# ALLEGHANIAN THRUST FAULTS IN THE KITTATINNY VALLEY, NEW JERSEY


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## Introduction

Major thrust faults involving both Proterozoic basement and Cambrian and Ordovician sedimentary rocks have been known in the Kittatinny Valley at least since the geologic mapping that resulted in the New Jersey State Geologic Map (Lewis and Kummel, 1910-12) and the Raritan Folio (Bayley and others, 1914). Three important thrust faults, the Jenny Jump, Portland, and Federal Springs, display quite different tectonic styles at the present level of erosion and, thereby, serve as showpieces of thrust fault tectonics for this part of the central Appalachian orogen. The purpose of this field trip is to demonstrate these three thrust faults and to present evidence for their late, probably Alleghanian age. In addition, attendant structural features such as autoclastic mélange and chert mylonite will be shown.

## Stratigraphy

Rocks pertinent to this study include Proterozoic Y gneisses and foliated granitoids and sedimentary rocks of Cambrian and Ordovician age. The pre-upper Middle Ordovician rocks of the Kittatinny Valley belong to the orthoquartzite-carbonate facies and were deposited on the great east-facing shelf of the North American craton. Subsequent to the foundering of that shelf, upper Middle and lower Upper Ordovician graywacke-shale flysch was deposited.

## Proterozoic Y Rocks

Proterozoic Y rocks form the nappe cores within the Musconetcong nappe system of the Reading Prong nappe megasystem. On this field trip, these rocks will be seen in the very large Jenny Jump and small Silver Lake I klippen of the Jenny Jump thrust sheet (fig. 1). In this part of New Jersey, the Proterozoic Y rocks consist of a sequence of metasedimentary and metavolcanic rocks and three suites of intrusive rocks (Drake, 1969).

## Metasedimentary and Metavolcanic Rocks

The metasedimentary-metavolcanic sequence consists of amphibolite and pyroxene amphibolite much of which is migmatized, pyroxene gneiss, dolomite and calcite marble, oligoclase-quartz, gneiss and quartzo-feldspathic gneiss which has potassic feldpar, biotite-quartz-plagioclase, and sillimanite-bearing end member variants. The sequence originally consisted of interbedded limestone and dolomite (marble, pyroxene gneiss, and some amphibolite), semipelitic and psammitic sedimentary rocks (quartzo-feldspathic gneisses), and felsic and mafic volcaniclastic rocks and related mafic flows (oligoclase-quartz gneiss and some amphibolite). Some amphibolite in New Jersey may have been intrusive, but there is no evidence for this in areas we have studied. These rocks were metamorphosed in the granulite facies during the Grenville orogeny.

The most abundant intrusive rocks in this part of northern New Jersey are hornblende granite, alaskite, and related pegmatite which are characterized by microperthite. Because of their close petrographic, petrochemical, and spatial relations, these rocks are thought to have stemmed from the same magma, and thereby, constitute an intrusive suite (Drake, 1969). Rocks of this suite occur in conformable sheets, pods, and hook-shaped refolded bodies which, in the past, were described as phacoliths. These granitic rocks have all the features usually ascribed to syntectonic intrusions. They are foliated and many bodies are gneissoid. Where they have enjoyed more intense Paleozoic deformation, they are auger, flaser, or mylonite gneiss, mylonite, or brecciated mylonite. Practically all the geologists who have worked in the Reading Prong have found that the bulk of the microperthite-bearing granitic rocks have intruded the metasedimentary-metavolcanic sequence although there is some evidence of granitization of amphibolite on the margins of some plutons (Drake, 1969). These rocks were intruded during the Grenville orogeny (Rankin and others, in press).

Smaller bodies of two other suites of intrusive rock occur sporadically in this part of northern New Jersey. One of these suites consists of alaskites and granites which are characterized by the presence of microantiperthite. Many of these rocks contain clinopyroxene and it is likely that they are related to the clinopyroxene- and microantiperthite-bearing granites and syenites so abundant in areas farther east in New Jersey (Baker and Buddington, 1970). The microantiperthite-bearing rocks are foliated and in most exposures have a strong lineation marked by lenticulated quartz. To our

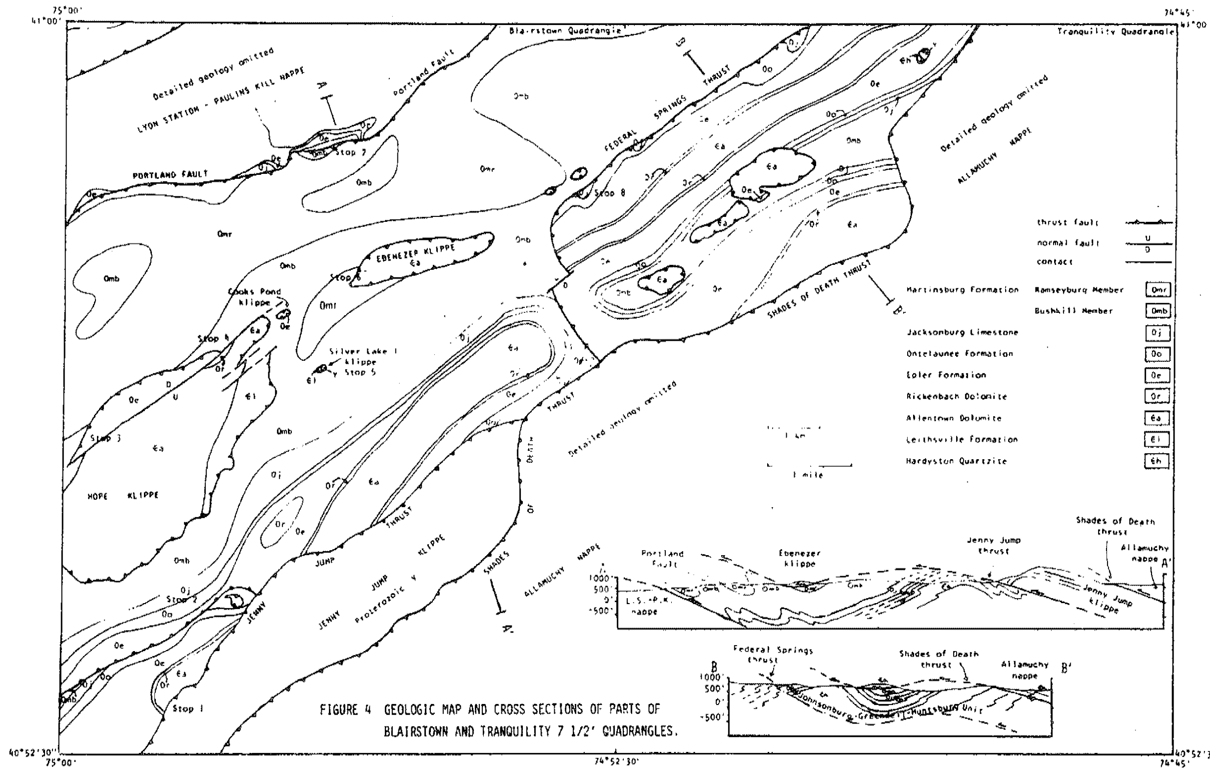



**Figure 1.** A. Geologic map and cross sections of parts of Blairstown and Tranquility 7½ minute quadrangles, New Jersey.

knowledge, these rocks have not been dated, but there is no reason to suspect that they are other than Grenvillian in age.

The third suite consists of bodies of sodic granite rocks that are fairly common throughout northern New Jersey. These rocks are thought to result from the anatectic remobilization of the metavolcanic oligoclase-quartz gneiss (Drake, 1969) during the Grenville orogeny.

## Cambrian and Ordovician Rocks

The Cambrian and Ordovician rocks of the Kittatinny Valley belong stratigraphically to the Lehigh Valley sequence as first defined by MacLachlan (1967) and tectonically to the Musconetcong nappe system (Drake, 1978). A brief description of the stratigraphy of the Lehigh Valley sequence is given in Table 1. The carbonate rocks between the Hardyston Quartzite and Jacksonburg Limestone, that is the Leithsville Formation, Allentown Dolomite, and Beekmantown Group have been termed the Kittatinny Limestone since the work of H. D. Rogers (1840). In New Jersey, the Kittatinny was first subdivided by Drake (1965) during his systematic geologic study of the Delaware Valley. Kittatinny is an old and honored stratigraphic name and is quite useful in describing the carbonate-rock terrane of Cambrian to earliest Middle Ordovician age in eastern Pennsylvania and New Jersey. We, therefore, introduce the term Kittatinny Supergroup to include the Leithsville Formation, Allentown Dolomite, and Beekmantown Group consisting of Stonehenge Limestone (not known in New Jersey), Rickenbach Dolomite, Epler Formation, and Ontelaunee Formation. It overlies the basal Hardyston Quartzite. The Hardyston has a facies relation with the overlying carbonate rocks as aptly shown by Aaron (1969). Inclusion of the Hardyston with the Supergroup of predominantly carbonate rocks follows the lead of Fisher (1977) who included the basal Poughquag Quartzite with the carbonate rocks in the Wappinger Group of Cambrian and Early Ordovician age in New York.

The Kittatinny Supergroup, as defined above, together with the Hardyston Quartzite, forms a part of the Lehigh Valley sequence which constitutes the cover rocks of the Musconetcong nappe system in the Reading Prong and Great Valley of New Jersey and eastern Pennsylvania. Its western limit is in the Reading, Pa. area where the rocks of the Musconetcong nappe system pass beneath the Lebanon Valley sequence of the Lebanon Valley nappe (MacLachlan, 1979b; MacLachlan and others, 1975). In addition, the quartzite-carbonate sequence of Cambrian to Early Ordovician age in the Buckingham Valley of eastern Pennsylvania likely belongs to the Kittatinny Supergroup although these rocks have not been studied in any detail. The Kittatinny Supergroup is directly on strike with the Wappinger Group in New York and is a correlative unit, although internal subdivisions may not be the same. The application of modern conodont biostratigraphic techniques should result in more exact correlations.

Table 1.--Lehigh Valley sequence of eastern Pennsylvania and New Jersey

| Supergroup | Group | Formation | Member | Description | Thickness (meters) |
|---|---|---|---|---|---|
| | | Martinsburg, upper Middle and lower Upper Ordovician (Geiger and Keith, 1891) | Pen Argyl (Behre, 1927 | Dark-gray to grayish-black, thick- to thin-bedded, evenly bedded slate; rhythmically interlayered with beds of quartzose slate or subgraywacke and carbonaceous slate. Upper contact is unconformable and site of a décollement. Contains mineral assemblage muscovite-chlorite-albite-quartz. Not present in northwestern N. J. | 1,000-2000 |
| | | | Ramseyburg (Drake and Epstein, 1967) | Medium- to dark-gray slate that alternates with beds of light- to medium-gray, thin- to thick-bedded graywacke and graywacke siltstone. Graywacke composes 20-30 percent of unit. Upper contact gradational. Pelitic elements contain mineral assemblage muscovite-chlorite-albite-quartz. | About 930 |
| | | | Bushkill (Drake and Epstein, 1967) | Dark- to medium-gray thin-bedded slate containing thin beds of quartzose slate, graywacke siltstone, and carbonaceous slate. Upper contact gradational. Contains mineral assemblage muscovite-chlorite-albite-quartz. | About 1350 |
| | | Jacksonburg Limestone, Middle Ordovician (Spencer and others, 1908) | Cement-rock facies (Miller, 1937) | Dark-gray, almost black, fine-grained, thin-bedded argillaceous limestone. Contains beds of crystalline limestone at places. Upper contact gradational. Contains mineral assemblage calcite-chlorite-muscovite-albite-quartz. | 100-330 |
| | | | Cement-limestone facies (Miller, 1937) | Light- to medium-gray, medium- to coarse-grained, largely well-bedded calcarenite and fine- to medium-crystalline high-calcium limestone. Upper contact is gradational in main outcrop belt but is apparently unconformable and marked by a conglomerate in the Paulins Kill lowland. Lower contact is marked by beds of dolomite-pebble to boulder-conglomerate in main outcrop belt. | 20-130 |
| Kittatinny (here named) | Beekmantown Clark and Schuchert, 1899) | Ontelaunee, upper Lower and lowest Middle Ordovician (Hobson, 1957) | | Medium- to thick-bedded medium dark-gray, fine-to coarse crystalline dolomite, that is very cherty at the base, passing up into medium- to thick-bedded, medium-gray, fine- to medium-crystalline dolomite that contains beds of medium crystalline calcilutite at the top in some places. Upper contact is sharp and unconformable. Unit only sporadically present east of Northampton, Pa., because of extreme erosion on the Middle Ordovician unconformity. | 0-200 |
| do | do | Epler, Lower Ordovician (Hobson, 1957) | | Interbedded very-fine-grained to cryptogranular, light- to medium-gray limestone and fine- to medium-grained light-gray to dark-medium-gray dolomite. Upper contact sharp and unconformable except where Ontelaunee is present. At those places it is gradational. | About 270 |
| do. | do | Rickenbach Dolomite, Lower Ordovician (Hobson, 1957) | | Fine- to coarse-grained, light-medium to medium-dark-gray dololutite, dolarenite, and dolorudite. Lower part characteristically thick bedded, upper part generally thin bedded and laminated. Upper contact gradational. | About 220 |
| do | do | Stonehenge Limestone, Lower Ordovician (Stose, 1908) | | Medium-light-gray to medium gray, finely crystalline limestone marked by silty or sandy laminae. Easternmost exposures contain a fair amount of dolomite. Unit has a facies relation with the Rickenbach Dolomite. Upper contact gradational. Unit not known in easternmost Pa. or N. J. | 0-75 |
| do | | Allentown Dolomite, Upper Cambrian and probably lowest Lower Ordovician | | Very fine- to medium-grained, light-gray to medium-dark gray, alternating light- and dark-gray weathering, rhythmically bedded dolomite containing abundant algal stromatolites, oolite beds, and scattered beds and lenses of orthoquartzite. Upper contact gradational. | About 575 |
| do | | Leithsville Formation, Lower and Middle Cambrian (Wherry, 1909) | | Interbedded light-medium-gray to dark-gray, fine- to coarse-grained dolomite and calcitic dolomite, light-gray to tan phyllite, and very thin beds and stringers of quartz and dolomite sandstone. Upper contact is gradational. Phyllite contains mineral assemblage muscovite-chlorite-albite-quartz. | About 350 |
| | | Hardyston Quartzite, Lower Cambrian (Wolff and Brooks, 1898) | | Gray quartzite, feldspathic quartzite, arkose, quartz pebble conglomerate, and silty shale or phyllite. Upper contact is gradational. Phyllite contains mineral assemblage muscovite-chlorite-albite-quartz. | Maximum about 30 |

**Structural Geology**

In the period between 1959 and 1970, a nappe theory has been devised to explain the highly complicated structural geology of the Great Valley-Reading Prong segment of the Taconides (Drake, 1980) in east-central and eastern Pennsylvania and New Jersey (Gray, 1959; MacLachlan, 1964; Drake, 1969, 1970). More recent work, however, has shown that the structural geology is even more complex and that the Proterozoic Y and lower Paleozoic rocks are involved in a nappe megasystem of Taconic age that was later deformed, during the Alleghanian orogeny, into a system of décollements at different tectonic levels that are linked by steep ramp faults like those of the Valley and Ridge (Drake, 1978, 1980; Faill and MacLachlan, 1980; MacLachlan, 1979a, 1979b; MacLachlan and others, 1975). This linked décollement style of deformation is beautifully illustrated by a long outcrop of Ramseyburg on the east-bound lane of interstate 80 about 2 miles west of the Hope exit (fig. 2). The structures in this outcrop, which is immediately adjacent to the Hope klippe, are typical of the décollement terrane of the Valley and Ridge; see for instance Harris and Milici (1977) and Perry (1978).

Three phases of folds have been recognized in this part of the Taconides in northern New Jersey: An eastnortheast-trending set of early folds and northeast- and nearby east-trending sets of later folds (Drake, 1978). Major thrust faulting occurred subsequent to the northeast fold phase and prior to the northeast-trending fold phase which, in turn, predated the nearly east-trending fold phase (Drake, 1978).

Rock fabric related to these deformations is best shown by rocks of the Martinsburg Formation. Penetrative slaty cleavage (fig. 3) is the dominant planar structure in most of these rocks. It essentially parallels axial surfaces of what appear to be the earliest eastnortheast-trending folds. The age of this cleavage is one of the more controversial problems in central Appalachian geology. Many workers (Drake and others, 1960; Maxwell, 1962) believe that this cleavage formed during the Taconic orogeny. Other geologists (Epstein and Epstein, 1969; Lash, 1978) have found strong evidence supporting an Alleghanian age for the slaty cleavage of the Pen Argyl Member of the Martinsburg rocks in the eastern Pennsylvanian slate belt. More recently, David Rowlands (written communication, 1979) and Nicholas Ratcliffe (personal communication, 1980) have independently found inclusions of cleaved Martinsburg within rocks of the Upper Ordovician Beemerville carbonatite-alkalic rock intrusive complex in northern New Jersey. This cleavage may predate the regional slaty cleavage in the Martinsburg and must date from the Taconic orogeny. We suggest that the dichotomy of cleavage age may be resolved by applying the concepts of Mitra and Elliott (1980) who found that the formation of penetrative cleavage may migrate in time progressively toward the foreland. If this is true for the Taconides of eastern Pennsylvania and New Jersey, what appears to be the same cleavage may date from the Ordovician in the older and tectonically lower parts of the Martinsburg and be of Alleghanian age in the younger and tectonically higher parts. In the Pennsylvania part of the Great Valley the upper Pen Argyl Member of the Martinsburg and perhaps parts of the middle Ramseyburg Member appear to be at a tectonically higher level than the lower Bushkill Member. This may help explain the differences in age assignment for the slaty cleavage in this region by various workers (Drake and others, 1960; Epstein and Epstein, 1969; Lash, 1978). Most of the New Jersey part of the Great Valley mapped by us is interpreted to be at a tectonically higher level than the Pennsylvania part.

For the above speculation to apply, the Taconic through Alleghanian deformational events must be considered as major pulses of one more or less continuous Paleozoic orogenic event. Such a concept receives some support from the recently gained seismic reflection profiles across the Appalachian orogen (Harris and Bayer, 1979). As a matter of fact, these data can be interpreted to define an orogenic period starting in the Later Proterozoic time and continuing until the present.

Superposed on this slaty cleavage is a less pervasive but locally penetrative strain-slip fabric (Drake and others, 1960, Drake, 1978). This strain-slip cleavage formed during the northeast-trending fold phase and roughly parallels the axial surface of folds in both cleavage and bedding. This cleavage is thought to be an Alleghanian feature (Drake and others, 1960; Drake, 1969, 1970, 1978; Epstein and Epstein, 1969). The latest, nearly east-trending fold phase has a poorly developed cleavage at only a few places (Drake, 1978).

Lineations related to the above deformation includes axes of small folds in both bedding and slaty cleavage, the intersection of bedding and slaty cleavage (a characteristic feature of the Bushkill Member; (see figure 3), and crenulated cleavage. Fabric data for the Martinsburg Formation in the Blairstown quadrangle are given in figure 4. The widespread of the plot of axes of small folds and bedding--slaty cleavage intersections (fig. 4A) reflects the polyphase deformation although the statistical maximum results from the early eastnortheast-trending folding. The plot of axes of small folds in cleavage (fig. 4B) reflects mostly the northeast-trending fold phase although there is some spread.

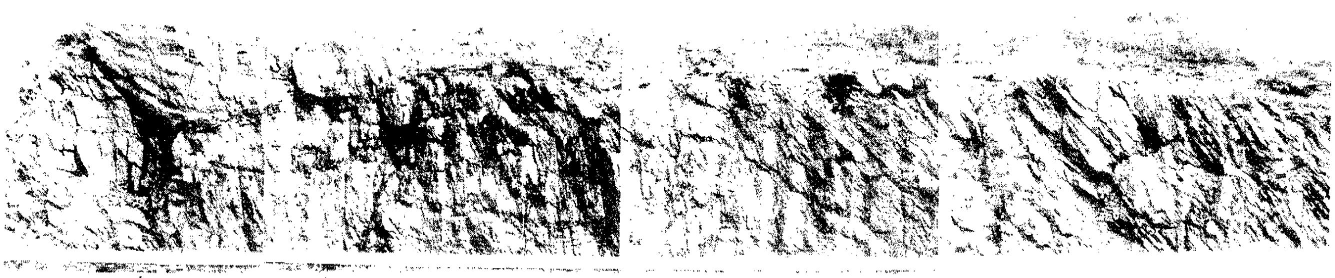


**Figure 2.** Outcrop of Ramseyburg Member of Martinsburg Formation illustrating linked décollement deformation. Note particularly, the fault-bonded phacoids in the left part of the photograph and the sharp-peaked "tepee fold" at the bottom center. Road cut ranges in height from about 4 to 6 meters.

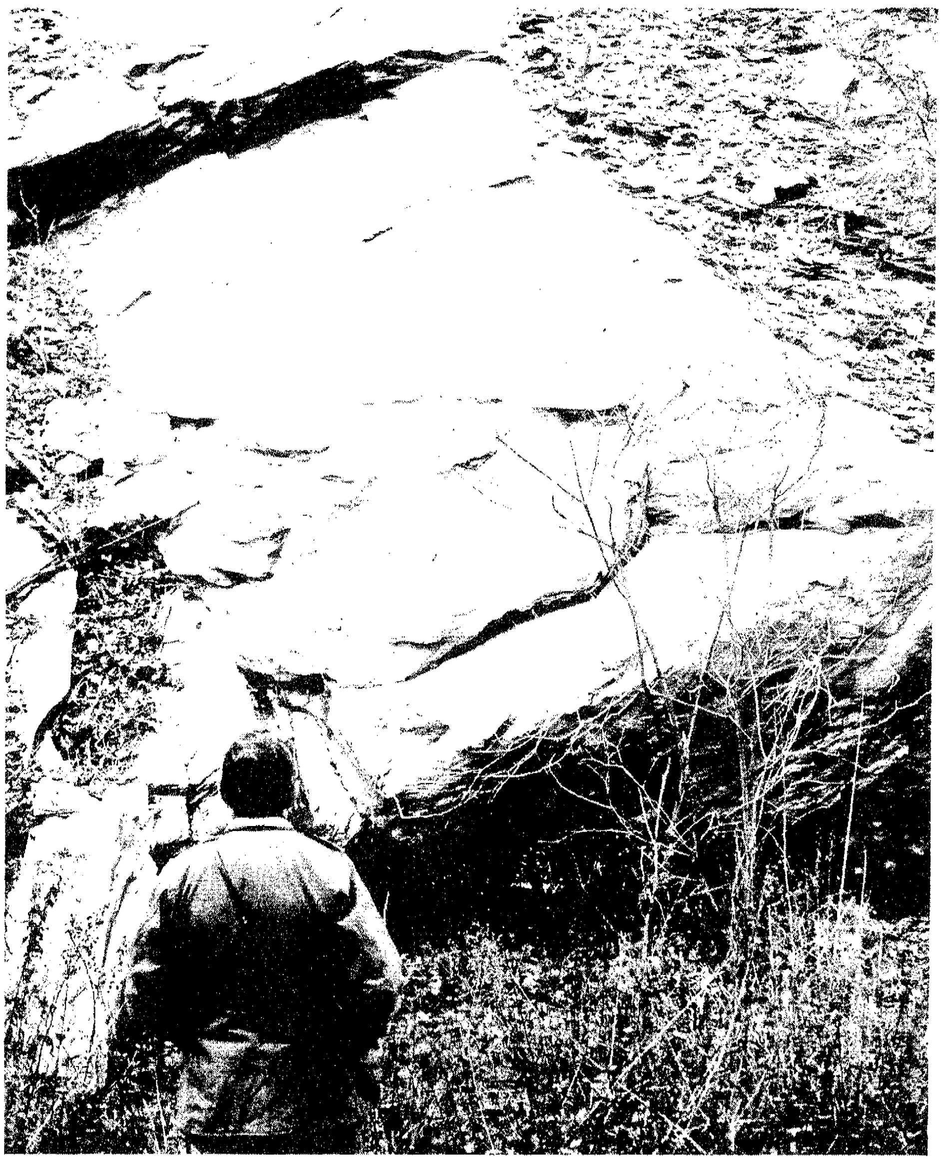


**Figure 3.** Typical ribbon slate of the Bushkill Member of the Martinsburg Formation. Bedding (inverted) dips to right and the slaty cleavage dips more gently to the right. The bedding-slaty cleavage intersection plunges southeast (toward the viewer) about parallel with the direction of transport on the nearby Federal Springs thrust fault.

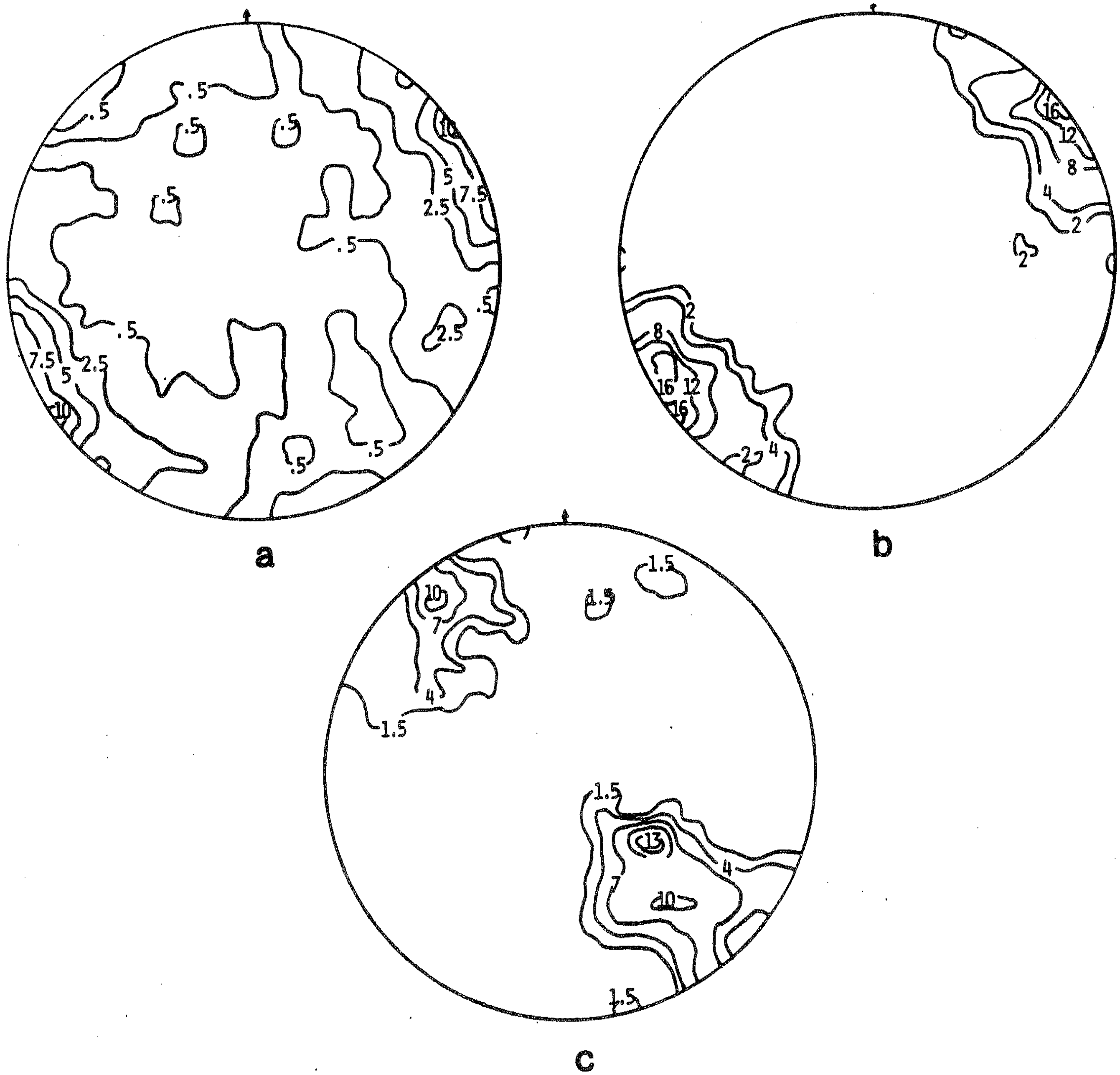



**Figure 4.** Fabric diagrams of rocks of Martinsburg Formation in the Blairstown quadrangle.

A . Equal-area plot (lower hemisphere) of 206 axes of small folds in bedding and bedding-slaty cleavage intersections. Contours at 10, 7.5, 5, 2.5, and .5 percent per 1-percent area.

B . Equal-area plot (lower hemisphere) of 52 axes of small folds in cleavage and crenulations. Contours at 16, 12, 8, 4, and 2 percent per 1-percent area.

C . Equal area plot (lower hemisphere) of 63 extension lineations. Contours at 13, 10, 7, 4, and 1.5 percent per 1-percent area.

A characteristic feature of the Taconides of eastern Pennsylvania and New Jersey is the rotation of small fold axes and attendant lineation toward the direction of transport near major thrust faults. This was particularly well documented for the Portland fault where it frames the Whitehall window near Catasauqua, Pennsylvania (Drake, 1978, fig. 11A). The rotation of fold axes toward the transport direction is an important clue to the recognition of major thrust faults. The phenomena can be seen at many places in northwestern New Jersey and is reflected by a weak maximum in the southeast and northwest quadrants of figure 4A.

The slaty cleavage at many places in northwestern New Jersey is marked by an extension lineation (smearing and stretching phenomena). These lineations were first recognized by Broughton (1947) who correctly related them to the emplacement of the Jenny Jump thrust sheet. A plot of these lineations (fig. 4C) shows that they fall on a girdle about an inferred axis essentially colinear with that of the northeast-trending fold hinges. The Jenny Jump thrust event then postdates the early eastnortheast-trending folds and related slaty cleavage and predates the northeast-trending folds.

The major tectonic units in this part of northwestern New Jersey are the Allamuchy nappe and Lyon Station-Paulins Kill nappe, which is exposed in the large Paulins Kill window, of the Musconetcong nappe system, the fragmented Jenny Jump thrust sheet, and the poorly understood Johnsonburg-Greendell-Huntsburg unit (fig. 1).

**Allamuchy Nappe**

The Allamuchy nappe is typical of the other crystalline-cored nappes de recouvrement of the Reading Prong nappe megasystem as described to the west (Drake, 1969, 1970; MacLachlan, 1979b; MacLachlan and others, 1975). It has not been studied in any detail as yet, but parts of both its upper and lower limbs appear to be exposed at the present level of erosion. This nappe was proved by diamond drilling by the New Jersey Zinc Company (Baum, 1967). Rocks of this nappe are brought above those of the Jenny Jump klippe of the Jenny Jump thrust sheet and Johnsonburg-Greendell-Huntsburg unit on the major Shades Of Death thrust fault (see fig. 1). This fault is probably the northeast continuation of the Lower Harmony fault (Drake, 1967a, 1967b; Drake and others, 1969). The Allamuchy nappe is not critical to the theme of this paper and will not be discussed further.

**Lyon Station-Paulins Kill Nappe**

The Lyon Station-Paulins Kill nappe is the frontal structure of the Musconetcong nappe system and has been described at some length by Drake (1978). The upper limb of the nappe is exposed in the Paulins Kill window, the crystalline core being blind. This nappe is separated from the other overlying structures of the Musconetcong nappe system by the Portland thrust fault which was first recognized by Drake and others (1969). It brings younger rocks over older and is strongly folded into the "snakehead" geometric form (Drake and others, 1969; Drake, 1978) typical of the décollement terrane of the Valley and Ridge. This fault clearly post-dates the slaty cleavage in the Martinsburg and is deformed by both the northeast- and nearly east-trending fold phases (Drake, 1978). Therefore, it is thought to be an Alleghanian structure. This fault is exposed at a deeper tectonic level than the others which are the subject of this paper and field trip.

**Jenny Jump Thrust Sheet**

The Jenny Jump thrust fault is the most obvious of such structures in northern New Jersey. It was recognized in the early geologic mapping of that state (Lewis and Kummel, 1910-12; Bayley and others, 1914). Geologic sections drawn at that time show the important fact that a very large thrust sheet has been fragmented into several different, essentially flatlying, klippen of both Proterozoic Y and Lower Paleozoic rocks, and that the thrust fault itself was folded. In 1929, George Stose, H. B. Kummel, and M. E. Johnson made a more thorough study of the thrust which led to an exellent manuscript which, for some reason, was never published. A copy of this manuscript which contained the important conclusion that the Jenny Jump thrust was somehow related to the Reading overthrust of Stose and Jonas (1935), came into Drake's hands upon the death of Anna Jonas Stose.

The litter of klippen which constitute erosional remnants of this thrust sheet in the Kittatinny Valley led Drake (1969, 1970) to the recognition that tectonism had operated at a higher level here than in eastern Pennsylvania and, because of the characteristic Musconetcong aeromagnetic signature along the leading edge of the Jenny Jump klippe (fig. 5), to the erroneous belief that the thrust sheet was the result of the core of the Musconetcong nappe shearing through its cover. This thrusting was considered at that time to be of Taconic age. This seems highly unlikely, however, as the largest klippe of Proterozoic Y rocks, the Jenny Jump, transects several folds in the Kittatinny Supergroup and lies on a variety of carbonate rocks of Ordovician Age as well as Martinsburg Formation (Fig. 4). The carbonate rocks beneath the klippe do not have a penetrative thrust fabric; however, they contain abundant subsidiary thrust faults which are marked by zones of ductile deformation (fig. 6), selectively occurring along layers of chert and(or) metabentonite within the

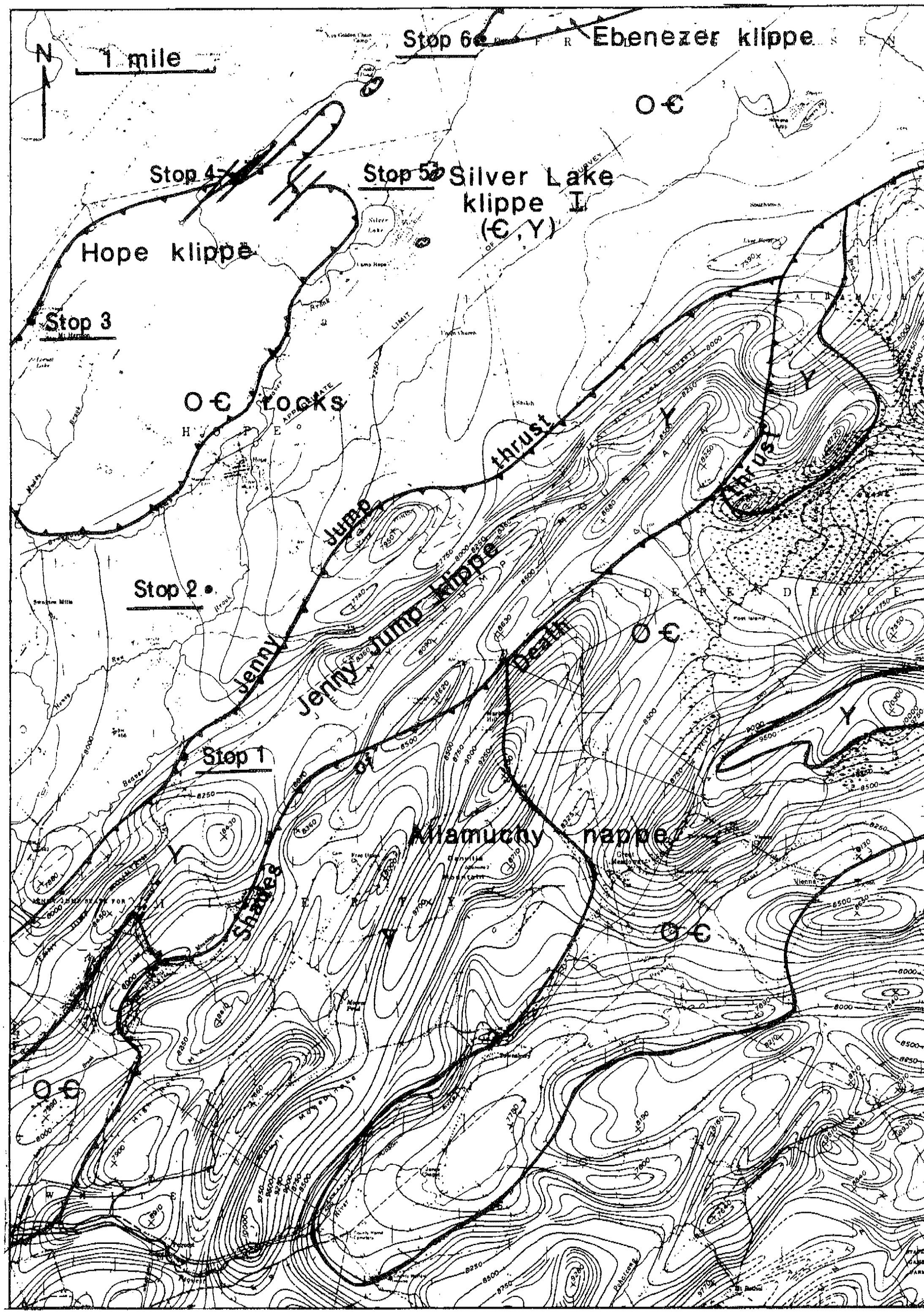



**Figure 5.** Aeromagnetic map of the south half of the Blairstown 7½-minute quadrangle and north half of the Washington 7½-minute quadrangle, New Jersey. Superimposed on it is a simplified geologic map emphasizing the following structural features:

a. the Jenny Jump thrust that brings the magnetic Proterozoic gneisses (Y) over the Cambrian and Ordovician carbonates and clastic rocks (C-O). Note the abrupt break in magnetic signature at the thrust fault clearly demonstrating that the Proterozoic gneisses do not extend under the lower Paleozoic rocks in the valley north of Jenny Jump Mountain. See Stop 1.

b. the Shades of Death thrust that brings the Allamuchy nappe (containing both Proterozoic gneisses and Lower Paleozoic rocks) over the Jenny Jump thrust sheet.

c. the Hope klippe containing Cambrian and Lower Ordovician dolomites that structurally overlie the Middle Ordovician Martinsburg Formation. See Stops 3 and 4.

d. the Silver Lake I klippe containing Proterozoic gneisses and Cambrian(?) dolomite structurally overlying the Martinsburg Formation. See Stop 5.

e. the Ebenezer klippe of Cambrian Allentown Dolomite structurally overlying the Martinsburg Formation. See Stop 6.

carbonate rock, a phenomenon recognized some years ago by Stevens (1962). At many places the mylonitic foliation was folded during the northeast-trending fold phase (fig. 7). The Proterozoic Y rocks of the klippe show the effects of two Paleozoic deformation phases, in which a mylonite fabric is overprinted by a more brittle fabric.

The other klippen of the thrust sheet lie in troughs in the slaty cleavage within the Martinsburg Formation, and therefore, obviously were emplaced subsequent to the early folding and attendent cleavage formation. Some of these klippen transect contacts between the Bushkill and Ramseyburg Members. The slaty cleavage in klippen areas is marked by an extreme extension lineation (see above) and the rock below klippen soles is severely smeared and tectonically disrupted into autoclastic mēlange (fig. 8). The carbonate klippen are reminiscent of those of the southern Appalachians in their general lack of obvious body deformation. The Proterozoic Y rocks of the small Silver Lake-I klippe show the effect of both ductile mylonitic and brittle deformation (fig. 9). This klippe is likely polykinematic, as the Proterozoic Y rocks appear to be in thrust contact with rocks of the Leithsville Formation.

If the various fragments of the Jenny Jump thrust sheet were reconstituted, they would likely form the crystalline core and upper limb of a nappe as the various klippen contain right-side-up, northwest-dipping rocks of the Kittatinny Supergroup from Hardyston Quartzite through Epler Formation. The thrust sheet probably stemmed from a nappe intermediate between the Allamuchy and Lyon Station-Paulins Kill nappes. This is far from certain, however, as the south end of the thrust sheet is cut off by the Shades Of Death thrust (fig. 4) and too little work has been done in New Jersey as yet to allow reasonable palinspastic reconstructions.

We believe that the Jenny Jump thrust sheet was emplaced during the Alleghanian orogeny, perhaps as a phase 1 feature (Drake, 1980) as it is deformed by two fold phases. It clearly post-dates Alpine-type nappe tectonism and the regional slaty cleavage. The problems of the cleavage age have been treated above, but we believe that the dichotomy in age noted by many workers may be real. That is, we may not be dealing with a Taconic *versus* an Alleghanian age for the regional slaty cleavage, but with Taconic *and* Alleghanian age for that cleavage.

### Johnsonburg-Greendell-Huntsburg Tectonic Unit

The Johnsonburg-Greendell-Huntsburg tectonic unit is not fully understood. On the basis of rock distribution, it appears to be a Martinsburg-cored syncline within Kittatinny Supergroup rocks. Klippen of Allentown Dolomite lie on the Martinsburg in the apparent synclinal core. The northwest margin of the unit is marked by the Federal Springs thrust fault and the Shades Of Death thrust fault brings rocks of the Allamuchy nappe above it on the southeast. It may be that this tectonic unit is exactly what it appears to be, but more than 20 years experience in this part of the Taconides teaches one caution.

Be that as it may, the Federal Springs represents yet another type of thrust fault. Where shown on this field trip, it stands quite steeply and clearly post-dates major early folding in rocks of the Kittatinny Supergroup and the slaty cleavage in the Bushkill Member of the Martinsburg. Its steep altitude combined with the fact that it separates tectonic units suggest that it may be a major ramping splay fault which has reached the surface. The field evidence cited above suggests that it too is an Alleghanian structure.

### Conclusions

Three thrust faults of different aspect have been described above, and will be examined on this field trip. All these faults post-date major early folds and the regional slaty cleavage in the Martinburg Formation. They serve as structural boundaries between and telescope major tectonic units which owe their major structural features to the Taconic orogeny. We think, therefore, that these thrust faults result from the Alleghanian orogeny.

## ROAD LOG

THE FIELD TRIP BEGINS IN THE PARKING LOT AT RUTGERS-NEWARK AND REACHES THE KITTATINNY VALLEY BY THE GARDEN STATE PARKWAY AND INTERSTATE 280 AND 80. SUBSEQUENT TO STOP 9, THE TRIP RETURNS TO RUTGERS-NEWARK BY ROUTE 206, INTERSTATES 80 AND 280, AND THE GARDEN STATE PARKWAY. GEOLOGIC NOTES ARE PROVIDED FOR THE ROUTE 206 SEGMENT OF THE RETURN. FIELD TRIP STOPS 1-8 ARE IN THE BLAIRSTOWN 7 ½-MINUTE QUARDRANGLE AND STOP 9 IS IN THE NEWTON EAST QUADRANGLE. (A COPY OF THESE TWO QUADRANGLES WILL BE PROVIDED TO EACH PARTICIPANT.) THE TRIP ROUTE ALSO TRAVERSES THE TRANQUILITY, NEWTON EAST, AND STANHOPE QUADRANGLES.

**Mileage**

0.0 Turn right onto Warren Street, leaving the parking lot.

0.1 Right turn at traffic light onto High Street. Continue for 0.5 mile north on High Street.

0.6 Left turn at traffic light onto Orange Street.

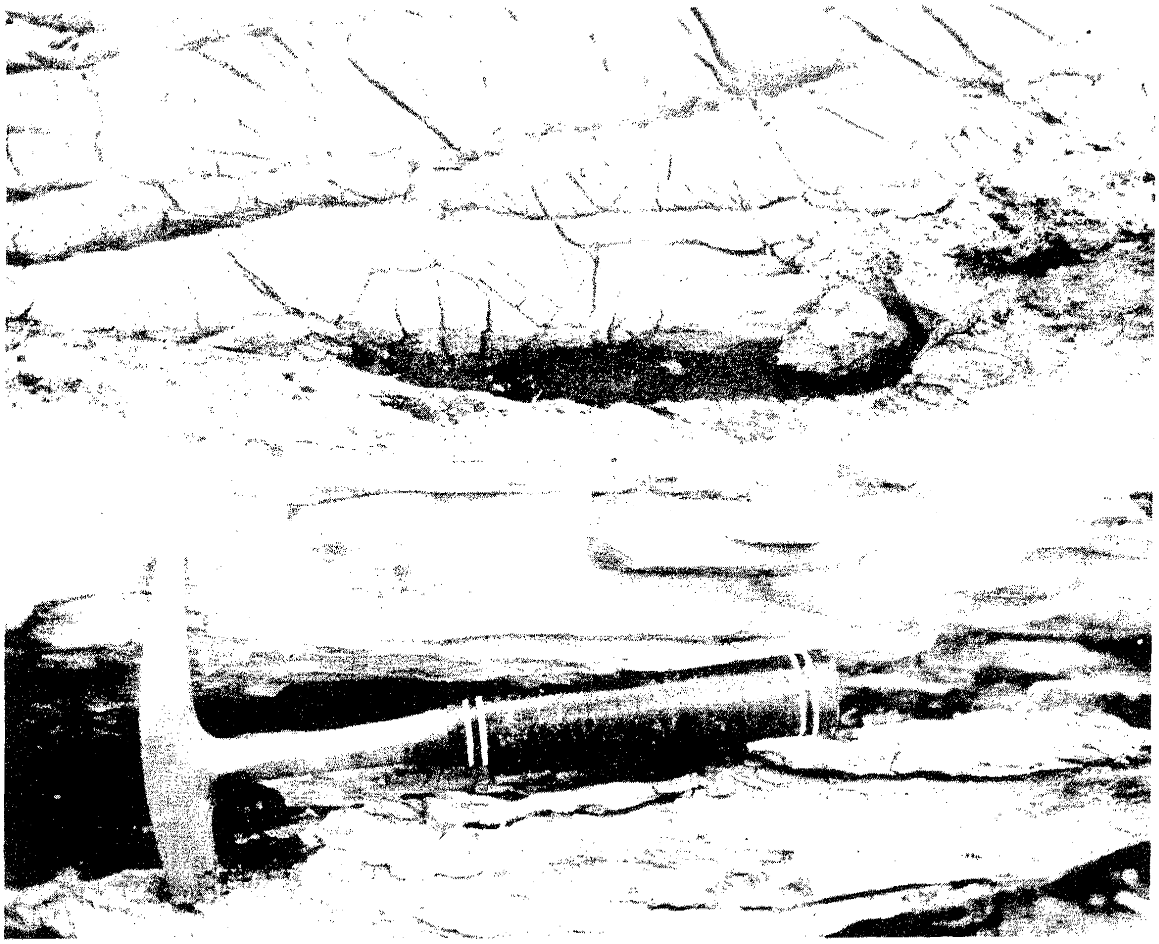


**Figure 6.** Chert mylonite in the Ontelaunee Formation. Undeformed dolomite at top of photograph, chert mylonite above the hammer, and dolomite autoclastic mélange beneath the hammer.

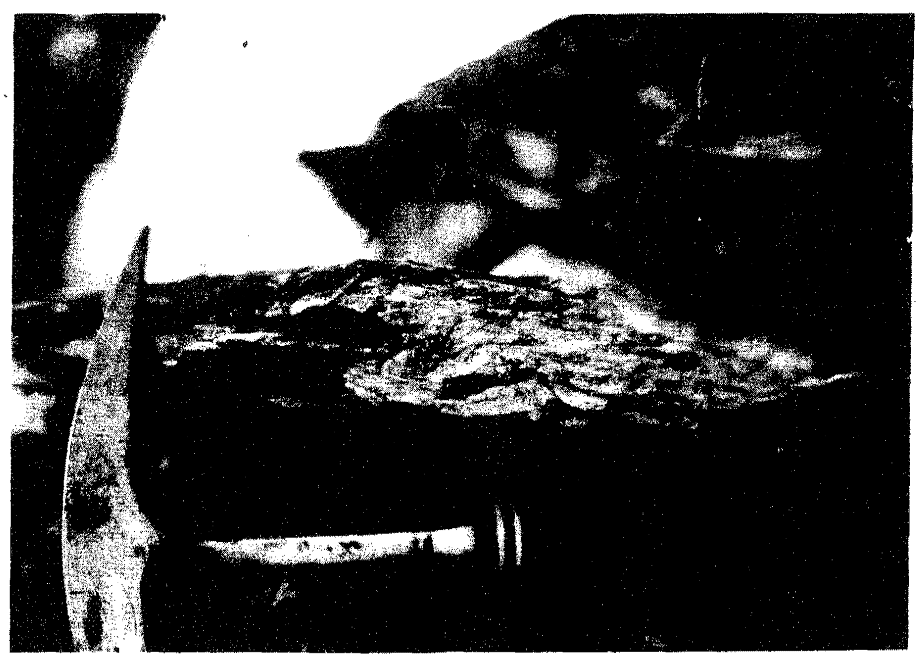
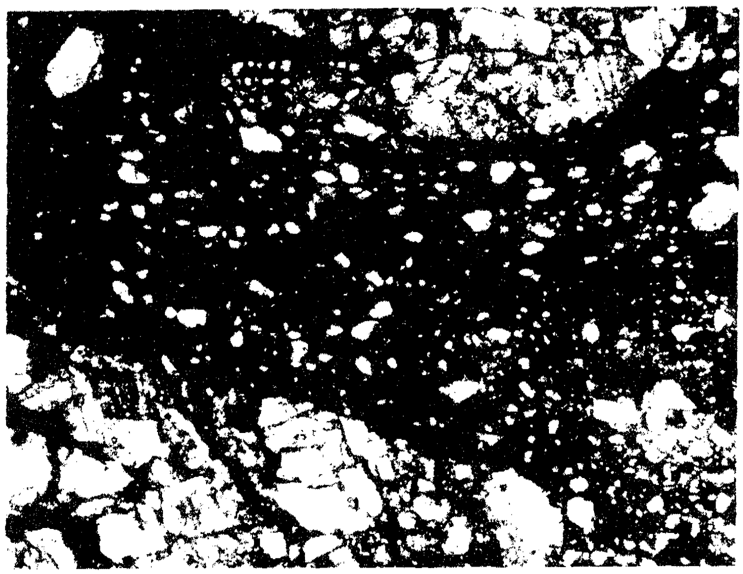


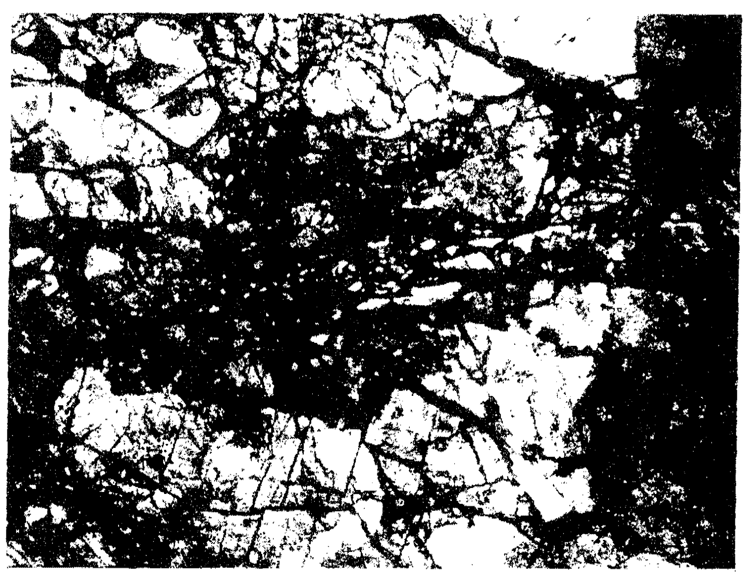
**Figure 7.** Small fold in mylonitic foliation in chert of Ontelaunee Formation. Axis plunges 15° N. 45° E.

**Figure 8.** Autoclastic mélange in Bushkill Member of Martinsburg Formation directly beneath the Hope klippe of the Jenny Jump thrust sheet. Note detached fold hinges and phacoids (tectonic fish) of graywacke swimming in the pelite sea.

**Figure 9.** Photomicrographs of Proterozoic Y mylonitized and brecciated granite—Silver Lake klippe I.



a . Large perthite and quartz crystals that have been severely strained. locally mylonitized (dark areas and stringers), and later brecciated. Scale: 1 cm on photo equals 0.5 cm.



Close up of mylonite stringer (dark band) between two large perthite crystals. The crystals and mylonite together have been brecciated. Note incipient break up of large crystal at bottom of photo. Scale: 1 cm on photo equals 0.5 cm.

0.7 Right turn at first traffic light onto Nesbit Street.

0.8 Left turn at "T" intersection (glass apartment building directly to north). Proceed straight across the intersection, going west, onto the ramp leading to the Interstate Highway 280 and the Garden State Parkway.

1.4 Alternating beds of red sandstone and mudstone with a few thin interbeds of gray siltstone and dark gray to black micaceous shale, occurring below the first overpass. These siltstones yield a probable late Norian palynoflora and occur about 1100 m below the First Watchung Mountain Basalt (Cornet and Traverse, 1975, p. 27). Sporadic exposures of sandstones and mudstones with fining-upward sequences, characteristic of meandering streams, occur along Interstate 280 for the next 4.4 miles.

2.1 Bear right for the Garden State Parkway.

2.1 Bear left for Interstate Highway 280.

5.8 Basalt of the First Watchung Mountain; contact with the underlying red beds is concealed. Note: characteristic radial columnar joint pattern.

7.3 Basalt of the Second Watchung Mountain; contact with the underlying beds is concealed.

10.3 Basalt of the Third Watchung Mountain is exposed to the south of the highway.

10.8 Passaic River Valley; the valley is underlain with glacial clays and silt that were deposited in Glacial Lake Passaic. The lake formed as glacial meltwaters were impounded betwen the New Jersey Highlands to the west and the Watchung Mountains to the south and east (see Kummel, 1940).

14.0 Termination of Interstate Highway 280. Bear left as Interstate 280 merges with Interstate 80 west.

17.0 Check point, Exit 42, Route 202 Parsippany and Morris Plains. Water tower on right is on Proterozoic (Precambrian Y) rocks of the N.J. Highlands.

17.9 Begin climb from Jurassic-Triassic Basin into the Highlands.

18.7 First roadcuts of Highlands rocks, here steeply dipping amphibolites.

23.1 Outcrops of very rusty metasedimentary biotite-quartz-plagioclase gneiss.

24.8 Exit 35 interchange to Mt. Hope and Dover. This was field area of famous Precambrian geologist Paul Sims. The ridge to right front is held up by the Silurian Green Pond Conglomerate.

26.9 Cruddy outcrops of Proterozoic gneiss.

28.0 Exit to rest area.

30.7 Lots of glacial till on left.

30.9 Large outcrop of strongly layered biotite-quartz-plagioclase gneiss of Proterozoic age on right.

32.5 Outcrops of hornblende granite of Proterozoic age.

32.8 More of same.

33.4 Exit to Route 206 South to Sommerville.

34.0 Outcrops of Proterozoic rocks.

35.0 Exit to Route 206 North. This is place where field trip route will rejoin Interstate 80 for return to Newark.

35.9 Outcrops of Proterozoic rocks.

37.3 Musconetcong River, formerly a great trout stream, now a temporary habitat for fish between hatchery and skillet.

37.8 Continuous outcrops of Proterozoic rocks on Allamuchy Mountain. These rocks are in the core of the Allamuchy nappe of the Musconetcong nappe system of the Reading Prong nappe megasystem. The rocks cropping out at the rest stop to the left and above the highway are severely deformed and contain several flat thrust faults.

39.5 Scenic overlook. If weather is fine, bus will pull off here and we will give a short briefing on the regional geology and this field trip. Looking north from this place, one has an excellent view of the Kittatinny Valley and Jenny Jump Mountain.

40.9 Allamuchy Interchange. Bold outcrops of Proterozoic rocks.

41.9 This outcrop of granite gneiss contains mafic segregations of plagioclase, epidote, garnet and magnetite surrounded by a rind of almandine garnet in a more felsic matrix of potassium feldspar, quartz, plagioclase, epidote, and accessories. Foliation appears to parallel gneissic layering and is oriented N. 45° E., 39° SE. Pegmatites are roughly parallel to foliation, but upon close inspection are seen to cut it.

42.3 Entering Bear Swamp. Rocks in this area are Allentown Dolomite of Late Cambrian age.

43.2 Nice outcrop of Allentown Dolomite. Beds strike N. 82° W., and dip 15° NE, cleavage strikes N. 55° W. and dips 22° NE, their intersection, roughly parallel to axes of small folds, plunges 14° N. 18° W. The beds face up and are probably in the upper limb of the Allamuchy nappe.

44.9 Begin the ascent of Jenny Jump Mountain, here we are crossing the trace of the Shades of Death thrust which brings rocks of the Allamuchy nappe onto rocks of the Jenny Jump klippe of the Jenny Jump thrust sheet. The Proterozoic rocks here are dominated by a sequence of marble, amphibolite, and lesser calcsilicate rock.

46.1 We have passed through the Proterozoic rocks of the Jenny Jump klippe and here enter a sequence of lower Paleozoic rocks beneath the thrust fault. Here the outcrops are Epler Formation of the Beekmantown Group of Early Ordovician age. These outcrops contain fairly abundant solution collapse breccia. Many bedding surfaces in these rocks are also thrust faults and a fair amount of carbonate mylonite has been formed. Axes of small folds plunge 5°S. 25° E. beneath the Proterozoic rocks of the Jenny Jump klippe.

46.9 Nice outcrops of Allentown Dolomite. Here we are about on the crest of an anticline which plunges 5° N. 45° E. Beds face up as shown by good algal stromatolites.

47.4 Long continuous outcrop beginning in Allentown Dolomite, Rickenbach Dolomite, Epler Formation, and Ontelaunee Formation. (See Markewicz and Dalton, this Guidebook.)

47.7 Large outcrop of sandy, mottled, laminated dolomite of the Epler Formation. The contact with the Rickenbach Dolomite is about in middle of this cut. It is placed at the contact of laminated, burrowed, mottled, finely crystalline dolomite (Epler) with thick-bedded, dark-medium-gray, medium crystalline dolomite (Rickenbach). Rock contains abundant cascade-type folds which plunge 5°-10° N. 25° E.

47.7 Crossing over N.J. Route 519.

47.9 Outcrops of Jacksonburg Limestone. Most of rock here is crystalline limestone but some beds are dark-gray, more argillaceous cement rock. Axes of small folds here plunge 20° N. 5° W. Slickensides on bedding surfaces plunge down the dip.

48.1 More outcrops of Jacksonburg Limestone.

48.4 More outcrops of Jacksonburg Limestone. A lot of conglomerate here. Outcrops to south of Interstate are Bushkill Member of the Martinsburg Formation. Slaty cleavage, which strikes N. 60° E. and dips 20° NW., is principal planar element in these rocks. The cleavage surfaces are marked by a strong extension lineation which plunges 5° N. 35° W. and crenulations which are nearly horizontal N. 70° E. Strong crenulation cleavage strikes N. 70° E. and dips 75° SE.

48.6 Leave Interstate 80 at Hope-Blairstown exit. Keep to left and turn left (south) on Route 521 toward Hope. We are driving on Bushkill Member of Martinsburg Formation. Outcrops to right are Allentown Dolomite in the large Hope klippe of the Jenny Jump thrust sheet. The dolomite beds face up, dip gently northwest, and contain abundant algal stromatolites and oolite.

49.4 Here we are at the base of the Hope klippe. The outcrop to the right is oolitic, shaly, Allentown Dolomite, probably the lowest beds of that unit. The beds dip gently to the northwest and face up.

50.1 Entering the town of Hope which is a pre-revolutionary Moravian settlement.

50.2 Outcrop on right is Leithsville Formation of Early and Middle Cambrian age. The gently northwest dipping rocks are right at the sole of the Hope klippe. They dip gently northwest, have a vague mylonitic foliation which strikes N. 45° E. and dips 18° NW., and a general mangled appearance.

50.6 Blinking light in center of Hope, continue straight on to the south. The road is now Route 519.

51.1 Outcrops on right are Jacksonburg Limestone. The rock here is well-bedded, calcarenite grainstone that contains abundant fossil hash and small scattered pebbles of dolomite. The beds strike N. 75° W. and dip 25° NE. They have a cleavage which strikes N. 55°E. and dips 15° SE.; this cleavage is marked by an extension lineation which plunges approximately down the dip. The intersection of the cleavage with the bedding plunges 7° N. 88° E. These rocks are *autochthonous to the Jenny Jump thrust sheet* and belong to an as yet unnamed tectonic element of the Musconetcong nappe system of the Reading Prong nappe megasystem.

51.5 Outcrop on right is Ontelaunee Formation of Beekmantown Group. This is Field Trip Stop 2 to which we will return.

52.0 Swayze Cemetery on right.

52.1 Turn left on Lake Just-It Road.

52.3 Bridge (6-ton limit) over Beaver Brook.

52.4 Poor outcrop of Allentown Dolomite on lawn on the right. Abundant, excellent outcrops of Allentown on wooded knoll to to the east.

52.9 **STOP 1:** Jenny Jump klippe of Jenny Jump thrust sheet;. speaker, Peter Lyttle. (Field trippers will disembark, bus driver will take bus to top of hill to Hissim Road to turn around. He should wait there for 30 minutes, and return down the hill to pick up the field trip in front of the house at the base of hill.)

We are on the northwest edge of the main mass of the Jenny Jump thrust sheet on the northwest side of Jenny Jump Mountain. The Proterozoic rocks we will be looking at here are primarily hornblende granite gneisses with minor fine-grained mafic dikes. These rocks structurally overlie the lower Paleozoic rocks of the valley that we have just driven through. Although the Jenny Jump thrust is nowhere exposed, there are several locations along the north side of Jenny Jump Mountain where outcrops of Paleozoic carbonate with structures dipping to the southeast occur within a few tens of meters of the Proterozoid gneisses. It is clear in map pattern (see Figure 4) that the Jenny Jump thrust truncates both contacts and structures in Paleozoic rocks.

In order to see all of the structures mentioned below, it is necessary to hike a hundred meters or so along the side of Jenny Jump Mountain in this area of semi-continuous outcrop. Almost all of the structures can be seen in several places and the diligent tripper should be able to find them all on his/her own. The most important structure to note at this outcrop is well-developed foliation that is, in most places, parallel to compositional layering and is axial planar to the rarely observed earliest isoclinal folds that are presumably Grenville in age. This foliation is seen in both the gneiss and mafic dikes. The orientation of the dikes appears to roughly parallel the foliation, but can by at an angle to compositional layering, indicating that the dikes intruded either during or before this early folding episode. This foliation is folded by a later event interpreted to be the emplacement of the Jenny Jump thrust sheet. Over most of Jenny Jump Mountain the foliation strikes roughly N. 60°E. and dips 30-40° to the southeast. However, at several places along the northwest edge of Jenny Jump Mountain, it is common to find the foliation folded by large, open, upright to slightly overturned folds.

There has been considerable slip on many foliation planes (evidenced by slickensides) and if the rocks at this outcrop are not wet or in the shade, the field tripper will note many narrow zones of mylonite that are roughly parallel to the foliation. Locally, these zones of mylonite are brecciated. These outcrops are very near the sole of the Jenny Jump thrust sheet and it is likely that the mylonitization and brecciation are related to the emplacement of the thrust sheet.

In one area of these outcrops, a thin mafic dike is cut by numerous small-scale thrusts spaced 3-10 cm apart. The sense of movement is always toward the NNW.

The gneisses here are quite magnetic, the magnetite probably being produced with chlorite at the expense of hornblende. Very little fresh hornblende is seen in thin section. Quartz, microcline oligoclase, minor hornblende and magnetite, and accessory zircon and apatite make up the bulk of the gneisses. The oligoclase and hornblende are commonly altered, and the quartz is highly strained and occurs in long sheared out stringers.

53.5 Bridge over Beaver Brook

53.7 Turn right on Route 519

54.2 **Stop 2:** Bedding-parallel faults in the Ontalaunee Formation; speaker, Peter Lyttle. (Driver pull bus onto turnout on left side of road.)

This will be a very quick stop to illustrate bedding-parallel shear and mylonitization in the Lower Ordovician Ontalaunee Formation. Other outcrops show this more extensively, but this outcrop is logistically more feasible for this field trip. Although pressure solution is the dominate deformation mechanism producing tectonic shortening in the carbonate rocks of the Great Valley, both the rocks within and tectonically beneath the Jenny Jump thrust sheet exhibit extensive faulting parallel to bedding. This shearing is commonly, though not exclusively, concentrated in chert-rich zones within dolomites. The chert need not be in continuous beds. Zones of nodular chert and very thin stringers appear sufficient to provide a contrast or inhomogeneity in rock strength sufficient to concentrate shearing within these areas.

Although this stop has well-developed zones of mylonite concentrated along chert zones that have behaved ductilely and show small drag folds (see fig. 7), other outcrops show a transition from brittle to ductile structures in these zones. This transition is achieved through a continual change in the mechanical properties of the rock probably because of the reduced grain size, water weakening or localized frictional heating rather than changes in external parameters such as external temperature and confining pressure. Initially, the dolomite and chert together form a breccia with pieces of dolomite ranging in size from 1-15 cm and pieces of chert ranging in size from 1 mm to 5 cm. Continued shearing pulverizes the chert which then acts as a fine-grained matrix surrounding pieces of dolomite which are still angular and recognizable, yet smaller, pieces of dolomite. At this stage the rock has a "frothy" appearance and the chert has lost its black translucence. More shearing produces a mylonite, such as the example at this stop (see fig. 6), and there are no longer any recognizable pieces of dolomite. Everything has been finely comminuted and the rock has a fluxion structure. At this outcrop the fluxion structure is folded into small drag folds.

It is important to realize that the fluxion structure or "cleavage" developed in these zones does not represent regional cleavage. The orientation of the "cleavage" or mylonitic foliation in these shear zones is related to the original attitude of the chert zones and is parallel to the shear zones. Regionally, this "cleavage" is best developed in narrow shear zones in and immediately beneath the large scale thrusts and is essentially parallel to these thrusts. The Jenny Jump thrust was slightly above the present erosional surface at this stop and may have caused the subsidiary thrusting and mylonization at this locality.

The Ontelaunee Formation at this stop is very finely to finely crystalline, light to medium gray, medium- to thick-bedded dolomite with thin beds of chert. Fabric information: bedding N. 67° W. 15° NE; extension lineation 13° S. 38° E; fold axis in mylonite 14° N. 48° E.; joints N. 85° E. 67° SE. and N. 15° E. 15° SE.

54.7 Outcrop at Jacksonburg Limestone on left.

55.0 Entering town of Hope.

55.3 Turn left on Union Street at flashing light and pass St. Luke's Episcopal Church on the left.

55.45 Turn right on Mt. Hermon Road toward Mt. Hermon and Vale (Methodist and Moravian Churches on left mark turn).

55.6 Bridge across Brookaloo Swamp.

55.8 Sole of Hope Klippe. Outcrops of Allentown Dolomite on the left. Beds strike N. 75°., and dip 25° NW. Rocks face up as shown by abundant algal stromatolites.

56.05 Outcrops of Allentown Dolomite on left. Here there are dolorudite beds and orthoquartzite lenses. Big, rounded bedding surfaces suggest algal stromatolites but internal ornamentation is not obvious.

56.6 Outcrops of Allentown Dolomite on right. Rock here is mostly oolite with some oolite matrix conglomerate.

56.7 Outcrops of oolitic Allentown Dolomite on right. Rock has strongly developed extension fractures which strike N.48° E. and dip 65° NW.

57.0 Enter town of Mt. Hermon.

57.13 Cross small stream which follows a steep normal fault which fragments the Hope klippe in this area.

57.25 Cross small stream which marks the northwest border of Hope klippe.

57.2 **STOP 3:** Hope klipppe of Jenny Jump thrust sheet; speaker, Avery Drake. (Park in Methodist Church parking lot on right, unless church services are being held; if services are being held, park on left side of street near Honeywell Hall.)

Here we are on the Bushkill member of the Martinsburg Formation at the northwest border of the Hope klippe. The bounding thrust fault lies in the stream a short distance to the southeast, and carbonate rocks of the klippe crop out on the ridge to the southeast of the streams. The klippe here has been fragmented by a later normal fault which has brought rocks of the Epler Formation into contact with the Bushkill. We will first observe rocks of the Bushkill on the slope to the southeast of Green Chapel Cemetery. The Bushkill here is very disturbed. In the fall of 1978 the following fabric elements could be measured: bedding, N. 30° E., 65°SE. (inverted); slaty-cleavage, N. 20° E., 40° SE.; and pseudo-slaty cleavage, N.38°E. 52°SE.; strainslip cleavage, N. 50°. 45° NW.; intersection of bedding and slaty cleavage and pseudo-slaty cleavage, 20° S.55° W., crenulations, 16° N. 36° E.; extension lineation on slaty cleavage,38°S. 50° E.; and a joint, N. 60° W. 60° SW. There are many folds in bedding, but the details have not been worked out. The pseudo-slaty cleavage is thought to result from the emplacement of the Jenny Jump thrust sheet. At this place the planar elements, save the strain-slip cleavage which results from post-klippe emplacement folding, dip beneath the carbonate rocks and the extension lineation plunges beneath them. Bushkill is also exposed in pavement outcrops in the secondary road to the southwest of the Mt. Hermon Road.

After observing the Bushkill, we will examine the outcrops of Epler on the ridge to the southeast. The rock there is finely crystalline to medium crystalline, light gray to medium-gray dolomite which contains thin partings, lenses, and very thin beds of orthoquartzite. The outcrop contains abundant solution collapse breccia. Many of the blocks in the breccia are quite large. Bedding in the outcrop is N. 45° E. 38° NW. A poor fracture cleavage has the altitude N. 10° E. 55° SE. Return to bus and continue northwest on Mt. Hermon road.

57.5 Turn right on Union Brick Road.

57.75 Outcrop of Ramseyburg Member of Martinsburg Formation on the left.

57.90 Overpass above Interstate 80.

58.1 Poor outcrops of Ramseyburg on the right.

58.3 More poor outcrops of Ramseyburg on the right.

58.5 Small pond on right. Geology along here is obscured by ground moraine.

59.2 Continue straight on to northeast, avoid left turn.

59.8 Small pond and Union Brick Cemetery on the left.

59.85 Turn right on Heller Hill Road.

60.3 Outcrops of Ramseyburg on left.

60.5 Continue straight on to south, avoid right turn onto Turpin Road.

60.65 Bridge over small brook.

60.75 Stop sign at T-intersection. Turn left on Hope Road. Mangled outcrops of Allentown dolomite of Hope klippe on the left. Continue north .15 mile distance and pull into turn-off on right.

60.90 **STOP 4:** Northwest boundary of Hope klippe; speaker, Avery Drake.

Here rocks of the Bushkill Member crop out in a cut at road level and carbonate rocks of the klippe crop out on the hill above. This is not a good exposure of the Bushkill, but it is extremely important as the rock here is an autoclastic tectonic mélange. Careful observation will reveal phacoids, "tectonic fish" of graywacke and slate, some of which are fold hinges, within the mangled slate matrix (see fig. 8). PLEASE NO HAMMERING OR PLUCKING OF "TECTONIC FISH." There are at least two flat cleavages interlacing within this outcrop, presumably the slaty and pseudo-slaty cleavages viewed elsewhere. The prominent foliation in this outcrop is due E. 10° S.

Here the carbonate rock of the klippe is Allentown Dolomite. The outcrop has a jumbled appearance and bedding is difficult to determine but seems to be about N 10° W., 10° NE. Most of the rock is rather nondescript crystalline dolomite, but there is a fair amount of dolarenite and some oolite, desiccation dolorudite, and dark-gray chert lenses and skims. In addition, some curved forms without internal ornamentation are suggestive of algal stromatolites. It is quite clear at this stop that the carbonate rocks of the klippe lie above the Bushkill. Reboard the bus and continue northeast on Hope Road.

61.05 Turn right on Mud Pond Road (10,000 pound limit). This road essentially follows a normal fault which has fragmented the Hope klippe in this area, carbonate rocks of the klippe on the right, Martinsburg on the left. Carbonate rock for first .2 mile along road is Rickenbach Dolomite.

61.35 Mangled outcrops of Allentown Dolomite on right.

61.40 Outcrops of severely mangled Martinsburg. Rock here is an autoclastic mēlange consisting of phacoids and lenses of graywacke and slate "swimming" in slate. Extension lineation plunges essentially down the dip of the principal foliation. The klippe sole here lies a few feet up the hill to the right.

61.5 Small pond on left.

62.6 Good pavement outcrop of Bushkill on the left.

62.8 T-intersection. Turn left.

62.9 Ramseyburg outcrop on the left.

63.0 T-intersection. Turn right on Ridgeway Avenue. Outcrops of slate containing a few thin graywacke beds at intersection.

63.05 Bridge over small stream. Bus will go a short distance farther and disembark the field trippers. It will then continue south on Ridgeway Road and turn around wherever possible, and return for the field trip in about 1/2 hour.

62.0 Cooks Pond on the left. Outcrop of cherty, laminated, finely crystalline medium-dark-gray dolomite of the Epler Formation on the right. This carbonate rock constitutes the small Cooks Pond klippe.

62.2 Turn right on Cook Road. Outcrops of Bushkill slate at intersection.

63.2 **STOP 5:** Silver Lake I klippe; speaker, Peter Lyttle.

The Silver Lake I klippe is a tiny erosional remnant of the Jenny Jump thrust sheet that contains a strongly deformed and perhaps highly telescoped section of Proterozoic granite and Lower paleozoic dolomite (probably Cambrian Leithsville Formation). Although the two or three outcrops that we will examine at this stop may at first glance be a little disappointing, this single locality records much of the tectonic history that we are trying to present on this field trip. We will look at a small ledge of Proterozoic granite that records an early tectonic event of high strain, local mylonitization, and retrograde metamorphism. This first event is interpreted to have occurred during the Taconic orogeny. Later, these same rocks were severely brecciated and comminuted, but not recrystallized (see fig. 9) photomicrograph. Although most of the rock consists of quartz, perthite, and plagioclase, there are minor amounts of magnetite and chlorite that appear to be alteration products of a mafic mineral, probably hornblende. All the minerals, particularly the perthite and quartz are highly strained, brecciated and rotated and severely reduced in grain size. These later structures are interpreted to have been produced during emplacement of the Silver Lake I klippe as part of the much larger Jenny Jump thrust sheet in Alleghanian times.

This small klippe structurally overlies the Middle Ordovician Bushkill Member of the Martinsburg Formation. After the bus picks us up we will head back north along this road passing an outcrop of the Bushkill at the first intersection. At this locality the slaty cleavage dips southeast under the Silver Lake I klippe. South of Stop 5 near Camp Hope (approximately 1/2 mile) the slaty cleavage in the Bushkill dips consistently to the northwest. Therefore, the klippe is sitting in a broad synfromal trough of the slaty cleavage. Although it is impossible to prove at this stop, the emplacement of the klippe postdates the formation of the slaty cleavage. We will establish this to the satisfaction of the sceptical field tripper at the last stop of the day, the Grand Union klippe.

The only structures recorded at this stop are a fairly flat mylonitic foliation, N. 16° E. 18° NW. and a steeper and later cleavage N. 78° E. 50° SE. These were both measured (with difficulty) in the highly weathered Proterozoic granite. The pervasive rusty weathering was probably facilitated by the extensive brecciation along the later fracture cleavage. The tiny outcrop of dolomite fractures in a rectilinear fashion no matter how small the pieces become. This may be related to the late fracture sets.

63.4 T-intersection. Turn right.

63.9 Small outcrops of Ramseyburg on left.

64.1 House with small pond on left.

64.25 **STOP 6:** Ebenezer klippe; speaker, Avery Drake (At about the Ebenezer sign, the bus will pull off to the right and allow field trippers to disembark. The bus will continue up hill to intersection with Lake Wasigan Road and park. Field trippers will walk up hill examining the outcrops. This will be the lunch stop.).

The first outcrop to examine is just to the north of the small stream. The rock here is Ramseyburg Member of the Martinsburg Formation. Fabric elements measured here in the fall of 1978 include: bedding, N.52° E. 25° NW.; slaty cleavage, N. 48° W. 5° NE.; strain-slip cleavage, N. 25° E. 20° SE,; a joint, N. 44° W. 70° SW.; intersection of bedding and slaty cleavage, 7° N. 48° E.; and extension lineation, 3° N. 35° W. The reader will note that here the bedding, slaty cleavage, and extension lineation have been rotated from their normal southeast dips and plunge so as to dip and plunge beneath the carbonate rocks to the north.

The last outcrop of Ramseyburg is about 400 feet to the north and the first outcrop of the carbonate rock of the klippe is about 375 feet north of there. The rock of the klippe is Allentown Dolomite. There is a particularly good outcrop of Allentown about 225 feet farther north which contains all the characteristic rock types of that unit: algal stromatolites, oolites, dessication dolorudites, etc. The sedimentary structures show that the carbonate rocks face up. The subtle field trippers will have noted that Ramseyburg crops out about 30 feet to the south of this Allentown outcrop for a length of about 20 feet showing that the klippe here, like the Hope klippe, is fragmented by later normal faults. The beds in the Ramseyburg clearly dip beneath the carbonate rocks of the klippe. There are additional good outcrops of Allentown along the road to the east of Lake Wasigan.

We plan to have lunch around Lake Wasigan. This is far from a perfect place, but our choices are limited. Following lunch, board the bus.

64.65 Turn left on Lake Wasigan Road. Lake Wasigan is to the front.

64.9 Continue straight, avoid left turn. Inverted Bushkill slate crops out on the left.

65.3 Pass under tracks of Erie-Lackawana Railroad. Excellent outcrop of Ramseyburg on the left. Some beds here are more than 1 m thick.

66.2 Turn left on Route 94 toward Blairstown. Outcrops of Ramseyburg on left.

66.55 Village of Paulina. Rocks here are Martinsburg Formation in the Musconetcong nappe system.

66.75 Crossing small stream. We will cross the trace of the Portland thrust fault within a few feet. Here the slaty cleavage in the Martinsburg is marked by a strong extension lineation which plunges down the dip. The Portland thrust fault frames the very large Paulins Kill window.

66.85 Large outcrops of Allentown Dolomite. These rocks are in the Lyon Station-Paulins Kill nappe which is exposed in the Paulins Kill window.

67.0 Intersection with Hope Road. Avoid left turn and continue west on Route 94. Allentown Dolomite crops out up Hope Road to the Left.

67.1 Route 602 joins Route 94. Avoid left turn and continue west on Route 94.

67.27 Bridge over Paulins Kill.

67.3 Very sharp right turn onto Route 521 North (Stillwater Road). Here Route 521 roughly parallels the Paulins Kill. The Blairstown Ambulance Corps is on the right.

67.5 Blairstown School on the right.

67.75 Outcrops of Allentown Dolomite in Lyon Station-Paulins Kill nappe on right. Rock is severely deformed, most bedding surfaces have served as fault surfaces. Outcrop is characterized by very abundant filled, northeast-trending extension fractures.

68.0 Continue straight on Route 521 (Stillwater Road), avoidvery sharp left turn.

68.15 Turn right on unnamed road and proceed down steep hill. Small outcrop of Allentown Dolomite on knoll to right.

68.2 Small pond to left front.

68.45 Bridge over small stream. Small pond on left.

68.65 Small pond on left. Small outcrop of Allentown Dolomite on right.

68.8 Outcrop of very sandy Allentown Dolomite on right. There are abundant orthoquartzite beds here.

68.9 Large outcrops of Epler Formation on the left. Rocks here include laminated sandy dolomite, laminated dark-gray dololutite, chert-ribbed finely crystalline dolomite, sandy medium to medium-coarse crystalline limestone, and excellent examples of solution collapse breccia. Axes of small folds here plunge 70° S. 15° W., down the dip of the beds.

69.1 **STOP 7** Portland thrust fault; speaker Avery Drake (Field trippers will disembark and examine outcrops along road to left. Bus will have to find some means of turning around. There is a small parking area along road to left. This stop is just above the abandoned grade of the New York Susquehanna and Western Railroad. This is a very narrow road and field trippers must use extreme caution.)

The first outcrop to observe is 500 feet along the road to the east. Here are slate outcrops of the uppermost Bushkill Member of the Martinsburg Formation. The slate contains abundant thin beds of graywacke. Fabric elements include: bedding, N. 85° E. 48° SE.; slaty cleavage, N. 72° E. 68° SE.; and intersection of bedding and slaty cleavage, 35° S. 55° W.

The Portland thrust fault crops out about 375 feet farther to the east. The observations recorded here were made in October 1978 shortly after the road was widened. Winters are particularly hard on exposures in this area and no guarantee can be made as to what the quality of the exposure will be at the time of the field trip. In any case, the Portland fault was found to have the attitude of N.78° E. 48° SE. and the slate above the fault to the east an attitude of N. 80° E. 55° SE. The carbonate rock beneath the fault is thoroughly tectonized. It is mostly medium crystalline, medium-gray dolomite that contains some solution collapse breccia, flat-pebble conglomerate, and dark gray sparr calcite. Judging from stratigraphically lower outcrops of extremely cherty dolomite up the hill to the north, this rock probably belongs to the Ontelaunee Formation. The dolomite contains several movement zones beneath the major thrust which are marked by carbonate mylonite. Extension lineations on the thrust surface plunge 45° S. 38° E. Post-thrust strain-slip cleavage has the attitudes of N. 80° E. 40° NW., and post-thrust crenulations plunge 10° S. 70° E. There are outcrops of both Ontelaunee and Epler along the road to the east and excellent outcrops of Epler up the hill to the north. We may examine some of these rocks depending on available time. (Board buses and follow unnamed road back up the hill to the north.)

70.1 Turn left on Route 521 (Stillwater Road) to return to Blairstown.

70.25 Keep to left on Route 521. Avoid right fork.

71.0 At flashing red light make very sharp left turn onto Route 94 and follow to east toward Newton.

71.6 Crossing the trace at the Portland thrust fault, the frame of Paulins Kill window.

72.2 Junction with Wasigan Road, continue east on Route 94.

72.4 Outcrop of inverted Bushkill slate at road intersection on the right.

72.9 Nice outcrops at Ramseyburg on the right.

73.2 More nice outcrops at Ramseyburg. Sedimentation sequences in these rocks begin with a cross-laminated interval which pass up into a planar laminated interval which is overlain by pelite. They are, then $T_{cde}$ turbidites and belong to turbidite Facies D of Walker and Mutti (1973). The cleavage in these rocks is marked by an extension lineation which plunges 35° S. 15° E.

73.9 Entering Village at Marksboro.

74.4 Very small pond on left.

80.0 Turn right up hill toward Johnsonburg. Outcrops of Bushkill slate on left past intersection. Cleavage here is marked by an extension lineation which plunges 20° S. 48° E.

80.3 Outcrops of Bushkill slate on the right. Extention lineation on cleavage here plunges 34° S. 25° E.

80.7 Farm with three small fish ponds on the right.

81.1 Rickenbach Dolomite in the small Alpha Klippe crops out to the left. Allentown Dolomite in the even smaller Beta Klippe crops out in the woods about .25 miles to the east-northeast. Both these klippen rest on Ramseyburg and are shown but not labeled on figure 1.

81.3 Stop sign at crossroads. Continue on to south. Just to south at crossroads there is a small dammed stream and pretty house. Rock is Bushkill.

81.5 Underpass beneath Erie-Lackawanna Railroad. (Immediately south of this underpass bus will pull off to right and field trippers will disembark. Bus will have to continue south to Johnsonburg and turn around. This will be an hour stop.)

**STOP 8:** Federal Springs thrust fault; speaker, Avery Drake. (Follow path to left of stop to reach the grade of the Erie-Lackawanna Railroad. Be extremely careful on the railroad grade, there are occasional trains. Follow railroad grade about 600 feet to west.

Here are beautiful outcrops of interbedded slate and thin graywacke of the upper Bushkill member of the Martinsburg Formation (see fig. 2). The Ramseyburg Member crops out along the road about 700 feet north of these outcrops. The rock in this outcrop is inverted as shown by sedimentary structures. Fabric elements are: bedding, 50° W. 45° SW.; slaty cleavage, N 70° W, 35° SW.; intersection of bedding and slaty cleavage, 20° S, 35° E., and extension lineation, 28° S. 38° E. Here, the bedding-cleavage intersections which are roughly parallel to the local fold axes plunge southeast beneath the Federal Springs klippe about parallel to the direction of transport as shown by the extension lineations.

Next, the field trip will turn around and follow the railroad tracks to the east. About 400 feet east of the overpass there are horribly mangled outcrops of Bushkill not very far beneath the Federal Springs thrust fault. The field trippers can sort out structures here at their pleasure. The Federal Springs thrust fault crops out about 500 feet farther to the east. The geologic relations at this site are quite complex as it is essentially a quadruple point between Epler Formation, Ontelaunee Formation, Jacksonburg Limestone, and Bushkill Member of the Martinsburg Formation. The Federal Springs thrust fault brings rocks of the Beekmantown Group and Jacksonburg Limestone onto the Bushkill. Two units occur within the Beekmantown here. The lower unit, the Epler Formation consists of very earthy, silty, finely crystalline dolomite that has silty partings, limey dolomite, and some limestone. The Elper is overlain by a unit of medium-gray, medium- to coarsely-crystalline dolomite which based on our experience in Pennsylvania, we assign to the Ontelaunee Formation.

The Jacksonburg Limestone appears to uncomformably overlie both Beekmantown units in these exposures. The Jacksonburg here is a small tectonic sliver of dark gray, shaly cement rock. A sample of this rock contained a poor conodont fauna which, according to John Repetski (written commun., 1979) included the following:

2 drepanodonti form elements, indeterminate, deformed
1 paltodonti form element A
1 paltodonti form element B

Another tectonic sliver of Jacksonburg crops out along the Federal Springs fault about 1100 feet N. 63° E. from this site. The Jacksonburg here is a radically different rock type, being medium-grained calcarenite grainstone. A sample from this site contained as, identified by John Repetski (written commun., 1979) the following conodont fauna:

PANDERODUS
PHRAGMODUS UNDATUS Branson and Mehl
dichognathiform elements
oistodonitform elements
phragmodontiform elements
PLECTODINA
cyrtoniodontiform (N) element

This rather nondiagnostic microfauna ranges from the Rocklandian to upper Richmondian. The conodont color alteration index (CAI) of the elements in this sample is 5, indicating host rock temperatures greater than about 290°C.

The structure above the Federal Springs thrust is quite complex. At the end of the railroad cut about 550 feet to the east of the fault, Epler crops out at track level. About 65 feet west of this point Ontelaunee is at track level, and about 250 feet farther west Epler comes back down to track level. This rock distribution defines a very tight fold which plunges about 35° N. 70° E. Small early folds within this part of the outcrop plunge 35° S. 47° E., essentially parallel to the extension lineation within the Epler. These folds have an S rotation sense when viewed in profile showing that this is an inverted limb. Other fabric elements here include: steep fracture cleavage, due N., N. 80° E.; pressure solution veins which plunge 40° S., 20° E., and opens buckle folds in bedding which plunge 10° N. 75° E.

Just at the Federal Springs thrust which trends northeast and at these places dips rather steeply, the Jacksonburg Limestone is transposed and the transposition foliation is folded with the rocks of the Beekmantown Group. The fabric elements within the Jacksonburg include: the transposition foliation, N. 25° E., 52°NW.; intersection of bedding and slaty cleavage 40° N. 20° W., extension lineation on the transposition foliation, 48° N. 40° W.; and axes of small folds in the transportation foliation 10° S. 45°W. The lineation formed by the intersection of bedding and cleavage streams around the fold hinge directly above the thrust.

Folds such as those above the thrust are not obvious in the slates of the Bushkill beneath the thrust. The fabric elements in the slate include: bedding, N. 75° E. 35NW. (sedimentary structures show that the rock faces up); slaty cleavage, N. 5° W. 35° SW.; fracture cleavage, N. 75° W. 40° SW.; and axes of small folds in slaty cleavage 12° S. 60° W. A wide variety of structures can be observed in the Bushkill to the west of the thrust and the interested observer can observe these at his/her leisure.

(Following the observations of the Federal Springs thrust, the field trip will return to the bus, board it, and retrace the field trip route north along the unnamed road toward Route 94.)

81.7 Stop sign at crossroads. Continue north.

83.0 Turn right and follow Route 94 to the east. Immediately on the right are outcrops of Bushkill.

83.2 More outcrops of Bushkill on right.

83.9 Entering Tranquility 7 1/2-minute quadrangle.

84.0 Junction with Johnsonburg Road. Continue east on Route 94. Small outcrop of Bushkill on left.

84.95 Junction with Yellow Frame Road. Yellow Frame Cemetery on right. We have just crossed Sussex County line.

85.25 Enter Newton West 7 1/2-minute quadrangle. There is a good view of Hunts Pond to the right front. We have done no geologic mapping in this area.

85.85 Pavement outcrops of Bushkill on the left.

86.2 Excellent Bushkill outcrop on the left.

86.6 Bushkill outcrop to right, small pond to left.

87.0 Road junction. Continue following Route 94 to the east. Bushkill outcrops on the left.

87.5 Outcrops of Bushkill on the left. Here, the slaty cleavage has been rotated past the horizontal and dips northwest. Route 94 is roughly paralleling the geologic strike in this area.

88.6 Fredon Township School. Continue east on Route 94.

89.1 Paulins Kill Lake Road on left. Continue east on Route 94.

89.5 Springdale Road on right. Continue east on Route 94.

91.3 Entering town of Newton.

91.6 Entrance to Newton Memorial Hospital on the left.

91.7 Scattered outcrops of Bushkill along here. Slaty cleavage dips to the northwest.

92.2 Keep to the left staying on Route 94.

92.4 At the Sussex County Courthouse begin going around the town square.

92.45 Turn left. This is combined Route 206 North and Route 94. From this point, follow signs for Route 206 North toward Vernon and Milford.

92.5 Turn left again at red light and continue around the square.

92.55 Back at Sussex County Courthouse. Turn right and follow Route 206 North.

92.85 Enter Newton East 7 1/2-minute quadrangle.

93.00 Outcrops of Martinsburg Formation on the left.

93.6 Turn left into Newton County Mall and drive to northeast end and park to right at Shepards Family Fashions. Field trip stop is to rear of this building.

**STOP 9:** Grand Union klippe; speaker Avery Drake.

This klippe is a relatively small slab of Allentown dolomite which lies on rocks of the Ramseyburg Member of the Martinsburg

**Figure 10.** Grand Union klippe of Allentown Dolomite (light-colored rock) overlying Ramseyburg Member of Martinsburg Formation. The Jenny Jump thrust (middle of photograph) about parallels bedding in the Allentown and is marked by gouge and crushed dolomite. Note the essentially vertical bedding in the Ramseyburg in the right part of the photograph and the gently northwest (left) dipping slaty cleavage.

Formation. The thrust fault beneath it (fig. 10) was well exposed during excavation for this shopping center. The thrust fault, thought to be the Jenny Jump thrust fault, is roughly parallel to the bedding in the Allentown N. 50°, E. 40° NW., and is marked by 1 to 3 inches of gouge as well as by a fair amount of crushed dolomite. The rocks of the klippe face up as is clearly shown by abundant algal stromatolites.

The rocks of the Ramseyburg beneath the thrust are isoclinally folded. The fold trains have a (zigzag) "M" pattern suggesting that the rocks occur in a fold hinge. Bedding immediately adjacent to the thrust is N. 35° E. 65° NW., and it approaches vertical several feet to the southeast (Fig. 10). Slaty cleavage is N. 20° E. 35° NW., has been rotated past the horizontal, and is truncated by the thrust. These data and their geometric relations suggest that the Ramseyburg here is in the brow and upper limb of a northwest-closing recumbent fold. The slaty cleavage is marked by an extension lineation which plunges 39° N. 55°W. and extension fractures are N. 38° E. 85° SE.

Close examination of the Ramseyburg shows that it, like other Martinsburg we have seen in exposures beneath the Jenny Jump thrust, is an autoclastic mélange. Here, most of the graywacke beds have been pulled apart and fragmented and swim as autoclasts in a more slaty matrix.

Two sets of small faults can be seen in the Ramseyburg. One set is N. 52° E., 40° NW. and has pressure solution veins which show left-separation. The other set is N. 50° E. 80° NW. and shows normal-separations.

This exposure is extremely important as it clearly shows that a klippe of the Jenny Jump thrust sheet was emplaced subsequent to major deformation and slaty cleavage development in rocks of the Martinsburg Formation. This klippe, like the others we have seen, lies in a synform in the slaty cleavage of the Martinsburg. (Following this stop, board the bus, and return to Newton on Route 206. As the town square is reached (marked) by Sussex County Courthouse, stay in left lane.)

95.05 Directly in front of Courthouse turn left sharply following Route 206 signs. Immediately get into right lane.

95.1 At stop light, turn right toward Netcong (an Armed Forces Recruiting Center is dead ahead when at stop light).

95.3 First Baptist Church at Newton on right. Veer slightly left staying on Route 206 South.

96.3 Large outcrops of Allentown dolomite on right. This rock is in the Allamuchy nappe.

98.1 Village of Springdale. Junction of Route 206 with Greendell-Tranquility Road. Veer left and continue south on Route 206.

98.6 Good outcrops of Allentown Dolomite on left.

98.8 Outcrops of Allentown Dolomite on the right.

99.4 Whites Pond on left.

99.6 Approximate common corner of Newton West, Newton East, tranquility and Stanhope 7 1/2-minute quadrangles.

100.0 Outcrops of Allentown Dolomite behind the Rustic Wine Cellar. This is in the Stanhope 7 1/2-minute quadrangle.

100.1 Outcrops of Allentown Dolomite on both sides of road.

100.25 Crossing tracks at Lehigh and Hudson Railroad.

101.0 Stop light at junction of Route 206 and Route 517. Continue south on Route 206. This is in village of Andover. Andover Ponds are to left front.

101.4 Tranquility - Hackettstown Road (Route 517 South) goes off to right. Keep left and follow Route 206 to the south.

101.8 Pass under tracks of Delaware, Lackawanna, and Western Railroad.

102.2 Proterozoic rocks at the Allamuchy nappe crop out to the right. The allochthonous nappe-nature of the tectonic unit was confirmed in this area by diamond drilling by the New Jersey Zinc Company (Baum, 1967).

102.25 More outcrops of Proterozoic rocks on the left. We will remain in these rocks until we rejoin Interstate 80.

102.6 Outcrops of hornblende granite. This is Bryam Township, the type area of the so-called Bryam Gneiss.

103.5 Cranberry Lake on the right.

105.9 Stoplight. Junction of Route 206 with road to Waterloo. Continue south on Route 206.

106.7 Keep right on Route 206. Avoid going left on Route 46. Begin to watch for Interstate 80 signs.

107.5 Pass under Interstate 80. Route 206 merges with Interstate 80. End of field trip. Continue east on Interstate 80 and return to Rutgers-Newark parking lot via Interstate 80, Interstate 280, Garden State Parkway, Nesbit Street, Orange Street, High Street, and Warren Street.

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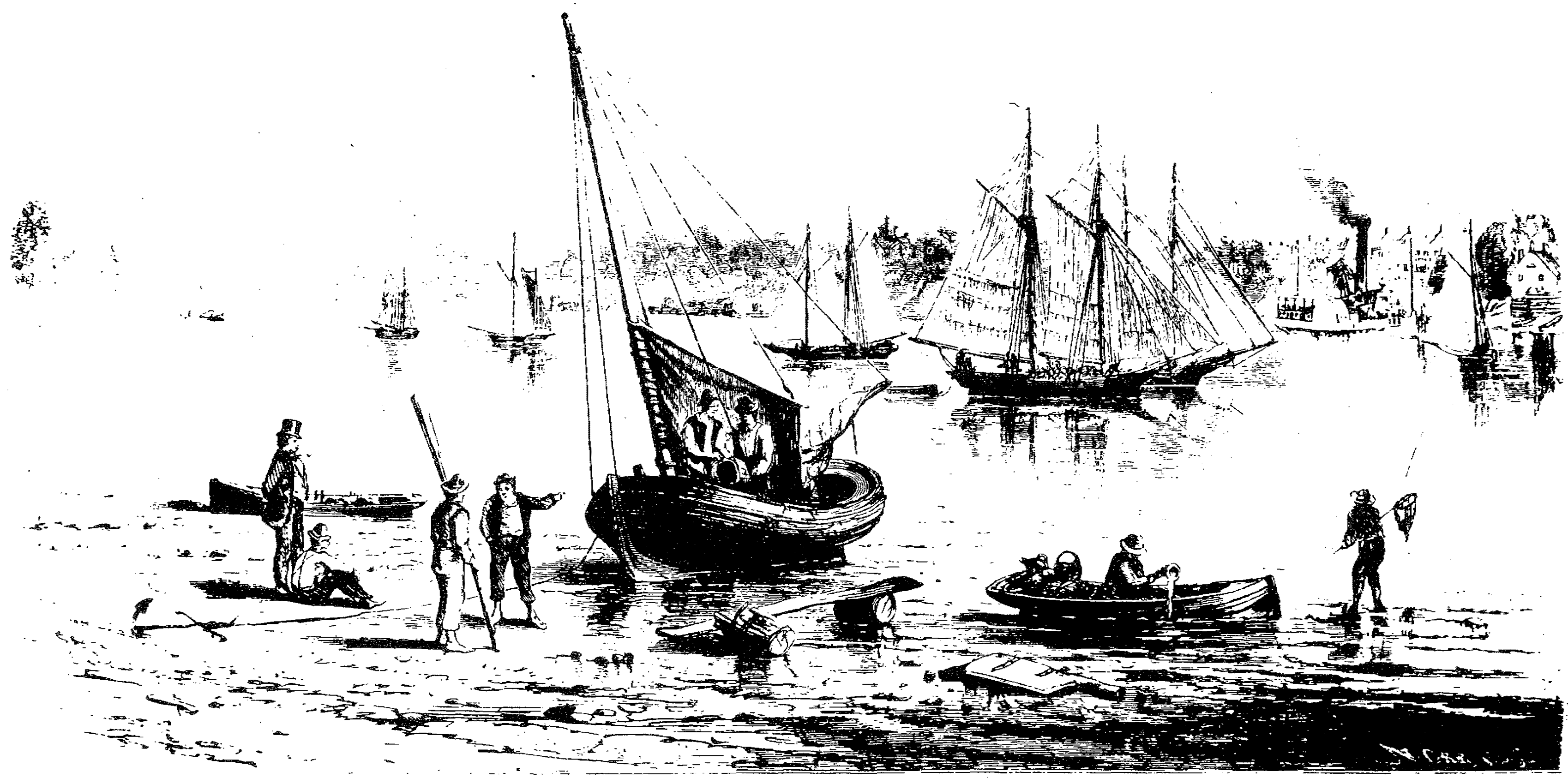

AT RED BANK.

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