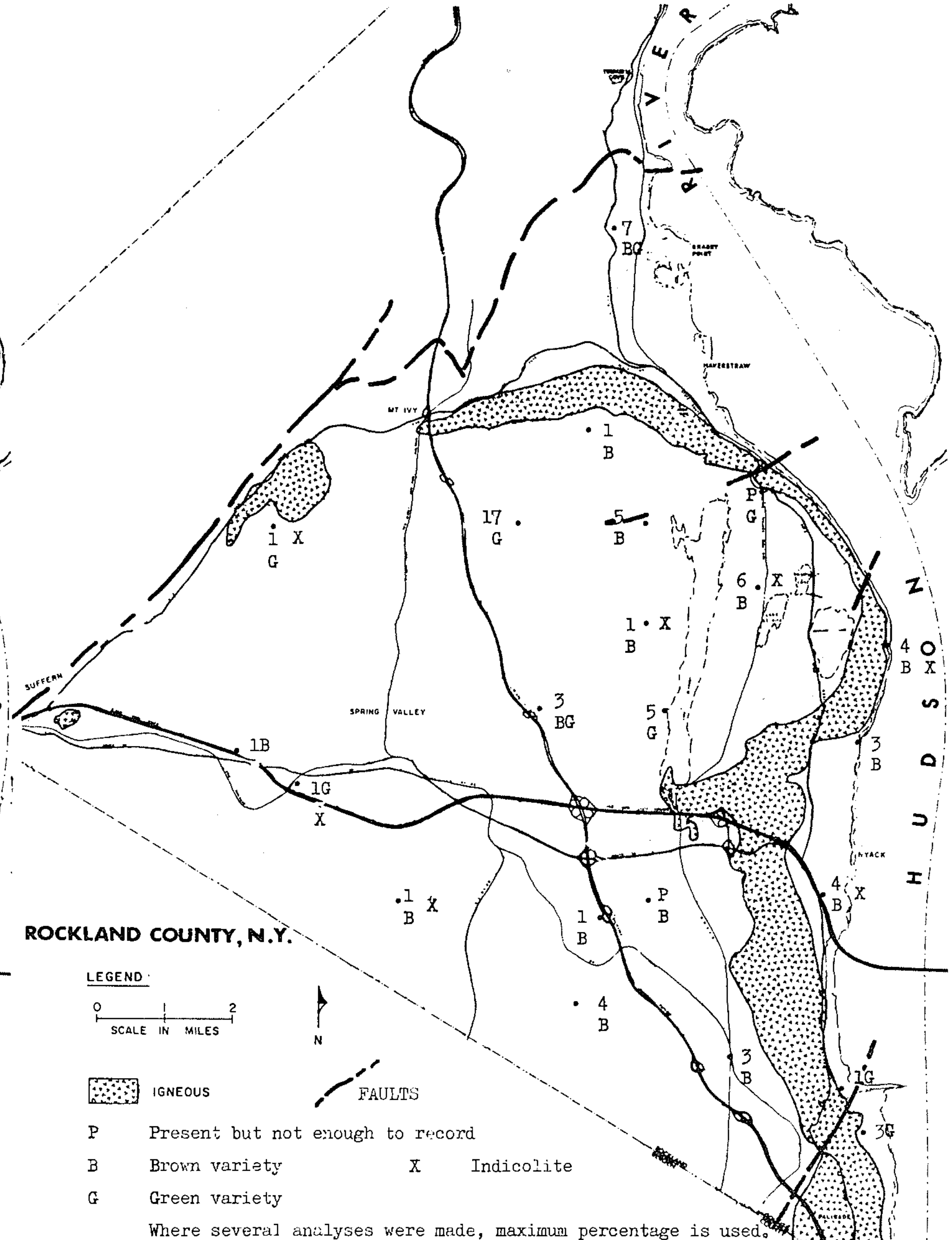


FIGURE 8 GEOGRAPHIC DISTRIBUTION OF VARIETIES AND PERCENTAGE FREQUENCY OF TOURMALINE

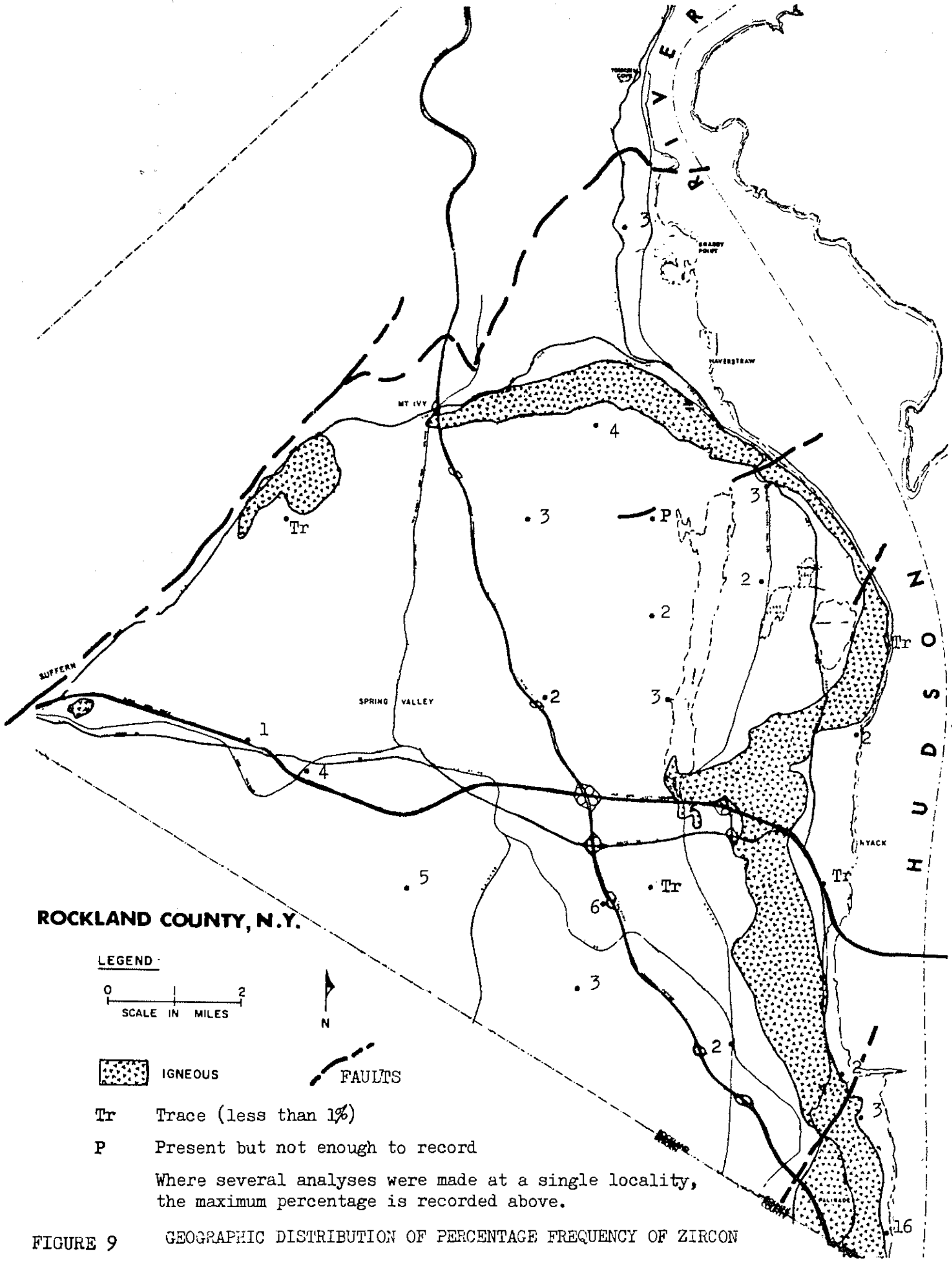


FIGURE 9 GEOGRAPHIC DISTRIBUTION OF PERCENTAGE FREQUENCY OF ZIRCON

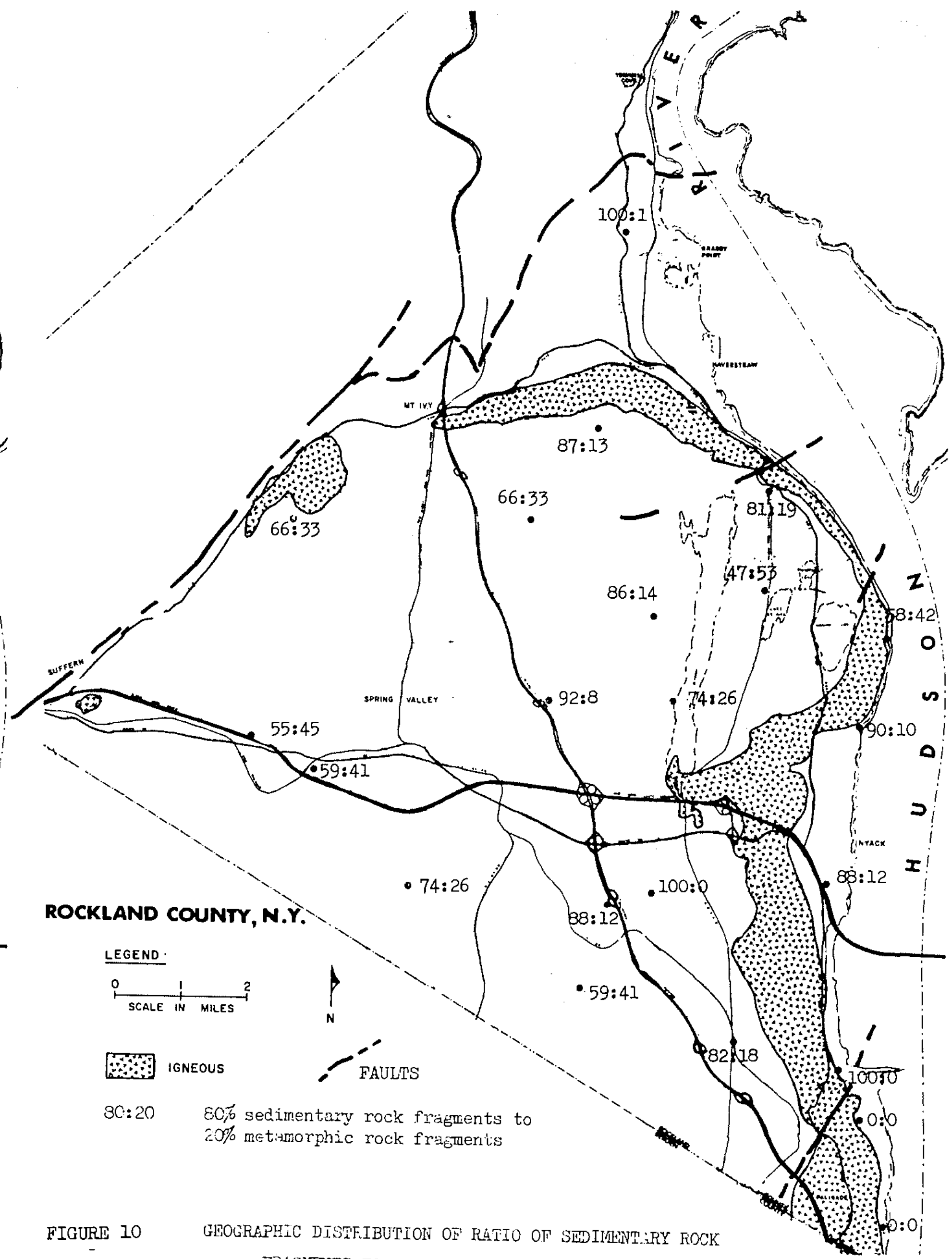


FIGURE 10 GEOGRAPHIC DISTRIBUTION OF RATIO OF SEDIMENTARY ROCK FRAGMENTS TO METAMORPHIC ROCK FRAGMENTS

origin. (Discussion at STOP 2.)

Maximum thickness of the sill in the field trip area is about 1000 feet (Kümmel, 1940, p. 105). Regionally it is not conformable, and cuts across the Newark Formations. Locally, the base of the sill rises and falls markedly in elevation, from 600-700 feet to sea level.

In many places the Palisade diabase has been quarried for trap, an operation that still continues. Just south of the New York State border zeolites were found near the base of the sill. (Nason, 1888, p. 38.) Xenoliths of Newark rocks have been caught up in the lower and rarely the upper parts of the sill.

The sill is marked by joints that resulted from cooling and, as a result of frost action along these, huge talus blocks accumulate at the foot of the steep cliffs. These talus cliffs are especially well developed in Rockland County from just north of Nyack to Haverstraw.

<u>The Ladentown Trap</u>.

This body measures 2 miles by 1 mile and is separated from the Mt. Ivy terminus of the Palisades (Figure 20). Across the 2 mile gap between the two traps, glacial deposits conceal any relationship between them. Kummel and previous workers suggested that the Ladentown body connects with the Palisades across the gap.

The rock here is finer-grained than the diabase of the sill except in its chilled borders. In places the Ladentown igneous rock is a vesicular basalt. Kummel reports ropy or pahoehoe structures similar to those in the Watchung flows. This, together with the curved cooling joints that are like those in lava flows, suggests that this rock is a flow (Kümmel, 1898, p. 41.)

No other lava sheets have been reported in Rockland County.

STRUCTURE

The Newark strata dip northwestward from a positive gravity anomaly over a low arch that separates them from their mirror image in the Connecticut basin, where the dip is eastward. Faults bound each of these basins at the borders where the thickest sequence of sedimentary rocks is preserved.

In the field trip area, the strike of the sediments is NE-SW and the dip is from 5° to 15°NW, in a faulted monocline. Locally, there are small open folds but these are relatively few and commonly obscured by glacial drift. Unlike most of the sequence, the border cobble conglomerates locally dip eastward away from the northwest border fault and toward the older Triassic sedimentary rocks.

The Palisade Sill is generally conformable with the strata until Nyack, where the ridge arcs toward the river across progressively older sediments. It then parallels the river to a point north of Nyack Beach State Park (STOP 3), where it curves back to the west across progressively younger sediments forming a "sickle-shaped" arc. In this structure the intrusive is reported to change from a 15°SW dipping sill to a steep-dipping 45°SW dike. It has been suggested that the diabase becomes a semi-circular dike dipping $40-50^{\circ}$ towards the center of the sickle (Lowe, 1959).

Faults.

Many small faults cut the Palisade Sill and the sedimentary rocks. The diagonal fault at the Lincoln Tunnel Plaza (Figure 12) and that at Sparkill Gap (Figure 17) are but two that exist in the field trip area.

The most prominent fault is usually inferred from topography. The differentially eroded scarp of the Pre-cambrian crystallines of the Ramapo Mountains marks the position of the Ramapo fault which terminates the Newark Basin to the west. The zone of slickensides exposed near Suffern, New York, is one of the few direct exposures of the fault zone.

CROSS-STRATIFICATION AND DISPERSAL

Cross-strata are frequently obscured by soot or are inaccessible. Coupled with glacial cover and urbanization, available outcrops for this study are sharply curtailed.

In Rockland County, cross-beds with a single exception of tabular cross-strata at Nyack (STOP 3), are trough shaped with curved basal contacts. Cross-beds vary from thin to thick-bedded layers, from small to medium scale, most being in the range of smaller medium sized cross-strata. The best preservation is found in the light arkoses and red sandstones (Savage, 1967, p. 43).

201 measurements were made in Rockland County and corrections were made for tectonic tilt. From one to 57 readings were made at any one outcrop. It was found that the average dispersal direction for the Brunswick is easterly, thus indicating derivation from a westerly source. It must be noted, however, that the strata in the area are only the beveled edges of the units and the information available may pertain only to the small strip exposed and not downdip. It is of interest, however, that the Stockton Formation at Snedens Landing shows dispersal to the northwest (Savage, 1967, pp. 43-52). Uncorrected measurements farther to the south (Van Houten), indicate that in northern New Jersey, the dispersal of the Stockton was more westerly. If these preliminary dispersal directions (illustrated in Figure 11) are examined in conjunction with the lithology of the units involved, it is obvious that some of these are not entirely compatible with what would be expected.

Preliminary studies indicated that the dispersal direction of the Stockton was to the west or northwest. This is reasonable since presumably a southeast or eastern source which could supply detritus of the necessary composition is feasible in that direction. The next highest sediments, stratigraphically, are exemplified by the sediments at Nyack (STOP 3) which seem to have a southeasterly dispersal. These sediments are not too much higher than the Stockton. The presence of feldspar and mica at Nyack along with large clasts of lithic fragments, e.g., schist, phyllite, garnet, etc., raises questions as to the source direction. A continuation of the study of the dispersal directions is being made because the composition of the sediments at Nyack, except for the metamorphic fragments which appear to be absent in the Stockton, seems to indicate either a source similar to that of the Stockton or a source to the northeast or east.

The feldspar and mica found at Cherry Hill, (STOP 7), also indicate that the southeastern dispersal direction obtained should be questioned.

The reason for raising these doubts about these preliminary results is that the

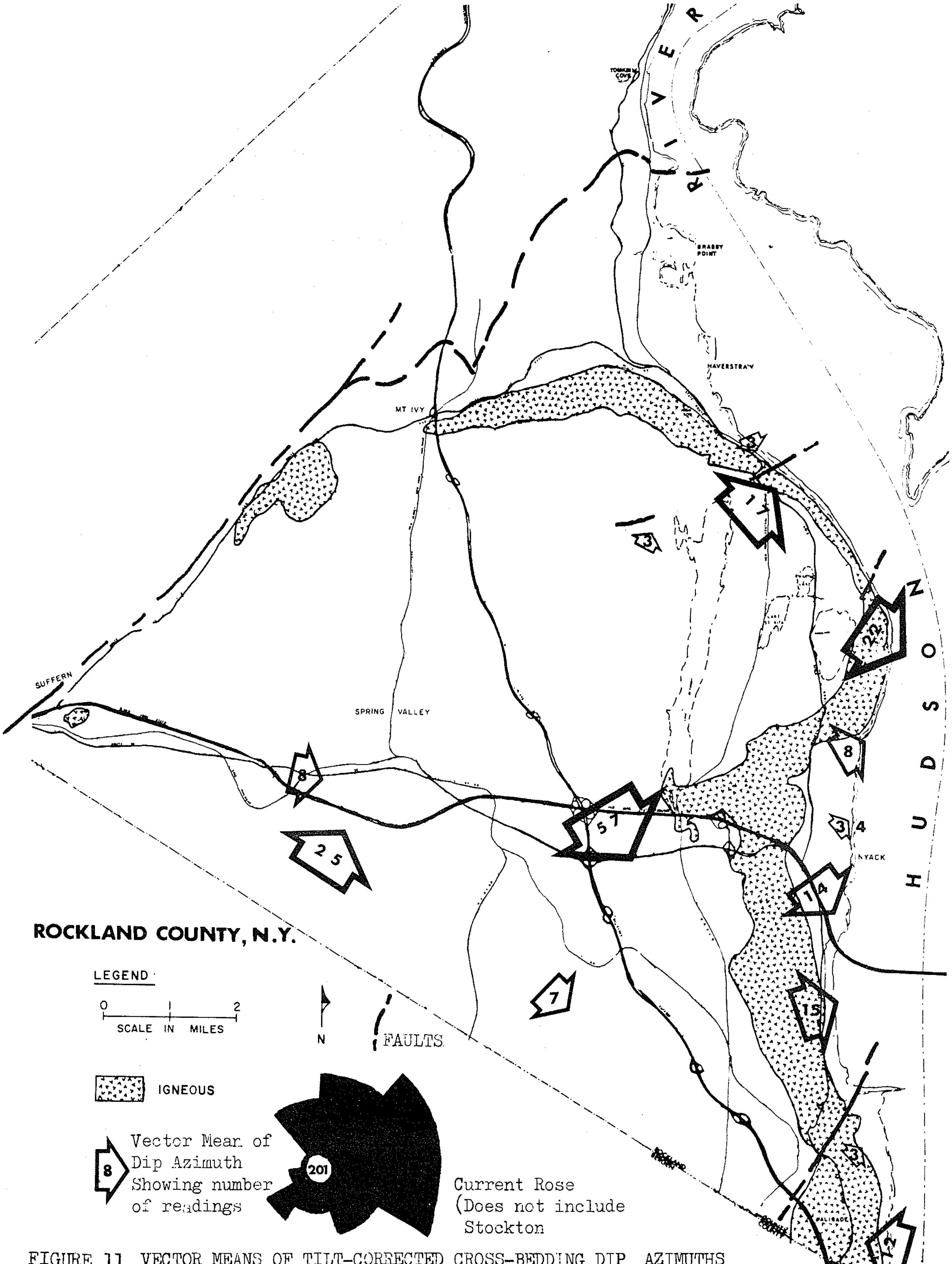


FIGURE 11 VECTOR MEANS OF TILT-CORRECTED CROSS-BEDDING DIP AZIMUTHS

border cobble conglomerates (not noted on Figure 11) have a dispersal direction to the south and east. Since the border cobble conglomerates are composed of Paleozoic clasts (which might be referred to (?)Kittattiny (Cambro-Ordovician) limestone, Green Pond (Silurian) conglomerates and (?)Devonian fossiliferous sandstones, this constitutes evidence that late in Triassic sedimentation the Ramapo Mountains to the west were still covered by Paleozoic sediments. It is interesting to note that the fossiliferous Devonian(?) sandstone appears to be more abundant along a line somewhat to the east of the border conglomerates, in slightly older strata. This would seem to be an indication of progressive stripping of the Paleozoic from the Ramapos. In Rockland County no granite gneiss has been found to any great degree except for a few isolated cobbles. This would seem to indicate that the Pre-cambrian crystallines had not as yet been uncovered in this area. If this premise is accepted, it then follows that it is not possible to derive feldspar from a westerly direction at the time that the lowest Brunswick sediments such as are found from the Stockton upper contact to Cherry Hill, were being deposited.

These inconsistencies may be explained by recalling that only a small part of the total rock layer is available for any individual stratum: its beveled edge - for making cross-bedding measurements. The concealed downdip cross-strata might rapidly reverse the directions if available since these sediments represent deposition by mature meandering streams which are characterized by the reversal of direction of half of each meander.

It is, therefore, suggested that unless further studies indicate an outright change in the dispersal direction, the following be considered among possible solutions:

1. The early Brunswick was derived from the east or northeast and once delivered might have spread longitudinally in various directions such as are indicated by the present studies. The sediments at Cherry Hill certainly seem to be smaller in size in the individual strata, and better sorted than those lower stratigraphically at Nyack. This possibility would assume that in Rockland County, the Brunswick would be derived initially from an eastern source, was distributed in varied directions locally. Later on sedimentation continued with progressive contamination from the west which shed only sedimentary rock debris.

2. A possible alternative view might be that the arkoses were derived from crystallines further to the northwest that had been stripped off the Paleozoic rocks. This would be compatible with the dispersal directions obtained so far, especially at Cherry Hill.

One other conclusion seems to be implied by the fact that the Ramapos at the beginning of Triassic sedimentation were still mantled with early Paleozoic sediments. To the east and southeast of the Triassic basin are presently exposed schists, marbles and gneisses, the metamorphosed equivalents of the same Paleozoic sediments that once existed on the Ramapos. It seems logical, therefore, to conclude that the basement beneath the Triassic sediments consists continuously of essentially the same lower Paleozoic rocks which start as gently folded sediments on the west and become progressively more intensely metamorphosed to the east and southeast. Although the contacts beneath the Triassic rocks are hidden by the Hudson River on the east tunnel borings have indicated a metamorphic basement along the west side of the river. (Berkey 1948, pp. 62-63.) Therefore, since deep erosion had occurred prior to Triassic sedimentation, it seems likely that the basal Triassic sediments were initially deposited on a differentially erosed basement of varied relief as has been suggested by McLaughlin and Willard (1949), prior to tilting of the basin.

The eastward extent of the Triassic basin must have been somewhat greater than it is at present, if only to account for enough cover for the Palisade sill. The angularity of the fragments in the Stockton seem to require a nearby source. The garnet and schist of the earliest Brunswick also require a nearby source. The various members of the New York City series or equivalent rocks provide source rocks for the earliest Triassic sediments. If these were the sources, this might be construed as evidence against broad terrane hypotheses inasmuch as these rocks had to be exposed in order to be shedding rock debris. However, this is still inconclusive and much more work needs to be done in order to further define the relationships of these sediments.

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ROAD LOG

By F. B. Van Houten and E. L. Savage

Leave Sheraton-Tenney Hotel parking lot. Proceed to 82nd St. (first major intersection which is overpass on Grand Central Parkway). Turn right, then immediately left onto entrance to Grand Central Parkway. At next intersection and stop sign turn diagonally across road onto Brooklyn-Queens Expressway. Continue through Queens-Midtown Tunnel. At exit follow DOWNTOWN sign. Turn left (downtown) to 34th Street. Turn right on 34th Street, across town, to Lincoln Tunnel at 41st Street and 10th Avenue. Distance through tunnel 1.8 miles.

<u>Mileage.</u>

0.0	0.3	Toll booth, west (New Jersey) end of Lincoln Tunnel. Use RIGHT lane.
0.3	0.4	Tunnel plaza and portal to north (left) are at southwest end of fault (Figure 12 A, B) cutting diagonally across Palisade Sill. Downdropped block is on east (right) side. There are many such faults along the Palisades.
0.7	0.1	Turn right (north) onto Hudson Boulevard East.
0.8	0.1	Jointed diabase on left.
0.9	0.2	Continue on Hudson Blvd. East; bear right (east) at traffic light.
1.1	1.0	Small park on right (east) commemorates duel between Aaron Burr and Alexander Hamilton. Regional erosion surface levels top of sill (Figure 13).
2.1	0.2	Turn right (east) at traffic light onto 60th St. Descend past gray apartment-house garages to River Road.
2.3	0.2	Olivine zone in Palisade Sill on left (see Figure 15A).
2.5	0.1	Sewage treatment plant near base of sill.
2.6	0.5	Metamorphosed rather well-sorted yellowish-gray to very pale orange Stockton arkose and overlying chilled border of sill on left.
		Coarse-grained arkose at contact, locally cross-bedded with dispersal to S or SW, contains abundant plagioclase and orthoclase, some quartz, pale green diopside and vermiculite, and minor sphene and talc. Fine-grained arkose within 12 inches of the contact consists mainly of albite, with minor vermiculite and talc, and a trace of chlorite.
3.1	0.2	Stockton arkose on left.
3.3	0.3	Large columnar joints with smaller joints in lower part of sill. Talus.

3.6 0.2 Stockton arkose and cliff of sill on left (just south of Lever Brothers Research Center). Bedded, coarse to very coarse-grained arkose with 2-foot unit of tabular cross-bedding with dispersal to SW.

3.8 0.1 Well-bedded, very dark, fine-grained Lockatong hornfels.

3.9 0.1 "Town of Edgewater" road sign on right.

4.0 0.1 Intersection of Gorge Road (uphill to left) and River Road (diagonally to right).

4.1 0.1 STOP 1. Gorge and River Roads. Lockatong Hornfels. Time here: 30 minutes. Park in lot of Celatex Corp. (Allied Chemical).

A composite section of Lockatong hornfels and interbedded Stockton arkose is exposed in the excavation (watch for falling rock) on River Road (Figure 14A) opposite the Mobile Service Center and in the roadcut on the west side of Gorge Road (Figure 14B). This sequence (strike N 40°E, dip 15°W) consists of (1) about 18 feet of dark gray, well-bedded Lockatong hornfels in 3 well-developed cycles, overlain by (2) about 15 feet of bedded, rather well-sorted yellowish-gray Stockton arkose, which is in turn overlain by (3) about 50 feet of dark gray, well-bedded Lockatong hornfels below the Palisade Sill.

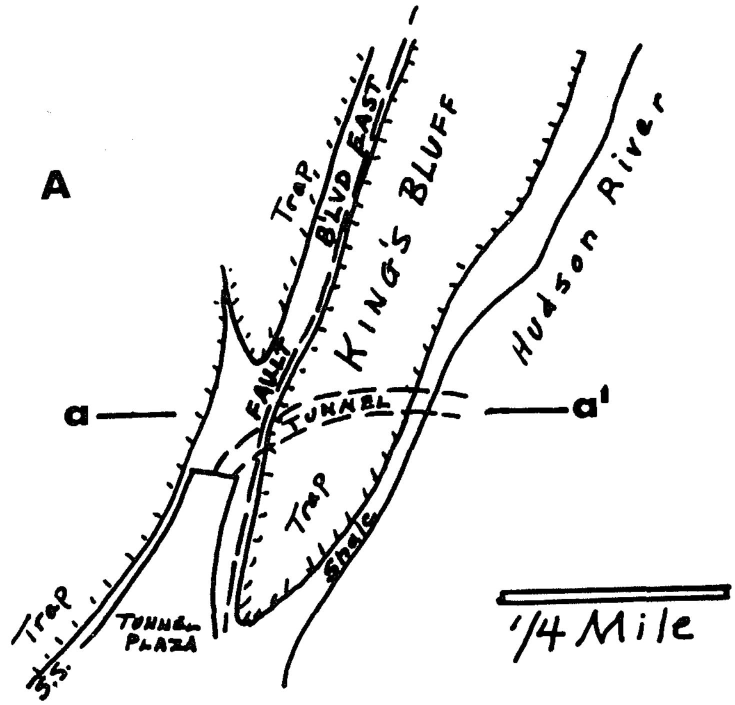
1. The asymmetrical cycles in the excavation are analcime-bearing " chemical" cycles like those found in western New Jersey and adjacent Pennsylvania (Van Houten, 1964, 1965). Because of their unique composition, these deposits were easily altered by isochemical thermal metamorphism. In contrast, the arkose 50 feet below the sill is virtually unaltered.

In pattern, each cycle (Figure 14C) originally consisted of a lower very dark gray to black shaly to platy carbonate-rich feldspathic mudstone (converted to a biotite-albite hornfels) with thin laminae and local beds (1 to 3 cm) of calcite and dolomite, a middle platy carbonate-rich portion with abundant disruption by shrinkage, converted to a calc-silicate hornfels, and an upper massive analcine-rich argillite, now commonly with a splotched fabric produced by metamorphism to a biotite-albite-analacine hornfels.

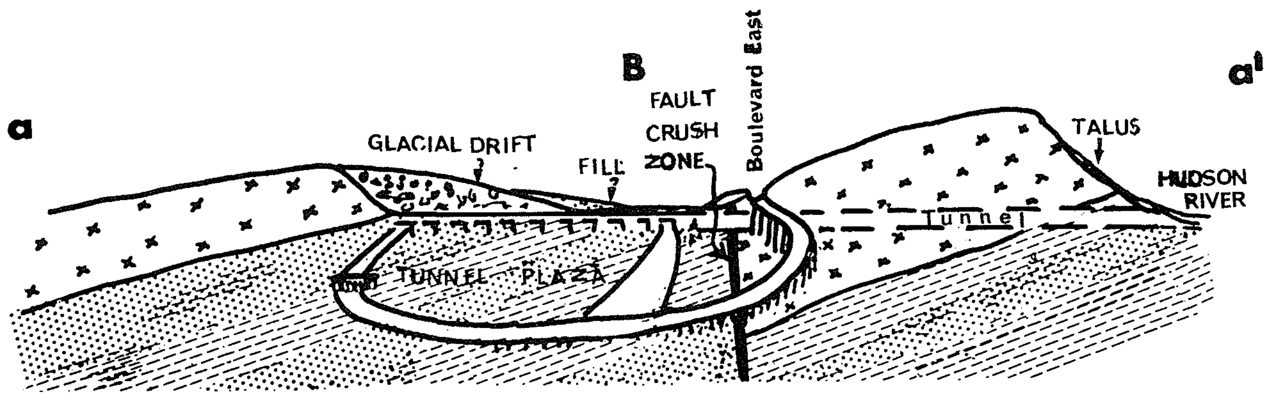
2. The slightly metamorphosed arkose 50 feet below the sill consists mainly of plagioclase, orthoclase and quartz, some vermiculite, and a trace of talc.

3. Spotted Lockatong hornfels of a tetrital cycle within 5 feet of the sill consists mainly of biotite and plagioclase, some orthoclase and andalusite, and a trace of chlorite and magnetite. Lockatong hornfels 15 to 20 feet below the sill contains minor analcime.

FIGURE 12



A. MAP ILLUSTRATING LINCOLN TUNNEL PLAZA AND DIAGONAL FAULT CUTTING PALISADE SILL (MODIFIED AFTER KUMMEL 1898)



B. SECTION OF PALISADE SILL AT LINCOLN TUNNEL PLAZA INCLUDING PORTAL AND ROAD TO BOULEVARD EAST. LOOKING NORTH. DOWNDROPPED BLOCK IS ON EAST. (MODIFIED AFTER BERKEY 1948)

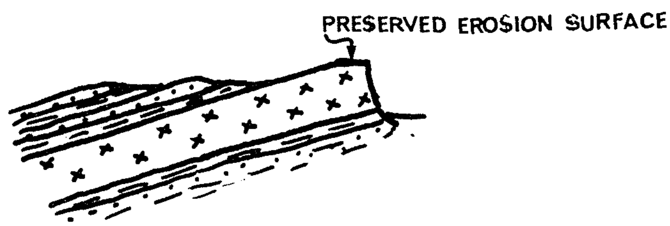


FIG. 13

SECTION OF PALISADE SILL ILLUSTRATING PRESERVED EROSION SURFACE (SCHOOLEY)

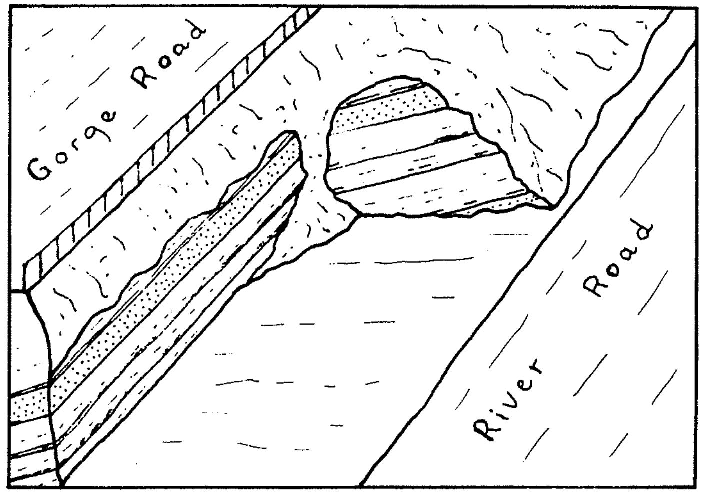
Figure 14. Hornfels zone below Palisade Sill, STOP 1.

A. Sketch of excavation on River Road showing 3 Lockatong chemical cycles and overlying Stockton arkose. Looking northwestward.

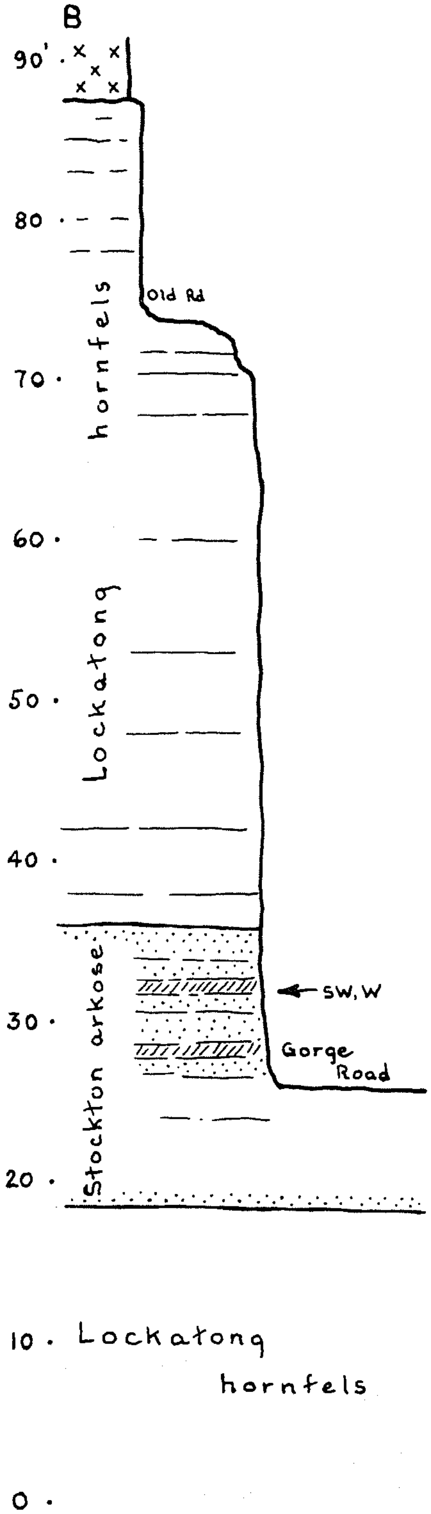
B. Composite section from River Road to base of sill above Gorge Road. Tongue of Stockton arkose in succession of Lockatong cycles.

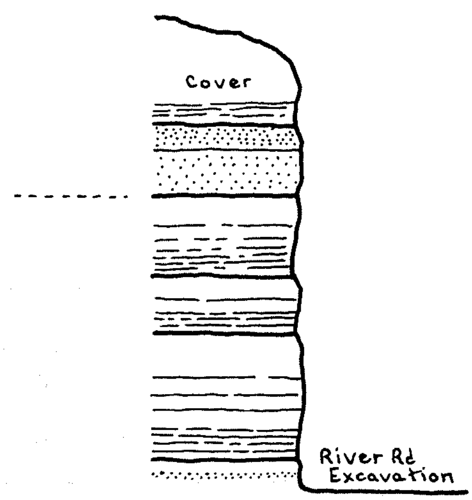
C. Model of hornfelsed Lockatong chemical cycle in River Road excavation.

A



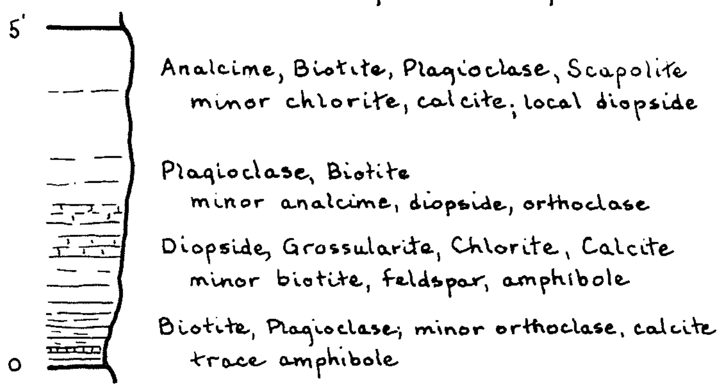
B





C

Minerals in Lockatong chemical cycle hornfels



The following additional accessory minerals have been found in this hornfels facies (Lewis, 1908, p. 136-147): pale green augite, apatite, cordierite, epidote, hornblende, sillimanite, scapolite, dark-green spinel, sphere, tourmaline, and vesuvianite.

The variations in mineral assemblages found here and in the Granton Quarry (STOP 8) resulted largely from differences in composition and amount of water present, and not from major differences in temperature and pressure.

4.2 0.1 Continue north on River Road.

4.3 0.2 Large xenolith (15 feet by 30 feet) of Lockatong hornfels about 15 to 20 feet above base of sill, exposed behind Virginia Lee Lace Co. Baking produced coarse-grained biotite-plagioclase hornfels with chlorite, pale green and colorless pyroxenes, and more coarsely crystalline stringers of chlorite, biotite, calcite, diopside, albite and very pale green muscovite.

4.5 0.1 Railroad overpass. Sill exposed on left (west), hornfels in cut to east (right).

4.6 0.1 Lockatong hornfels below sill behind Edgewater Welding Co.

4.7 0.5 Stockton arkose and Lockatong hornfels behind Edgewater sewage treatment plant.

5.2 0.5 Continue north past traffic light at Russell Avenue.

5.7 0.3 Turn left (west) up Dempsey Avenue to Undercliff Avenue at top of hill. Turn right (north)

6.0 STOP 2. Palisade Sill and Lockatong Hornfels along abandoned trolley route. Time here: 1 hour. Park on east side of Undercliff Avenue, opposite small park with 3 benches.

Traverse through Palisade tholeiitic diabase sill (Figure 15 A, B, C) - up (southwest) an abandoned trolley route along a brook, behind houses:

Lockatong Hornfels below sill, as at STOP 1.

Irregular cross-cutting contact (Figure 16A).

Xenolith 2 feet thick, 15 feet above base of sill; unusually coarse-grained biotite-plagioclase hornfels.

Olivine diabase, generally about 15 feet thick, 50 feet above the base at switch-back on trolley route. Dr. S. Bhattacharji will discuss its origin.

Normal diabase throughout the middle of the sill.

Upper coarse diabase with pegmatitic schlieren.

Upper chilled border.

Hypotheses proposed to explain differentiation of the diabase sill and to account for the layer of olivine diabase are:

1. Gravitational settling of early-formed olivine and later pyroxene crystals (F. Walker, 1940). Although widely cited as such, the Palisade Sill probably is not a good example of gravitational differentiation.

2. Fractional crystallization (Figure VH 2, C) by ionic diffusion and convection circulation of magma, supplemented by minor gravitational settling of large olivine crystals (Hess, 1956, p. 1960).

3. Fractional crystallization, with late-stage injection of a new pulse of magma into the partially crystallized mush. Large olivine crystals concentrated by gravitational settling (K.R. Walker, 1962; 1967 in press).

4. Mechanical or hydrodynamic flow differentiation, with central concentration of early-formed olivine crystals during intrusion of the magma. Crystal mush then settled as a result of fluctuation of velocity and pressure (S. Bhattacharji, 1967).

6.0	0.1	Proceed north on Undercliff Avenue to next corner. Turn right on Hudson Avenue, to bottom of hill (River Rd.). Turn left (north) on River Road.
6.1	0.4	Bear left on NY 5W which leads to top of sill.
6.5	0.3	Olivine zone halfway up cliff on left.
6.8	0.1	Olivine zone is at road level.
6.9	0.2	Palisades Amusement Park on left at top of sill.
7.1	0.7	Intersection of NY 5W and 67. Turn right (north) on NY 67 (Palisades Avenue).
7.8	0.1	Outcrop of sill on right.
7.9	0.7	Horizon Towers apartment complex on right.
8.6	0.1	Cross Main Street on Fort Lee.
8.7	0.2	Sign to George Washington Bridge. Use lane farthest LEFT. A phytosaur, Clepsysaurus (Rutiodon) was found in the Stockton arkose below the bridge.

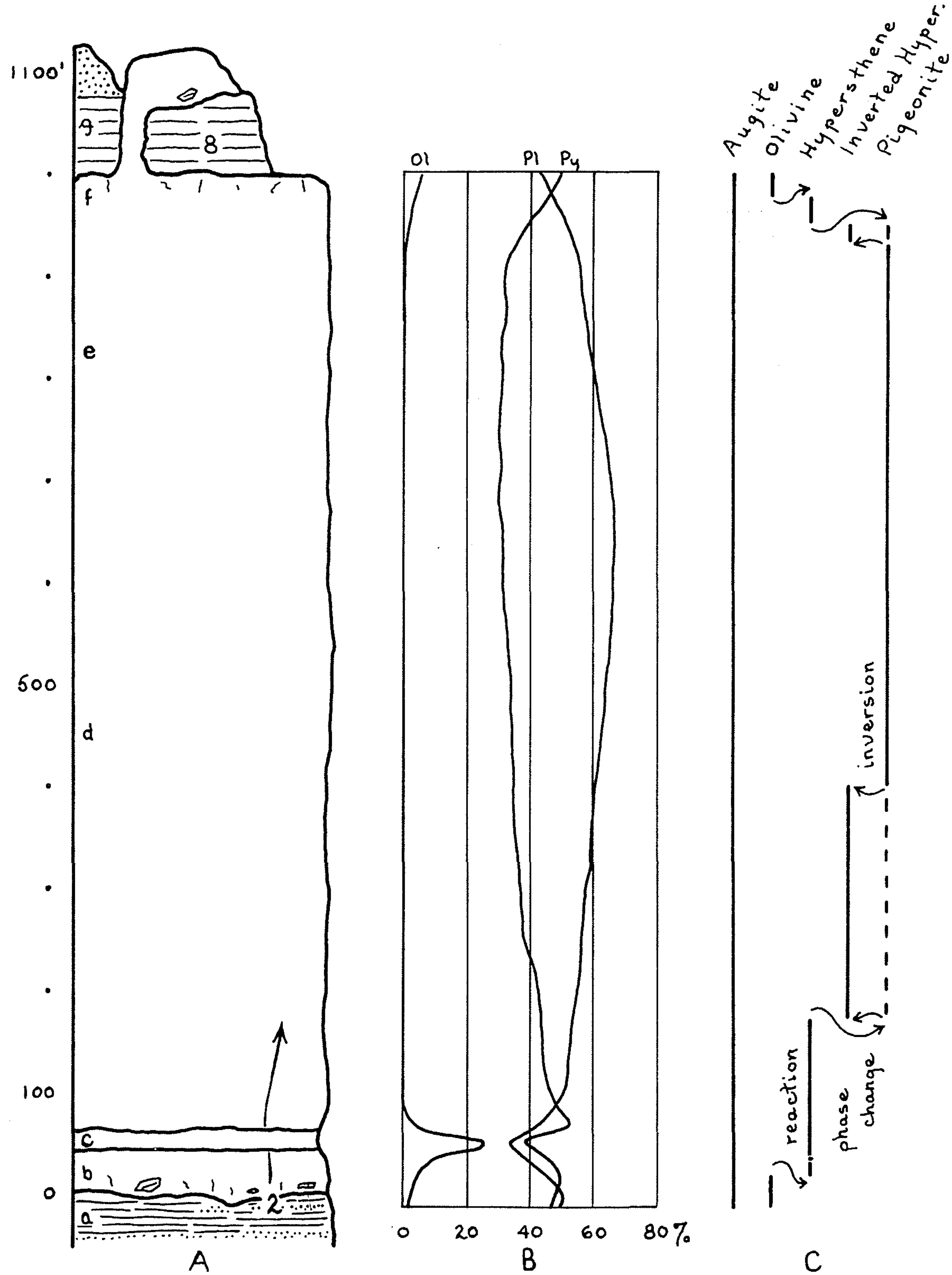
Figure 15. Vertical section of Palisade Sill.

A. Composite profile from "trolley route" (STOP 2) to Granton Quarry (STOP 8).

a. Lockatong hornfels and Stockton arkose, as at STOP 1.
b. Chilled border of sill with white veins and xenoliths. See Figure 16A.
c. Olivine diabase 3 to 20 feet thick.
d. Normal diabase, coarser and more acidic toward the top.
e. Coarse diabase with pegmatitic schlieren.
f. Chilled border with white veins, xenoliths rare.
g. Lockatong hornfels and Stockton arkose. See Figure 16B.

B. Percentage by weight of olivine, plagioclase and pyroxene (Walker, 1940).

C. Model of crystallization sequence (Jacobsen, 1949).



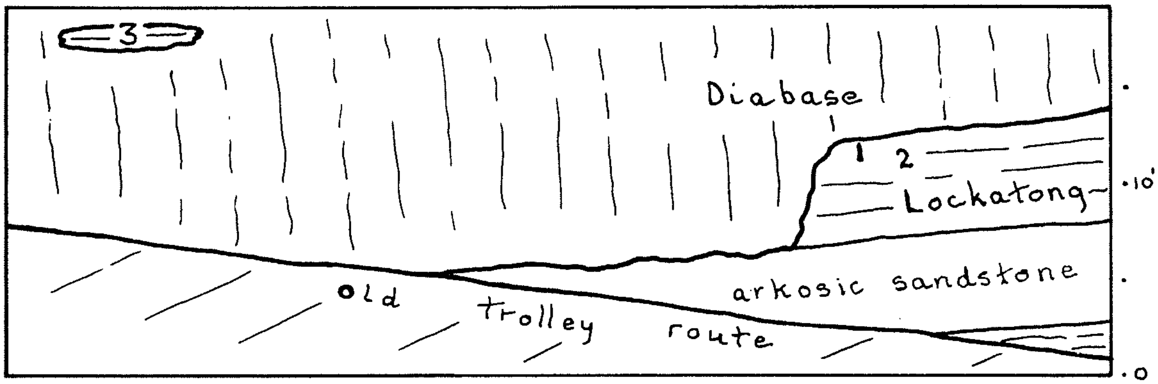
1100'
500
100
0
a
b
c
d
e
f
g
8
2
Ol
Pl
Py
0
20
40
60
80%
Augite
Olivine
Hypersthene
Inverted Hyper.
Pigeonite
inversion
reaction
phase change
A
B
C

Figure 16. Lockatong hornfels at STOPS 2 and 8.

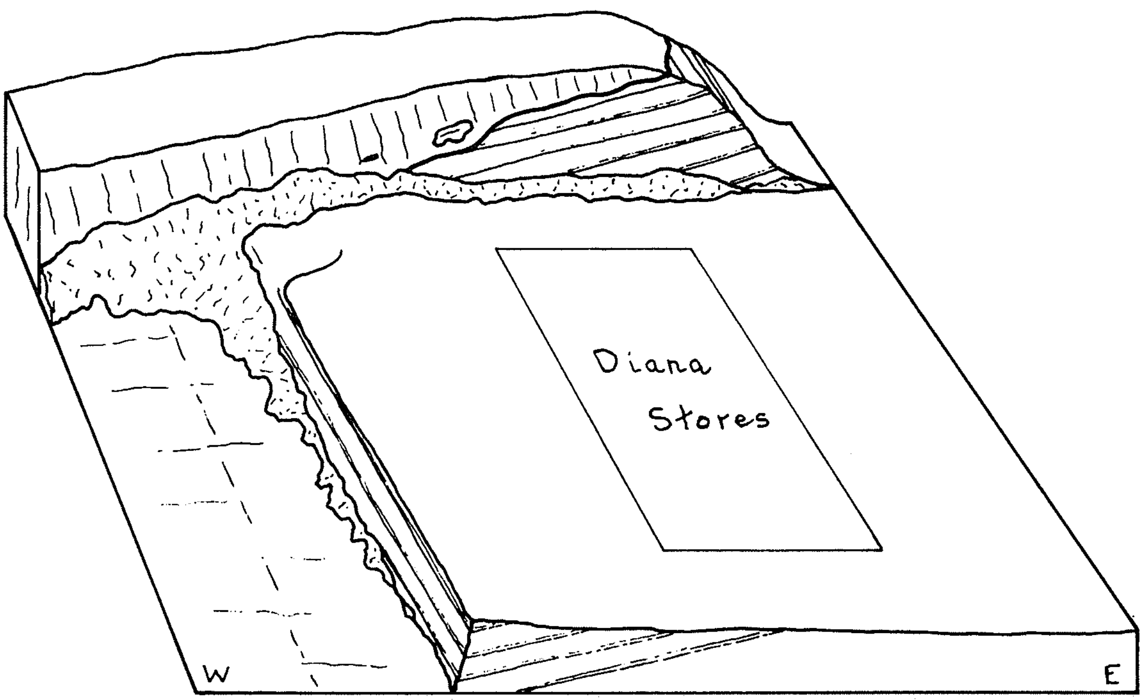
A. Sketch of contact zone at base of Palisade Sill, STOP 2, showing irregular contact and tongue of arkose. Uppermost Lockatong hornfels: 1. Abundant plagioclase and biotite, minor orthoclase, scapolite, muscovite and diopside, trace of chlorite. 2. Abundant scapolite and chlorite, minor analcine, trace of plagioclase and magnetite. 3. A 2-foot thick xenolith 15 feet above base of the sill: very coarse-grained plagioclase and biotite, minor very pale green and colorless pyroxenes, and trace of chlorite.

B. Sketch of north end of Granton Quarry, North Bergen, New Jersey, STOP 8. Five complete hornfelsed detrital cycles and xenoliths in wall of upper level and 2 complete cycles along wall of lower level lie above the Palisade Sill and below a subsidiary sill. See Figure 15.

A


3
Diabase
1
2
Lockatong
.10'
old trolley route
arkosic sandstone
.0

B


Diana Stores
W
E

8.9	0.3	Turn left onto access road at sign to US 9W.
9.2	0.1	Outcrops of sill on both sides of road.
9.3	0.3	Turn right onto US 9W North.
9.6	0.2	Cross Palisades Interstate Parkway access road.
9.8	0.5	Outcrop of sill.
10.3	0.2	Prentice-Hall Book Company on right.
10.5	0.7	Outcrop of sill on left.
11.2	0.2	Cross NJ 505.
11.4	0.6	REST STOP. 15 minutes.
12.0	0.3	Outcrop of sill on right. Lipton Company on left.
12.3	0.6	Outcrop of sill on left.
12.9	0.6	Traffic light, road to Tenafly. Continue north on US 9W.
13.5	2.6	Glacially polished diabase on right.
16.1	0.2	Cross NJ 502 at Closter.
16.3	0.5	Jointed diabase on both sides of road.
16.8	0.1	Service road to Palisades Interstate Parkway North.
16.9	1.7	Service road to Palisades Interstate Parkway South.
18.6	0.1	Glaciated diabase on right.
18.7	1.0	Palisades Interstate Parkway access road.
19.7	0.1	Underpass
19.8	0.2	Entrance to Palisades Interstate Parkway North on left.
20.0	0.1	Cross road to Lamont Geological Observatory of Columbia University.
20.1	0.8	New Jersey-New York and Bergen County-Rockland County boundaries.
20.9	1.2	Cross Oak Tree Road.

Along Hudson River at Sneden's Landing approximately 45 feet of light gray thick-bedded and locally cross-bedded Stockton arkose is interbedded with reddish-brown to pale lavender baked mudstone. Dispersal was to the northwest (Figure 11). Locally dikes of arkose have been injected into the mudstone. The arkose contains angular pebbles of quartz and pink feldspar as much as an inch in diameter; in contrast to sandstone found north of Piermont (and higher in the stratigraphic sequence) zircon, rutile and anthigenic anatase are abundant, tourmaline and garnet are rare, and metamorphic rock fragments are absent (Savage, 1967).

22.1 0.2 Outcrops of diabase at entrance to Tallman's State Park. Olivine zone.

22.3 0.1 Continue north on US 9W, across NY 340.

22.4 0.4 Sparkill Gap. Sparkill (formerly Overpeck) Creek in the gorge is the only stream that flows eastward across the Palisade Sill into the Hudson River. Presumably it flows along a cross-fault (such as seen at Lincoln Tunnel plaza) that has offset the sill more than 900 feet westward on the north side.

According to Johnson (1931) the Hudson River originally flowed southwestward on the Schooley erosion surface above the position of the sill, was superposed on it and cut a water gap (Figure 17). Later a subsequent stream flowing on relatively non-resistant rocks east of the sill captured the ancient Hudson drainage by headward erosion. Overpeck Creek then reversed the original drainage direction. This explanation does not account for the coincidence of the gap and a cross-fault (see Thornbury, 1954, p. 234-240, for discussion of the problem).

Between Piermont and Nyack Beach State Park (STOP 3), there are many outcrops and abandoned quarries of "brownstone" which was used extensively for building-stone more than 50 years ago. Most of the rock is a dark brown to reddish brown well-sorted medium to fine-grained arkose, commonly interbedded with reddish brown mudstone. Some of the lighter colored arkose is coarser grained, but conglomerate is rare. Presumably these deposits are a gradational sequence between the uppermost part of the Stockton Formation and the lower part of the Brunswick Formation, and differ in heavy mineral content, sedimentary-metamorphic rock content and dispersal direction from those in the upper part of the Stockton Formation to the south (Savage, 1967, p. 34).

22.8 0.3 Glacial till overlying diabase on right.

23.1 0.2 More till on diabase on right.

23.3 2.1 Outcrop of diabase on left.

25.4	0.3	Town of Nyack road sign. Bear right onto Broadway (downhill). View of south end of Verdreitege Hook (Hook Mountain) portion of Palisade Sill above Nyack Beach State Park.
25.7	0.1	Overpass
25.8	0.6	Stop sign. Continue on Broadway (middle road).
26.4	1.0	Large glacial erratic on right, on lawn of library built of "fieldstone."
27.4	0.8	Upper Nyack School on left.
28.2	0.3	South end of Verdreitege Hook with spectacular talus slope. 5 minute stop for photographs.

North of Nyack the Palisades are as much as a mile west of the Hudson River because the sill intruded a higher part of the west-dipping Newark sequence. Then it swings back to the river at Nyack Beach State Park, cutting across somewhat lower Newark strata (Figure 3). At its north end the intrusion is a dike that intrudes successively higher Brunswick beds (Figure 2) and turns sharply to the west almost perpendicular to strike; at its western end it completes a sickle-shaped arc. Diamond-drilling in a quarry at Little Tor near Haverstraw shows that the intrusion dips about 45°SW (Lowe, 1959).

A distinct olivine-rich zone is absent at the northern end of the Palisade intrusion as it is at its southwestern end in west-central New Jersey.

28.5	0.5	Nyack Beach State Park. Take road to right down steep hill. Park buildings of typical reddish-brown arkose. Outcrop at base of hill, near entrance to Men's comfort station, consists of cross-bedded reddish-brown mudstone interbedded with micaceous reddish-brown sandstone and greenish-gray arkose.

STOP 3. Nyack Beach State Park. Lower Brunswick deposits. Time here: 1 hr. 45 min.

LUNCH will be served after a 1 and 1/3 mile walk to outcrops in the lower part of the Brunswick Formation.

The Park authorities have made this convenient stop available to us. Do not disturb the foliage or the crops. Please collect specimens only in those areas where there has been recent blasting of ledges.

Watch out for copperhead snakes, yellow-jacket wasps, poison ivy and poison sumac.

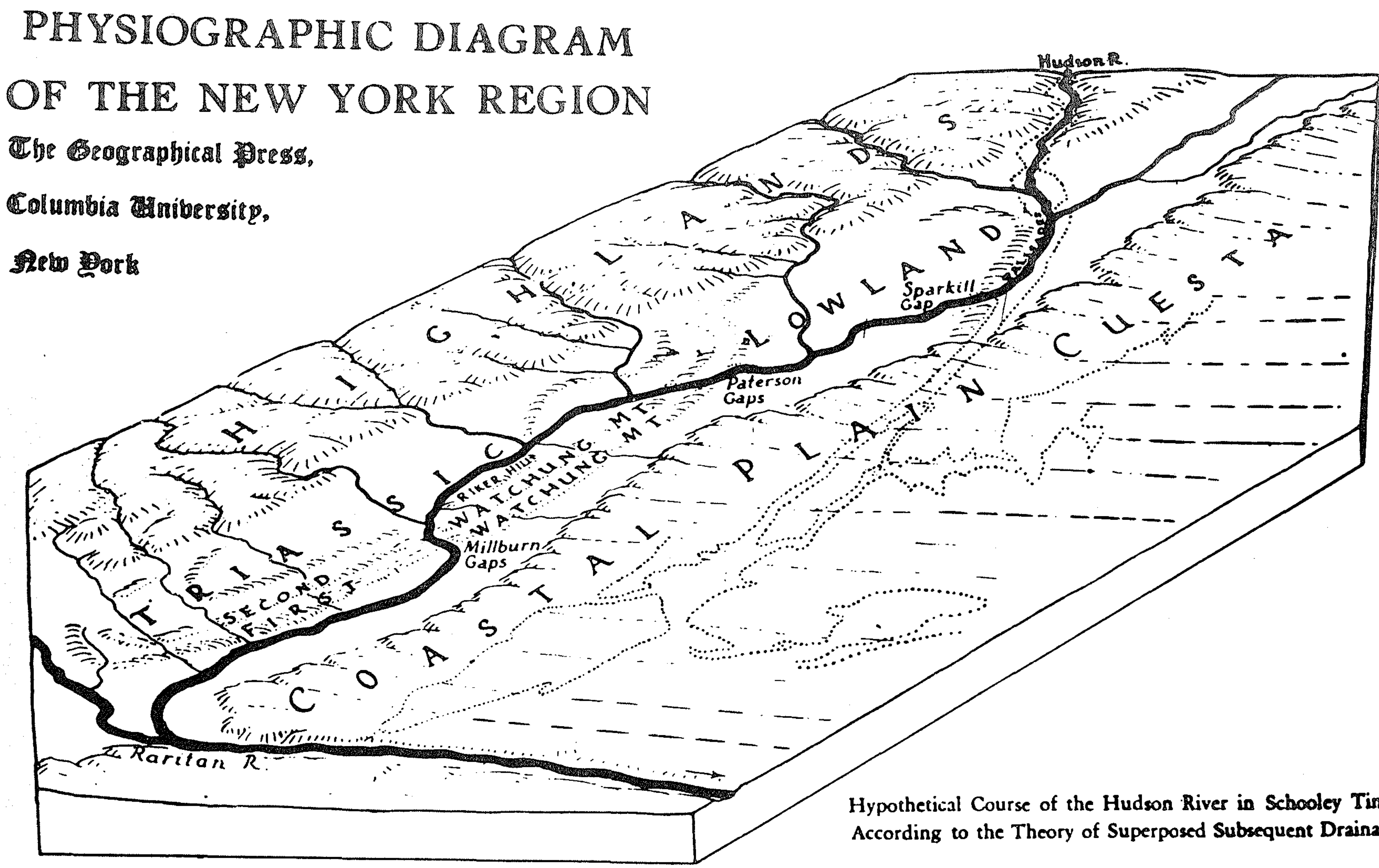


DIAGRAM TO ILLUSTRATE Professor Johnson's THEORY FOR THE ORIGIN OF THE GAPS IN THE WATCHUNG RIDGES. (Drawn by E.J. Raisz for Johnson: Atl. Slope)

FIG. 17

ANCESTRAL COURSE OF THE HUDSON RIVER. ACCORDING TO JOHNSON (1931) A SUBSEQUENT STREAM FLOWING ON RELATIVELY NON-RESISTANT ROCKS EAST OF THE PALISADE SILL LATER CAPTURED THE HEADWATERS OF THE HUDSON, LEAVING SPARKILL GAP. (FROM JOHNSON 1931)

Traverse along footpath leading north from north end of parking area. Distances noted below were measured from beginning of the path.

200': 15 to 20 feet of yellowish-gray arkose crop out 40 inches above the path.

895-950' : Picnic tables; old quarry in reddish-brown mudstone and yellowish-gray arkose.

1450-1570' : Outcrop exhibiting rapid facies changes, especially at north and south ends:

7' : Massive reddish-brown mudstone; cross-bedded; marked channelling.

8' : Reddish-brown shale.

13' : Micaceous reddish-brown siltstone and shale; cross-bedded. Scattered pebbles of quartzite and quartz, and pieces of shales.

8' : Reddish-brown shale.

2' : Massive reddish-brown mudstone.

Path level

1570-2215' : Much talus.

2215-3745' : More talus; columnar joints in diabase. Note sinuous joint surfaces. Pass fireplaces.

3745-3925' : Tree-clad slope.

4040-4405' : Outcrop near open stone shelter:

10' : Massive light gray arkose, locally cross-bedded.

2' : Reddish-brown mudstone.

4' : Thin-bedded, pale reddish-brown arkose, interbedded brown mudstone.

8' : Massive, tough light-gray arkose, rare cross-bedding and coarse layers with pebbles of angular quartz as much as 2 1/2 inches in diameter, pieces of feldspar as much as 1 inch long and intraformational mudstone clasts.

Path level.

Continue along winding path. Diabase above is conspicuously jointed. Sing-Sing prison across river to east.

5571-6039': At south end diabase is at path level. Rises to north to reveal contact with arkose which has not been metamorphosed more than a few feet from the sill. Beware of yellow jacket nests in brush near this contact.

6039-6080': Cover. Beyond retaining wall 10 feet of cross-bedded light-gray arkose overlies reddish-brown mudstone.

6230-6420': Cover.

6445-6465': Arkose with rare gray limestone and quartz clasts to 1 inch in diameter; pink feldspar to 2 inches in diameter, and rare pebbles of pegmatite.

6570': Arkose in large block is cross-bedded, contains clasts of quartz, red sandstone, pink feldspar, shale, mica schist, and relatively abundant almandine garnet.

6575': Excellent outcrop extends northward for about 1000 feet. Exhibits rapid facies changes and variety of sedimentary features characteristic of fluvial sedimentation (Figure 18A). N62W, 13^{o}W.

5': Yellowish-gray arkose with large scale channeling and cross-bedding.

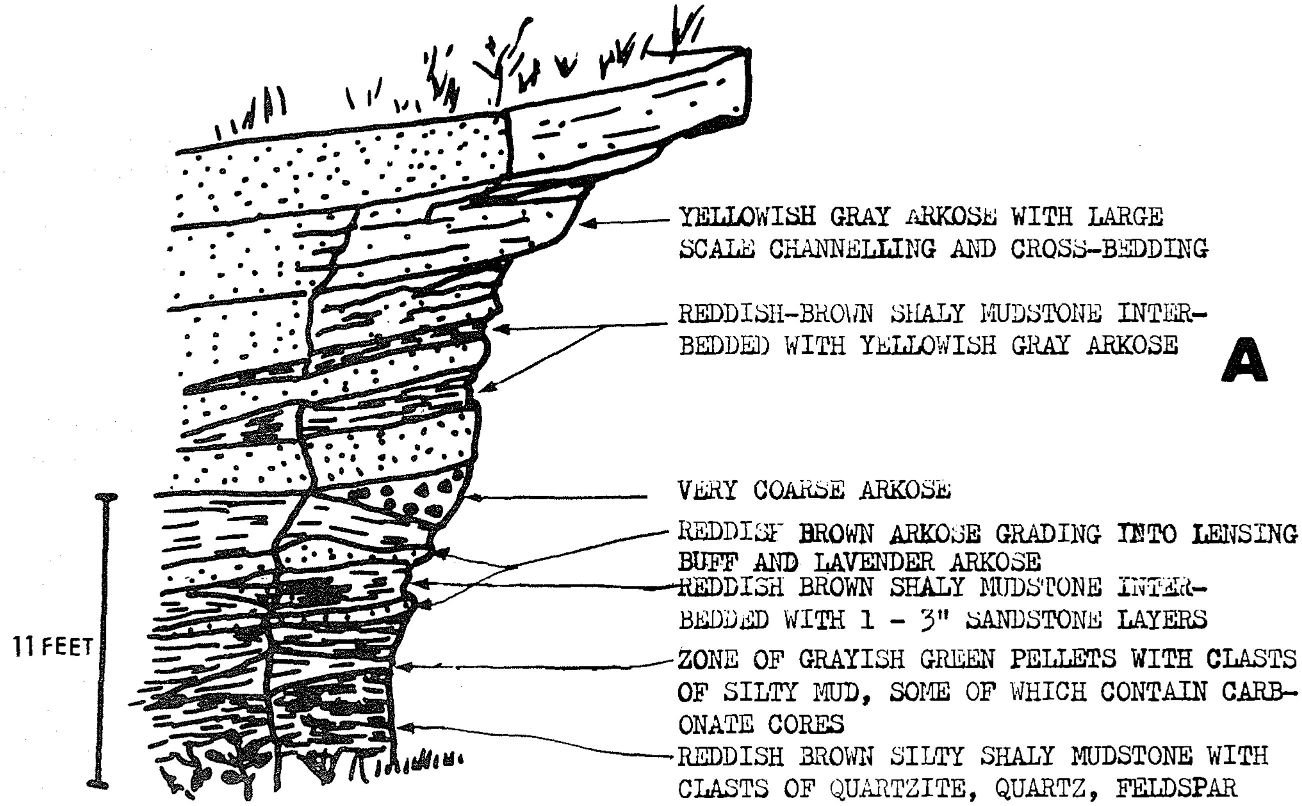
6': Interbedded yellowish-gray arkose and reddish-brown mudstone. Unit pinches out to north.

11': Reddish-brown to lavender mudstone with irregular upper contact. Cross-bedding, with scour and fill, burrowing, mudcracks, and ripplemarks (2 inch crests, N68W), as well as load and flute casts. Interbedded with layers of medium to coarse-grained micaceous reddish-brown arkose grading (Figure 18A) into lensing buff and lavender arkose with pebbles of limestone and feldspar. The lower part of the mudstone also contains pebbles of quartzite, quartz and feldspar. About 5 feet above the base at the south end of the outcrop a greenish-gray layer consists largely of rounded grains of silty mudstone. Some may be Paleozoic lithic grains, but many with concentric structure, elongate shape and calcite cores apparently are intraformational mud pellets.

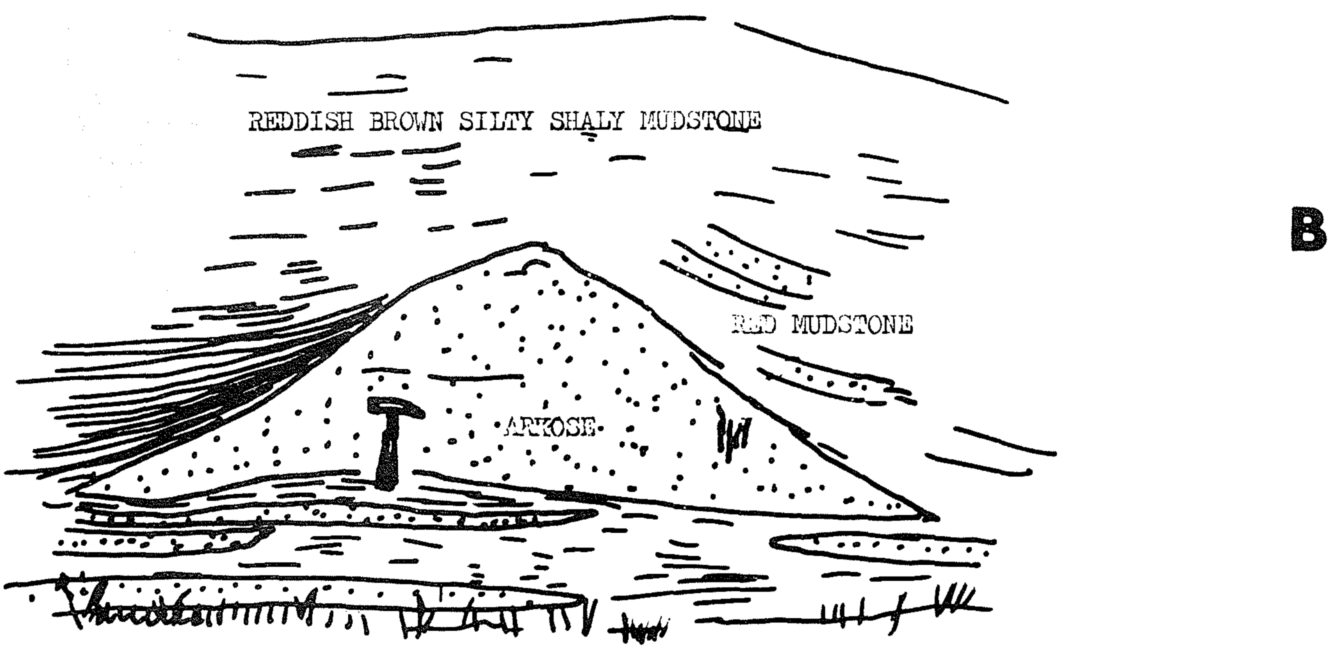
6580': Very coarse arkose with angular quartz as much as 1 inch in diameter, pieces of shale parallel to bedding, and clasts of limestone and feldspar, interfingers with reddish-brown mudstone.

6665': Well-developed tabular cross-bedding, rare in Newark rocks in Rockland County.

Figure 18

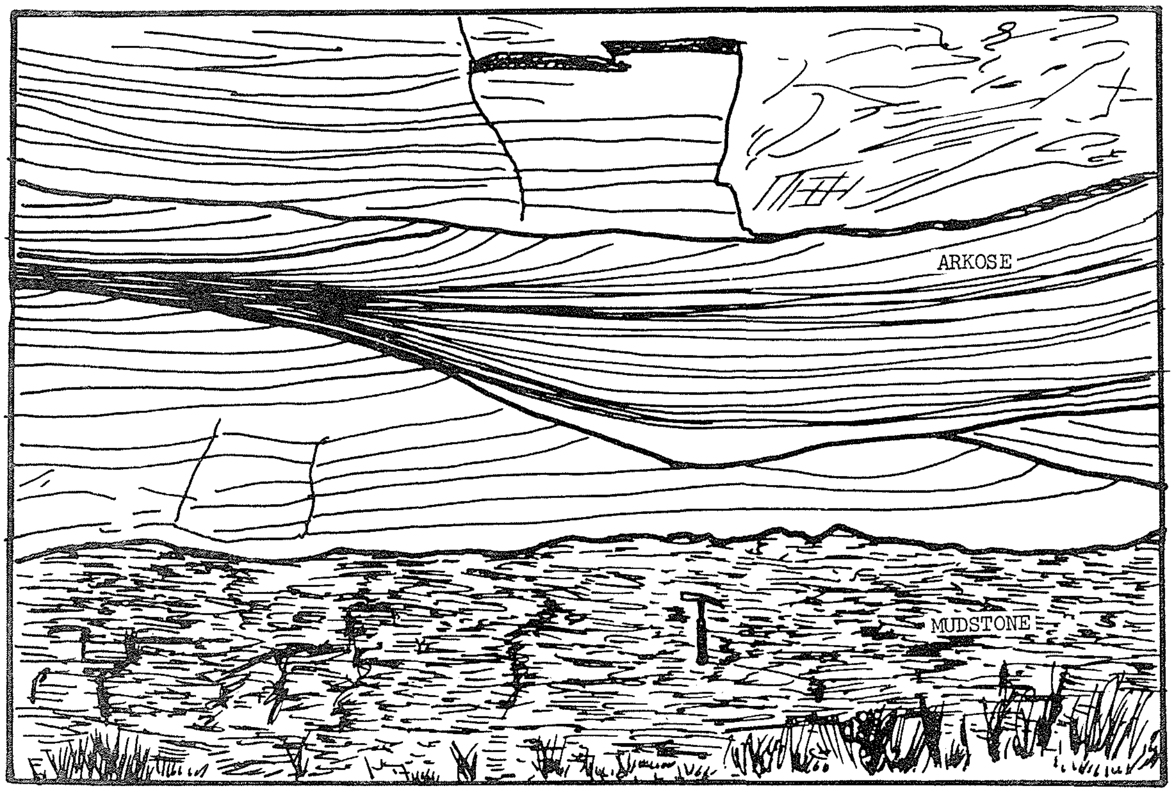


A. GENERALIZED SECTION OF STRATIGRAPHY AT NYACK BEACH STATE PARK (STOP 3)

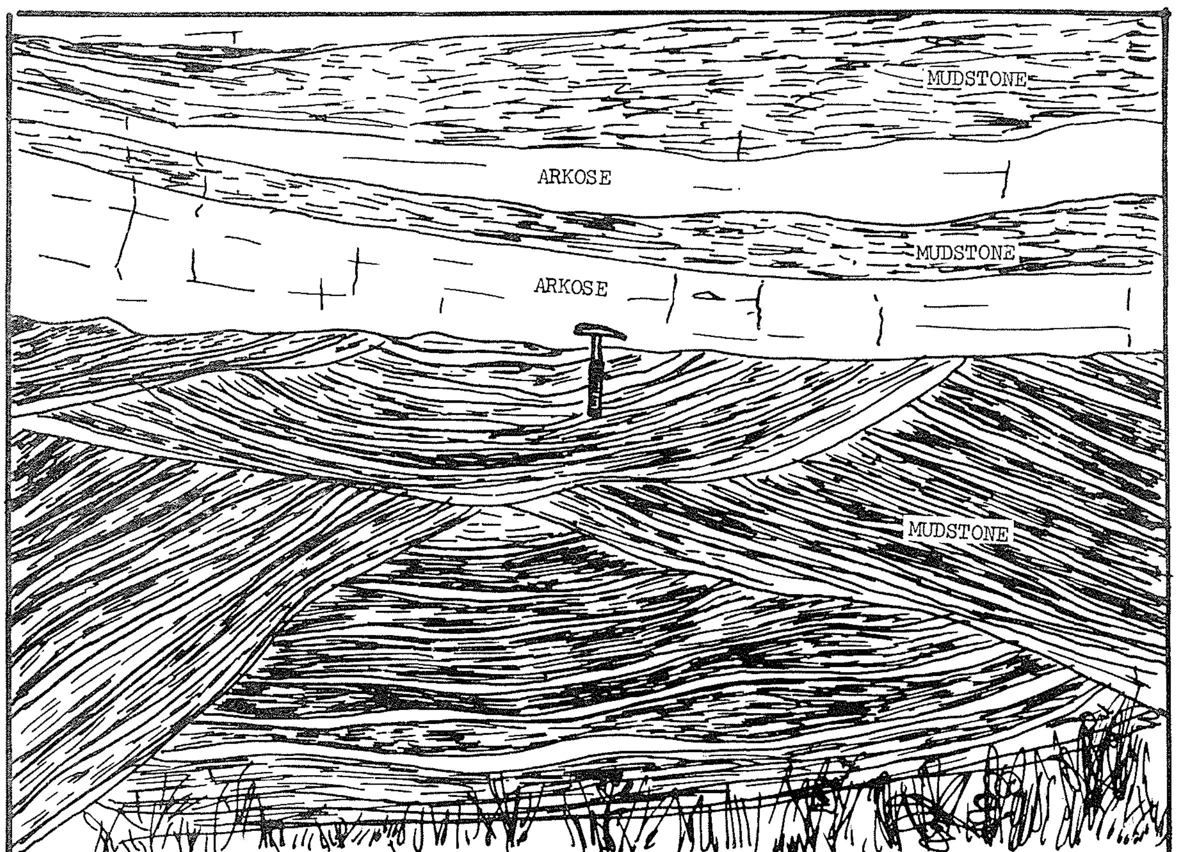


B. DETAIL OF ARKOSE CHANNELED ON BOTH SIDES. REDDISH-BROWN MUDSTONE AT NORTH END OF ARKOSE WAS PROBABLY INJECTED DURING BURIAL. (STOP 3)

Figure 19



A. YELLOWISH GRAY ARKOSE OVERLYING REDDISH BROWN SHALY SILTY MUDSTONE. NOTE RARE LARGE SCALE CROSS-BEDS IN ARKOSE WITH CURVED BASAL CONTACTS. SKETCHED FROM A PHOTOGRAPH. (NYACK BEACH STATE PARK STOP 3)



B. TRANSITIONAL ARKOSE-SHALY, SILTY MUDSTONE UNIT OVERLYING REDDISH BROWN MUDSTONE INTERBEDDED WITH REDDISH BROWN SILTY SANDSTONE WITH MARKED CROSS-BEDDING AND SCOUR AND FILL. LOOKING WEST. SKETCHED FROM A PHOTOGRAPH. (NYACK BEACH STATE PARK STOP 3)

6755': Upper contact of lower reddish-brown mudstone unit is about 5 feet above the path.

6755-6770': Arkose scoured by channels. Reddish-brown mudstone dikes at north end probably was injected during burial (Figure 18B).

6775': 5': Massive yellowish-gray arkose.
5': Interbedded reddish-brown mudstone and tan arkose.
11': Reddish-brown mudstone.

Path level.

Northward the top of the extensively burrowed lower unit is 8 feet above the path and is overlain by mottled arkose 11 feet thick which in turn is overlain by 4 feet of yellowish-gray arkose with large scale cross-bedding (Figure 19A).

6930': Slumped mudstone 3 feet above path.

6980-7015': Six inch layers of reddish-brown mudstone interbedded with reddish-brown silty sandstone a few inches thick with marked cross-bedding and scour and fill (Figure 19B).

7185': Well-developed cross-bedding in yellowish-gray arkose. Return to Park. LUNCH will be served at tables south of the parking area. Time here: 30 minutes.

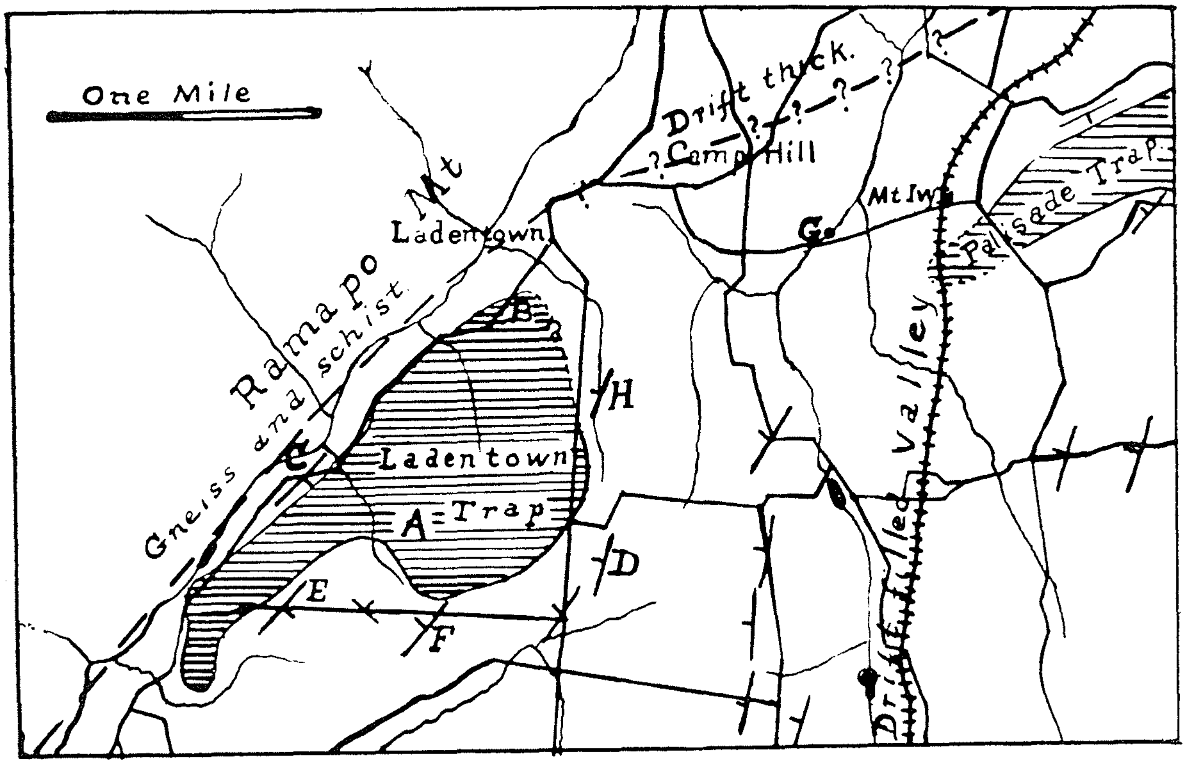
29.0	1.1	Leave Nyack Park, onto Broadway.
30.1	0.5	Turn right onto Birchwood Avenue; offset to left at 30.3.
30.6	0.3	Turn north (right) onto US 9W North at Rockland Lumber Mart.
30.9	0.4	Thermally metamorphosed yellowish-gray arkose and reddish-brown mudstone (as seen at STOP 3) in excavation on left.
31.3	1.0	Beginning of roadcut through Verdreitege Hook to inner side of the "sickle" (Figure 1).
32.3	0.4	Rockland Lake Landing Road. Gaps to east (right) and northeast (ahead) across Palisades may be controlled by faults (Thompson, 1959) or are former superposed stream valleys (Kümmel, 1898, p.24).
32.7	0.9	Continue on US 9W North. Erratics on shore of Rockland Lake.
33.6	0.9	Cross road to Congers at traffic light.
34.5	0.4	Gneiss and diabase erratics in till on right. Some are more than 6 feet long.
34.9	0.4	Excavation in till.

35.3	0.5	Cross NY 303.
35.8	0.1	Junction with NY 304.
35.9	0.2	Unusually well-developed polygonal jointing in diabase at right, and in New York Trap Rock Quarry at Little Tor above road to left. North side of "sickle."
36.1	0.1	Talus slope up hill on left.
36.2	0.7	Arkose above tough reddish-brown mudstone on left, on northern and outer side of the "sickle."
36.9	0.5	Talus with very steep angle of repose.
37.4	0.5	Scarp has receded to the west.
37.9	0.4	Continue on US 9W North across New Main Street (to Haverstraw).
38.3	0.6	Turn left onto US 202 West. Road follows the north rim of High Tor and progressively crosses younger strata to the west.
38.9	0.9	West Haverstraw road sign. Ramapo Mountains visible to the west.
39.8	1.6	Glacial erratics common.
41.4	0.5	Deposit of meltwater delta (?) on right; in lowland between sill (left) and Ramapo Mountains (right).
41.9	0.2	Cross NY 45 South.
42.1	0.2	Cross NJ and NY Railroad tracks.
42.3	0.4	Cross Palisades Interstate Parkway access road. Mt. Ivy Sand and Gravel Company quarry in Mt. Ivy meltwater delta dispersed to the south or southwest. About 5 feet of steeply dipping, light tan foreset beds above 8 to 10 feet of horizontal dark brown and reddish-brown to dark gray beds, and overlain by very poorly-sorted glacial (?) deposits.
42.7	0.2	Intersection with east end of old NY 202.
42.9	0.1	Cross Camp Hill Road.
43.0	0.6	Ramapo Mountains rise to west.
43.6	0.1	Cross NY 306.
43.7	0.2	Cross west end of old NY 202.
43.9	0.6	Outcrop of Ladentown diabase.

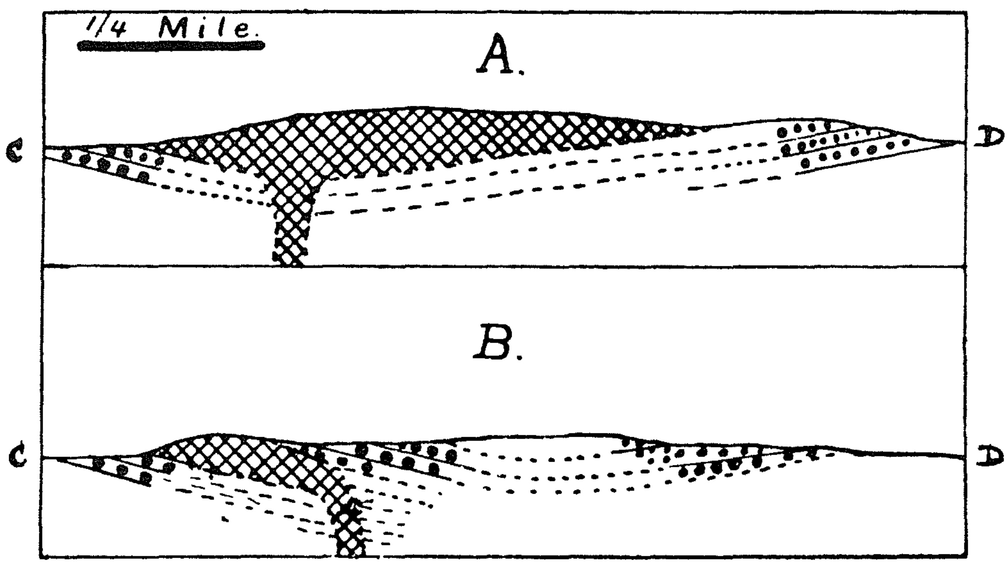
The Ladentown diabase extends for about 2 miles along the road, forming a series of low hills. It is crossed by several streams and is locally covered by glacial drift. The rock varies from fine-grained diabase to medium-grained vesicular basalt with intersertal texture, and structures like pahoehoe have been reported.

This igneous mass may connect with the Palisade diabase across the 2-mile drift-covered stretch to Mt. Ivy (Kümmel, 1898, p. 41). The flow-like features of the Ladentown sheet and its position high in the stratigraphic sequence suggest that here the northwest end of the Palisade intrusion may have reached the surface.

44.5	0.1	Steep hill of diabase on left (east).
44.6	0.2	Jointed diabase on left.
44.8	0.1	Closely-spaced, curved joints in diabase on lift differ markedly from the large-scale vertical jointing in the sill along the Hudson River.
44.9	0.1	Crossing north end of Wilder Road.
45.0	0.1	East-dipping poorly-sorted conglomerate with clasts of Paleozoic rocks. In lower part some clasts are 1 to 2 feet in diameter.
45.1	0.4	Limestone conglomerate underlying hill.
45.5	0.1	Hill steepens on left. Ladentown diabase.
45.6	0.1	Turn east (left) onto Limekiln Road.
45.7	0.4	Hill of Ladentown diabase and outcrop at road level on left (north). Fine-grained vesicular diabase with intersertal texture, but without flow texture in specimen examined. Interstices filled with very dark devitrified glass; scattered patches of iddingsite, amygdules of wordenite with a slender vein of quartz in some.
46.1	0.1	Intersection of Wilder Road and Limekiln Road. One of several abandoned quarries in linestone conglomerate on farm on southeast corner of intersection. Exposure of conglomerate on glaciated surface between old barn and house, just west of the private driveway.
46.2		<u>STOP 4.</u> <u>Limekiln Road.</u> Border Conglomerate in Upper Brunswick Formation. Time here: 20 minutes. This spectacular border conglomerate consists of rounded clasts as much as 4 feet in diameter in gravelly reddish-brown sandstone. Most of the clasts are gray cherty limestone, formerly quarried for burnt lime. Clasts of quartzite and sandstone are also present. The conglomerate is remarkably closely packed with little matrix. Conglomerate in this area east of the Ladentown diabase dips about 5° west (Kümmel, 1898, p. 40). See Figure 20 A, B.



A Sketch map showing relations of trap and sedimentary beds near Ladentown.



B

Sections showing the supposed relations of the Ladentown trap to the adjoining conglomerate.

FIGURE 20 (FROM KÜMMEL 1898)

This fanglomerate facies occurs at several places along the western boundary of the Triassic basin and is well-known as the "Potomac Marble" from Point of Rocks, Maryland.

46.2	0.6	Return to US 202 on Limekiln Road (travel west).
46.8	0.7	Turn left onto US 202. Proceed southward. Ramapo Mountains to the west. The road parallels the Mahwah River which flows along the fault zone at the western border of the Triassic basin.
47.5		Intersection with old US 202. Outcrops of limestone conglomerate on both sides of the road.

STOP 5. Old US 202. Border Conglomerate in uppermost Brunswick Formation. Time here: 30 minutes.

The section exposed along the west side consists of about 10 feet of boulder conglomerate interbedded with, and overlain by reddish-brown gravelly sandstone. The clasts consist largely of a variety of Paleozoic limestones, together with red sandstone and Green Pond (Silurian) conglomerate and quartzite.

On the east side of US 202 the deposits are less coarse, and exhibit well-developed cross-bedding with dispersal direction to the south. The regional dip of the sequence is to the southeast, toward the Ladentown diabase (Figure 20 A, B).

A 12-foot limestone boulder has been reported just south of here.

47.5	3.0	Continue south on US 202.
50.5	0.1	Gneiss of Ramapo Mountains exposed on right .
50.6	0.2	Turn right onto Pavillion Road. Exposure of slickensides in the Ramapo Fault zone. Present relief between Precambrian crystalline rocks and Triassic sedimentary rocks is due to differential erosion. Top of hill on gneiss; quarry in diabase of Union Hill seen to the southeast.

At Union Hill, the trap is associated with dark purplish-red cobble conglomerate which contains clasts of quartzite, reddish-brown, greenish-gray and gray limestone, and amygduloidal basalt. The largest clasts present are as much as 1 foot in diameter and one 3 feet in diameter has been reported. About 30 percent of the clasts here are limestone.

50.8	0.4	Return to US 202.
51.2	0.1	Turn left from US 202 onto NY 59 East.
51.3	4.2	At light, NY 59 bears left at Lafayette Avenue through Suffern.
55.5	0.8	Glacial erratics on right.

56.3	1.0	Glacial drift on right.
57.3	0.9	Spring Valley.
58.2	2.0	Howard Johnson Restaurant. REST STOP. 15 minutes.
60.2	0.2	Cross entrance to service road to Palisades Interstate Parkway, South.
60.4	0.6	Cross entrance to service road to Palisades Interstate Parkway, North.
61.0		STOP 6. East end of Cherry Hill - NY 59. Brunswick Formation. Time here: 30 minutes.

The Clarkstown Police will conduct our group across the highway to the best outcrops on the north side of the road.

This section in the lower part of the Brunswick Formation is about 0.2 miles long and consists of about 125 feet of strata (N3OE, 6^{O}W) composed of interbedded buff to reddish-brown feldspar-rich sandstone and reddish-brown mudstone. Many of the layers have well-developed cross-bedding (Figure 21) commonly in the 1 to 2-foot sets; one cross-bedded unit is 11 feet thick. Dispersal direction generally is to the southeast, although some cross-beds dip westward (Figure 11). Unbedded mudstone and fine-grained sandstone apparently were mottled by burrowers.

The feldspar-rich sandstones here, as in much of the Stockton Formation, contain relatively abundant sodic plagioclase.

The traverse proceeds from east to west along the outcrop:

Top of Sequence (west end).

50'+: Reddish-brown mudstone, variably silty and fissile, with local sandy layers. On south side of road, at about this level, a 1-foot pebbly layer contains quartz clasts as much as 1/2 inch in diameter.

20': Reddish-brown sandstone interbedded with mudstone that is variably fissile. Base is marked by scour and fill, or flutes, and the basal bed contains intraformational mud chips. Lowest sandstone unit is conspicuously parallel-bedded, with convolutions overturned to the east. Local ripple-marks have crests trending N27^{O}E. Scour and fill is common throughout the sequence.

Mudstone in the lower part of the unit contains a thin layer of drab mudstone with calcareous pellets. An 11-foot silty mudstone with thin layers of sandstone in the middle unit is conspicuously cross-bedded.

15' : Reddish-brown, cross-bedded mudstone, commonly weathers into slivers and chips. Drab calcareous nodules in upper part.

4' : Reddish-brown sandstone with very thin mudstone interbeds, and a 3-inch layer of mudstone in the middle. Round mudstone clasts on some bedding planes; scattered quartz pebbles, locally in small lenses.

2.5' : Reddish-brown fissile mudstone, with interbedded sandstone

10.5' : Reddish-brown feldspathic sandstone. Commonly medium-grained with rare pebbles and locally cross-bedded.

5' : Reddish-brown fissile mudstone.

East end of Outcrop.

61.0	1.3	Continue east on NY 59.

The following stop is optional:

61.1	0.1	At east end of Cherry Hill outcrop turn right onto Cherry Hill Lane.
61.2	0.4	Turn left onto Foxwood Road.
61.6	0.4	Turn right onto Sickletown Road.
62.0	0.1	Backslope of Palisade Sill to east (left).
62.1	0.6	Optional STOP 7. Conglomerate in lower Brunswick Formation Time here: 10 minutes.

Low ridge on lawn 157 Sickletown Road (Wright's property) consists of reddish-brown quartz pebble conglomerate and sandstone, locally cross-bedded. Clasts are principally rounded quartz as much as 1 inch in diameter, a few pebbles are as much as 4 inches in diameter. This conglomerate, about 1/2 mile from STOP 6, emphasizes the lateral variation in Triassic deposits in Rockland County.

62.7		Return north on Sickletown Road. Turn east on NY 59.

62.3	0.3	Turn south on NY 303.
62.6	3.8	Outcrop of Palisade Sill on left.
66.4	1.8	Access road to Palisades Interstate Parkway.

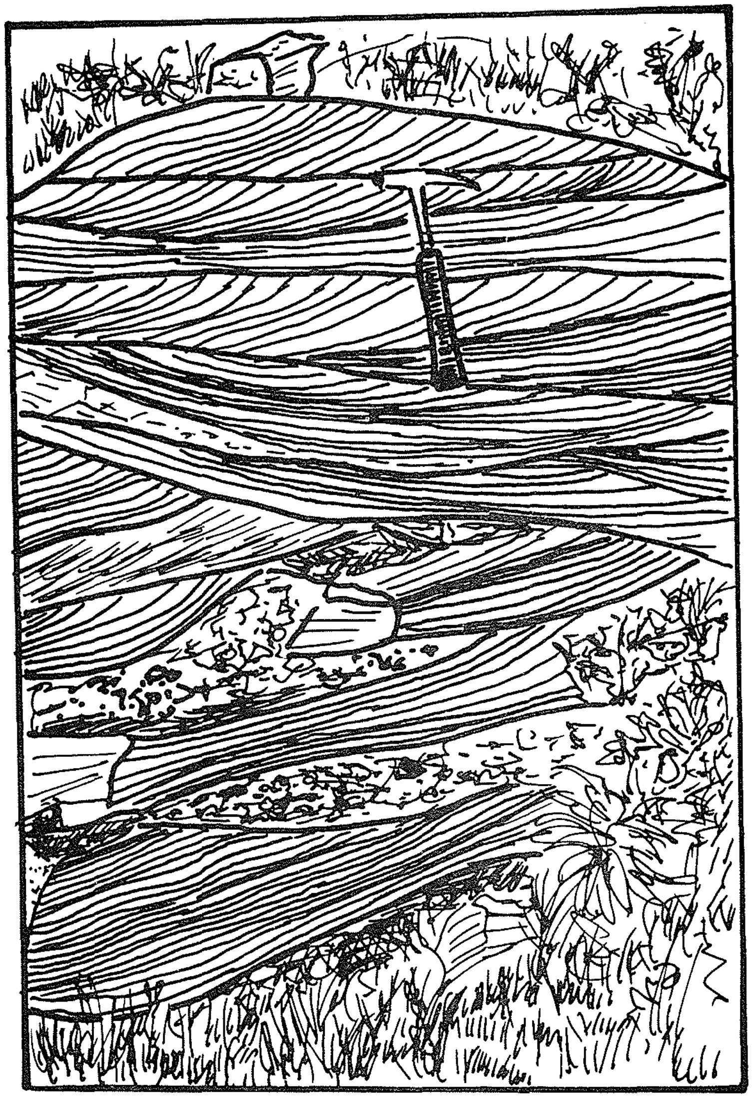


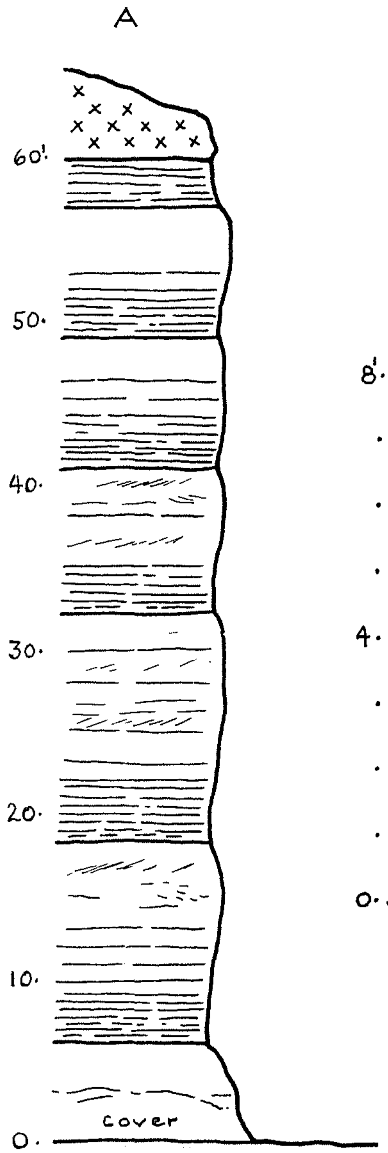
FIG. 21

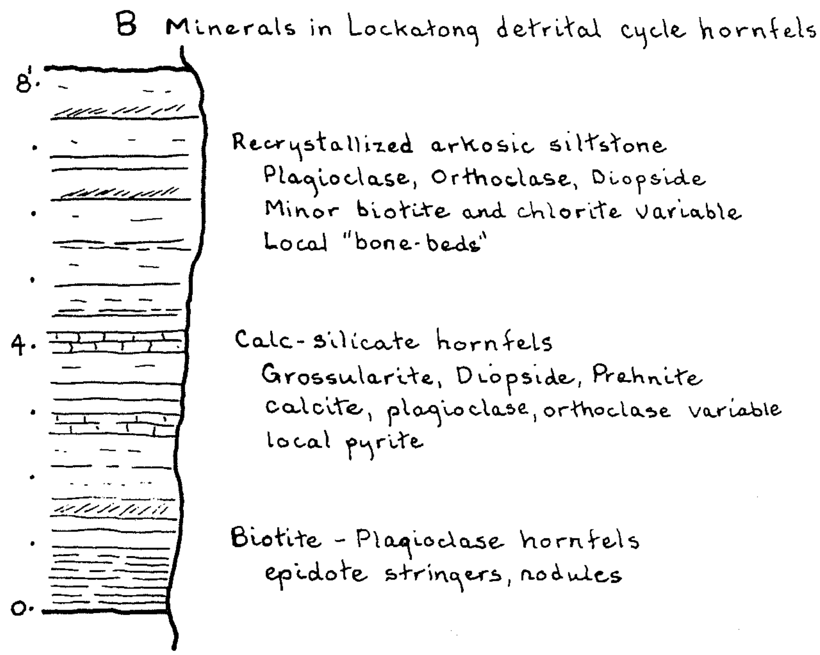
CROSS-STRATIFICATION IN THE RED-BROWN AND BUFF FINELY BANDED FELDSPATHIC SANDSTONE ON THE NORTH SIDE OF CHERRY HILL, ROUTE 59 NEW YORK (STOP 6) ILLUSTRATING AVERAGE SIZE AND TYPICAL STRUCTURE OF THE CROSS-BEDS. (SKETCHED FROM A PHOTOGRAPH).

Figure 22. Lockatong hornfels above Palisade Sill, STOP 8.

A. Succession of five complete detrital cycles, north end of upper level of Granton Quarry. See Figure 16B.

B. Model of hornfelsed Lockatong detrital cycle.


A
60'.
50.
40.
30.
20.
10.
cover
0.


B Minerals in Lockatong detrital cycle hornfels
8'.
4.
0.
Recrystallized arkosic siltstone
Plagioclase, Orthoclase, Diopside
Minor biotite and chlorite variable
Local "bone-beds"
Calc-silicate hornfels
Grossularite, Diopside, Prehnite
calcite, plagioclase, orthoclase variable
local pyrite
Biotite - Plagioclase hornfels
epidote stringers, nodules

68.2	0.7	Turn left onto Oak Tree Road at traffic light (J.J. Crowley Real Estate and State Line Restaurant).
68.9	0.9	Turn right (south) on NY 340.
69.8	9.8	Continue on NJ 501 south (Carter, Piermont, County, Huyter, Engle, Dean and Van Nostrand roads).
79.6	0.1	NJ 501 turns to left.
79.7	2.8	Turn right onto NJ 93 South (Grand Avenue).
82.5	0.8	Cross NJ 46. Continue south on NJ 935.
83.3	1.6	At traffic light (Connor Insurance Company) and traffic circle bear left then right to US 1 and 9 South (Bergen Turnpike and Tonnelle Avenue).
84.9	0.4	Hill of cross-bedded calcareous arkose on right (west). This sandstone with an interbedded 2-3 inch limestone unit (Kindle, 1944, p.4) overlies the Lockatong strata exposed in the Granton Quarry 1/2 mile to the south (see Figure 15A).
85.3	0.1	Diana Stores and knob of sill at Granton Quarry, North Bergen, on right.

<u>STOP 8.</u> <u>Lockatong Hornfels and subsidiary sill.</u>
Time here: 30 minutes.

85.4	0.1	Enter driveway at south end of Diana Stores property. Drive to rear, turn right and drive to north end of property and south face of escarpment (see Colbert, 1966, Figures 1,2).

About 60 feet of Lockatong hornfels lies between the top of the Palisade Sill to the east and a subsidiary sill at Granton Quarry, North Bergen (Figures 15A, 16B, 22). The excellent exposure at the north end of the Diana Stores parking area consists of five complete hornfelsed "detrital" cycles (Van Houten, 1964), two of which are exposed along the east wall of the lower quarry. In contrast to the "chemical" cycles in the River Road excavation (STOP 1) each of these is thicker, shows extensive evidence of burrowing as well as shrinkage cracking, and contains cross-bedded siltstone and very fine-grained arkose pervaded by diopside in the upper part. The presence of prehnite and recrystallized feldspathized arkose in the middle and upper part of each cycle suggest metamorphism in presence of water vapor.

The overlying subsidiary sill, more than 20 feet thick, has been reported to contain an arkose xenolith a maximum of 10 feet thick and 100 feet long (Lewis, 1908, p. 135).

In spite of the extensive hornfelsing of the Lockatong rocks they still yield fossils of reptiles, fish, estheriids and plants (Colbert, 1965, 1966).

85.5 Return to US1 and 9. Turn right (south) for Lincoln Tunnel; turn left (north) for George Washington Bridge.

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