Bedrock Geology of the Goshen-Greenwood Lake Area, N. Y.

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LEGEND

Devonian
- Dsc — Schunemunk conglomerate
- Dbv — Bellvale sandstone

(Devonian section broken by faulting)

ANGULAR UNCONFORMITY

Middle Ordovician (Normanskill shale)
- Osh — Snake Hill shale
- Oag — Austin Glen grit and shale
- Omm — Mount Merino shale

ANGULAR (?) UNCONFORMITY

Lower Ordovician
- Orhl — Rochdale limestone and Halcyon Lake calc-dolomite

Upper Cambrian
- Ɛbpp — Briarcliff dolomite and Pine Plains formation

Lower Cambrian
- Ɛst — Stissing dolomite
- Ɛh — Hardyston quartzite

MAJOR NONCONFORMITY

Precambrian
- wb — West block
- mb — Middle block
- eb — East block

Contact, approximate and projected

Axial trace of syncline

Axial trace of overturned syncline

Axial trace of anticline

Normal fault or high-angle reverse fault; U, up; D, down

Thrust or low-angle reverse fault

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Bedrock Geology of the Goshen-Greenwood Lake Area, N. Y.[1]

by Terry W. Offield[2]

ABSTRACT

The Goshen-Greenwood Lake area is located in southeastern New York, 35 miles northwest of New York City. One-fourth of the area is underlain by Precambrian rocks of the Hudson Highlands, and the remainder by Cambrian, Ordovician and Devonian rocks.

In the Precambrian terrane, charnockitic rocks showing retrograde metamorphic effects are believed to be separated from overlying metasedimentary rocks by an unconformity. Superposition of almandine-amphibolite facies metamorphism on an older pyroxene granulite terrane is suggested. A regional mantled gneiss dome configuration is further evidence of a polymetamorphic Precambrian history. Three areas of different metamorphic characteristics make up the Precambrian basement. Different metamorphic levels are inferred to have been juxtaposed by Precambrian block-faulting that postdated regional metamorphism.

The Lower Paleozoic section (11,000 feet?) consists of Lower Cambrian quartzite and five Lower Cambrian thru Lower Ordovician carbonate units, overlain unconformably by a Middle Ordovician shale sequence of three units with a basal conglomeratic limestone. The shale sequence includes Normanskill Shale and Snake Hill Shale,[3] both of which are shown, by graptolite faunas, to be younger than they are in the Taconic region. Only the uppermost part of the lower Normanskill (upper Mt. Merino) is present; the underlying basal limestone apparently is equivalent to the lower Mt. Merino found in eastern New York. Three Middle Devonian clastic formations are present in an outlier faulted into the basement.

Minor folding of the Cambrian-Ordovician carbonate sequence is thought to have occurred prior to deposition of the shale sequence. Both sequences were deformed in the Taconian Orogeny; this is recorded especially in the development of the low folds, poor fracture cleavage, and minor thrust faults in the shales.

A large syncline in Cambrian-Ordovician rocks was formed after the Taconian event, as indicated by rotation of the old cleavage in the Ordovician shale and development of a new cleavage. The folding is attributed to draping over a rising basement fault block, now exposed at the surface. A similar origin is proposed for the Devonian outlier, a partly overturned isoclinal syncline in which the shales have fracture cleavage. The syncline has been down-faulted into the basement at least 5,500 feet. Block-faulting of the basement, part of a regional basement upwarp, took

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[2] U.S. Geological Survey. Formerly with the Geological Survey, N.Y. State Museum and Science Service, August 29, 1957—September 9, 1959, summer of 1960.

[3] Since this paper was prepared for publication, an article by W. B. N. Berry (1963, Amer. Jour. Sci., v. 261, p. 731-737) has appeared which advocated discontinuation of the name Snake Hill Shale. The name is retained here in its earlier sense to avoid introduction of a new name.

place along lines of Precambrian faulting; in some places the older movement sense was reversed. Age of the deformation is uncertain. If the drape structure hypothesis is correct, the folding and faulting occurred together during either Late Paleozoic, or Triassic periods of deformation. If folding preceded faulting and faulting merely accented the structures, the deformation may relate to successive Late Paleozoic and Triassic movements.

Introduction

LOCATION and GEOGRAPHY

THE GOSHEN-GREENWOOD LAKE AREA is located in Orange County, New York, about 35 miles northwest of New York City (figure 1). Only the New York portion of the area is described. The geology is shown in detail on six 7½′ quadrangles at a scale of 1:48,000 and in generalized fashion on inside front cover.

Main east-west access routes to the area include U.S. Highway 6, and State Highways 17, 17A, and 17M. North-south access routes are State Highways 84 and 94. An excellent network of primary and secondary roads assures easy travel throughout the area in all weather.

A pronounced change in the character of topography in the southern part of the area marks the boundary between two physiographic provinces. The low, rolling topography north and west of this irregular boundary is characteristic of the Great Valley, a part of the Appalachian Valley and Ridge physiographic province. Middletown, Goshen, and Warwick are the largest communities in this part of the area, and the surrounding countryside is devoted to agriculture. South and east of the topographic boundary are the Hudson Highlands, part of the Reading Prong section of the Appalachian Highlands physiographic province. Elevations range from 400 feet to a little more than 1300 feet; relief is moderate. The Highlands are sparsely settled except for the summer resort of Greenwood Lake.

Topography throughout the area shows a northeast-southwest trend. In the Precambrian Highlands, areas underlain by well-foliated gneisses are marked by narrow parallel ridges; areas of more massive rocks make poorly-defined, broader uplands. Valleys mark zones of less resistant gneisses and of shearing along faults. Glaciation has modified the topography by scouring the ridges to make abundant outcrops and filling the valleys enough to make outcrops uncommon in low areas.

In the Great Valley, the northeast-southwest topographic trend is a direct result of the "grain" of the underlying folded Paleozoic shales and dolomites. The continental ice sheet in this part of the area, however, left a much thicker mantle of glacial debris than in the Highlands. Bedrock topography is thus muted to a large extent, and outcrops are few. Highway cuts often provide the only chance to study the bedrock. An extreme case of indirect mantling effects of glaciation is the large peat bog and swamp along the Wallkill River south of Middletown, which resulted from blocking of drainage by a recessional moraine.

Main drainage lines generally follow the topographic grain. Drainage is northeastward, eventually emptying into the Hudson River.

ACKNOWLEDGMENTS

Most of this study was done while I was on the staff of the Geological Survey, New York State Museum and Science Service, and the Survey provided complete financial support for the field work, done mostly during the summers of 1958-60.

The study was used as a doctoral dissertation at Yale University, and Professors M. S. Walton, John Rodgers, and J. E. Sanders gave advice on the problems, and critically read the manuscript. Helpful discussions on the Precambrian rocks, structural geology, and regional interpretations were held with J. L. Baum, Edward Hansen, and Y. W. Isachsen. W. B. N. Berry, G. A. Cooper, Jean Berdan, and D. W. Fisher made the fossil identifications on which the stratigraphic synthesis is based. A. D. Welling furnished information on unusual minerals in the Franklin Marble. Special thanks are due Virginia Offield, who helped to prepare the illustrations and gave encouragement during the entire study.

PREVIOUS GEOLOGIC WORK

For work in the Highlands prior to 1923, the following discussion is based in part on the excellent historical summary given by Colony (1923).

The first noteworthy study of the geology of the area appeared in a report by Mather (1839) on the "First Geological District" as an appendix by Dr. William Horton on the Geology of Orange County, New York. This report contains many careful descriptions of rock types observed, with particular regard to the mineralogy, but it is a rather disconnected account of the geology as a whole. In this, and in a later report by Mather (1843), the white marble of the Highlands was regarded as a recrystallized equivalent of the blue Paleozoic carbonate rocks of the Great Valley, a misconception which persisted until the turn of the century.

Mather (1843, p. 439) discussed under the heading "Metamorphic rocks": ". . . . such rocks . . . of which there is demonstrative evidence, or such as renders it highly probable, that they were originally sedimentary rocks but have since been altered in their character, so as to change them into such rocks as have usually been called primary." In a separate chapter on "Primitive rocks," he discussed granite, gneiss, hornblendic gneiss, and "sienite."

Between 1843 and 1885, no significant work on the geology of southeastern New York appeared, but a number of studies of the New Jersey Highlands were published (e.g., Kitchell, 1856; Cook, 1868). These were concerned primarily with the geology of the magnetite deposits. Mather's category, "Metamorphic rocks", was greatly expanded by the New Jersey geologists, who believed that the magnetite layers and the enclosing gneisses all were of sedimentary origin. This interpretation prevailed generally until 1904 when Spencer concluded that only the marbles, rusty or graphitic gneisses, and part of the amphibolitic gneisses could be regarded as metasedimentary. Foliation and dark layers in the felsic gneisses were regarded as magmatic flow and contamination phenomena: the magnetite was attributed to action of hydrothermal solutions.

Berkey (1907, 1921), working in the New York Highlands in the vicinity of the Hudson River, reached the same conclusion as Spencer. A dual nomenclature for the two areas was proposed and firmly established by the work of Spencer, Berkey, and Bayley. This is dealt with in the section on nomenclature.

In 1914, Fenner commented on the similarity of the Highlands gneisses to certain European gneisses which were believed to owe their mixed character to *lit-par-lit* magmatic injection along favorable structural planes. Colony (1923), in the only comprehensive report on magnetite deposits in the New York Highlands, expanded the idea of *lit-par-lit* injection, in accordance with his view that the Highlands gneisses (and magnetite) were dominantly igneous in origin. He recognized, however, the complexities introduced by syntexis, anatexis, metamorphic differentiation, and original differences in the host rocks and the invading material.

Only three directly applicable modern studies of Highlands rocks in New York and New Jersey have been published (figure 1). A report on the Dover magnetite district (Sims, 1958) presents an excellent detailed subdivision of lithologies together with thorough descriptions of the rock types involved. This is especially useful because the Dover area lies only eight miles southwest along strike from the Sterling Lake—Ringwood area covered in part by the present study. The latter area was mapped by Hotz (1953) at a scale of 1:31,680 in a war-time study of magnetite resources. Although the western part of the area was remapped for the present study at a scale of 1:12,000, only minor changes in Hotz' map resulted. The report, however, was brief and largely concerned with the magnetite deposits. Rock types in the Dover and Sterling Lake areas are quite similar and a rough correlation of at least some of the New Jersey lithologies with their New York counterparts seems in order, perhaps for the first time.

A superb map of the Franklin Marble belt along the western edge of the New Jersey Highlands (Hague, *et al.* 1956) completes the framework of recent published studies which largely provides the basis for the broader conclusions of the present study. The report accompanying the map is very brief, but the general stratigraphic and structural characteristics of the western sequence are evident.

Buddington and Baker have made a study, not yet published, of the geology of the Franklin-Hamburg area, New Jersey.[1] Their map includes Franklin Quadrangle and parts of the surrounding quadrangles (figure 1). Buddington graciously let me study the manuscript, and much of the information in it has been of material aid in my formulating conclusions presented here. It should be pointed out that those conclusions do not entirely coincide with Buddington's interpretation, primarily with regard to regional relations.

For geology of the Paleozoic rocks, the first report after Horton (1839) was a reconnaissance survey of Orange County by Ries (1895). He devoted only cursory attention to the Highlands rocks, but his descriptions of the sedimentary rocks and his notations of specific important outcrops were accurate, thorough, and quite helpful in the present study. Indeed, only a few changes in the boundaries of the major rock sequences have been necessary.

Outside this area, Dwight (1889 and earlier) had recognized that the Wappinger carbonate sequence east of the Hudson River could be divided into a main dolomitic

[1] Map published with manuscript (1961, U.S. Geol. Survey Map I-346).

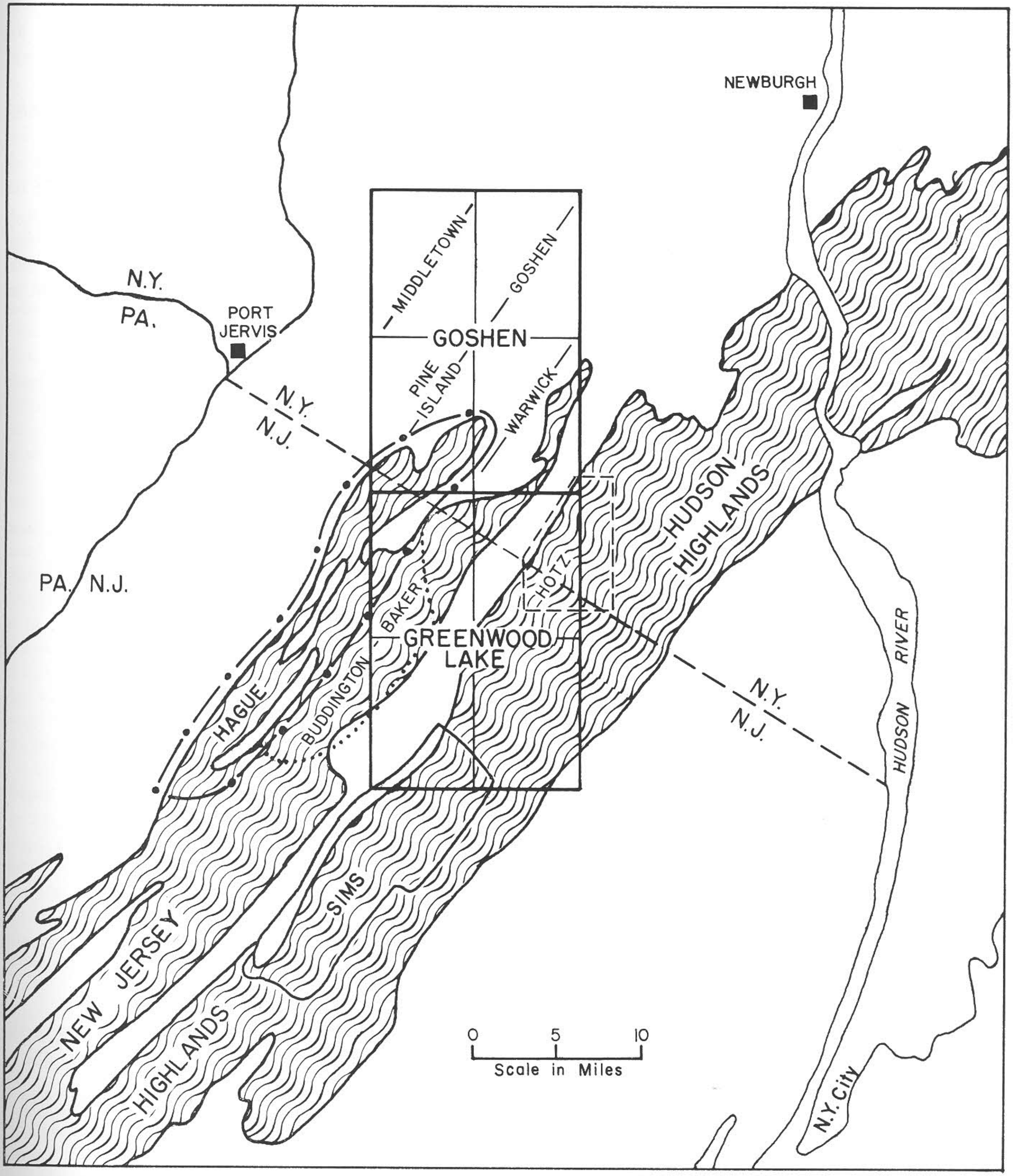


FIGURE 1. Index map showing the Precambrian Highlands the location of 15 minute and 7½ minute quadrangles in the Goshen-Greenwood Lake area, and the areas mapped by Buddington and Baker, Hague, Holtz, and Sims.

section (Calciferous) overlain by Trenton limestone. Kümmel and Weller (1901) observed the same sequence in the Kittatinny carbonate section in New Jersey. Subsequent work by many people in Pennsylvania and New Jersey resulted in subdivision of the Kittatinny section into four formations apparently of great continuity along strike. E. B. Knopf (1946, 1956, 1962) in the vicinity of Stissing Mountain, east of the Hudson River, was able to define seven carbonate units. Six of these have been recognized in the Goshen Quadrangle.

Good descriptions of the Ordovician shales and graywackes of the "Hudson River" sequence in the adjoining Newburgh Quadrangle were given by Holzwasser (1921). She was unable to distinguish smaller units within the shale. Later work by Ruedemann (1942, e.g.) to the north showed that three units could be distinguished on the basis of graptolites, and partly on lithologic characteristics. Berry (1962) has restudied the type sections of Ruedemann's units and has discerned an even finer zonation of fossils and lithologies. Much of the stratigraphic interpretation presented here is based on Berry's work and his identifications of graptolites newly found in the Goshen area.

Darton (1894) and Hartnagel (1907) briefly studied the Silurian and Devonian rocks of the Schunemunk-Bellvale syncline and defined the stratigraphic section involved.

Geology of the Precambrian Rocks

GENERAL STATEMENT

THE HIGHLANDS ARE PART of a terrane of Precambrian metamorphic and igneous rocks extending more or less continuously from Reading, Pennsylvania, to the Green Mountains in western Vermont. A Precambrian age is clearly indicated by the nonconformity separating these rocks from overlying fossiliferous rocks of Early Cambrian age. The Precambrian rocks consist largely of quartzo-feldspathic and amphibolitic gneisses, generally well foliated and remarkably linear in trend. More massive granitic gneisses and a few unfoliated granites also occur, and are generally conformable to the regional trend. Marble is a conspicuous rock type near the western edge of the Highlands in New York and New Jersey. The metamorphic character of the Highlands rocks is typical of the upper amphibolite and granulite facies of regional metamorphism.

In the Goshen-Greenwood Lake area, the metamorphic character of the Precambrian rocks changes from east to west. The main changes in the character of metamorphism are believed to coincide, in gross terms, with clearly defined faults of considerable vertical displacement which delimit three structural blocks. To facilitate discussion, *the separate structural blocks will be referred to informally as the east, middle, and west blocks.* An index map of these blocks is included in the explanation of the accompanying geologic map (plate 1). The term *inlier complex* is used to refer to the structurally detached portion of the middle block (Goose Pond-Sugarloaf-Snake Mountains) at the east edge of Warwick Quadrangle.

NOMENCLATURE AND CORRELATION OF ROCK UNITS

The geology of the New York-New Jersey Highlands is imperfectly known, not only in detail, but also in the sense of broad geologic relationships. Since the surge of geologic work in New Jersey at the turn of the century, only a few reports have been published, generally dealing with widely separated areas. As a result of this, no geologic synthesis has been possible for the Highlands as a whole.

One of the major barriers to building up a coherent picture of Highlands geology is the confused nomenclature applied to the rock units involved. Until quite recently, two generally parallel systems of nomenclature have prevailed: Spencer (1908) for New Jersey, and Berkey (1907) for New York. These workers recognized and named major lithologic groupings. Essentially all units which fell (or were pushed) into one of the major categories were deemed to be of similar age and origin. Intermediate or aberrant rock types were explained by variations in contamination or differentiation of magmas. Brief descriptions and discussions of the rock units as originally proposed are given below:

Byram gneiss: (Spencer, 1908)

> Includes several varieties of granitoid gneiss lithologically related by prominence of potash-bearing feldspars. Composed essentially of quartz, and microcline or microperthite, with variable proportions of hornblende, pyroxene, and mica. Oligoclase usually very subordinate, but occasionally equals potash feldspar. Accessory magnetite, zircon, apatite, and sphene. There are several facies of the rock which vary greatly in appearance in the field, but almost without exception show greater resemblance to each other than to varieties of other gneisses with which they are associated. In a broad way the unit can be separated into light and dark facies. Usually light varieties are somewhat finer-grained and less foliated than the dark facies and carry mica rather than hornblende or pyroxene. Includes the obsolete "Hamburg", "Sand Pond", and "Edison" gneisses of Wolff, the "Oxford" type of Nason, and gneissoid granite (Storm King) of Breakneck Mountain on the Hudson. Appears to cut the Pochuck gneiss and the Franklin marble; relationship to the Losee diorite gneiss unknown. Type locality: Byram Township, Sussex Co., N.J.

Storm King granite: (Berkey, 1907, 1921)

> Medium- to coarse-grained, rather dark, slightly greenish and sometimes greasy looking, with a marked, but crude gneissoid structure. Gray or red feldspar (perthite or microcline, subordinate oligo-

clase), gray quartz, black streaks of hornblende or augite. Biotite not abundant, garnet occurs more in the marginal portions. Sometimes syenitic. Type locality: Storm King Mt., Rockland Co., N.Y.

The similarity of the Storm King granite and the Byram gneiss has long been recognized, and the two usually have been considered to be the same unit. Simon Schaffel (personal communication, 1960) has made a reconnaissance study of this granite in the Highlands. In a strike belt extending along the eastern margin of the Highlands from the Hudson River to Pennsylvania, Schaffel has observed numerous occurrences of hornblende granite indistinguishable from the type Storm King. The granite occurs in separate masses, however, so equivalence of the granites may only be inferred. Also, the extent of occurrence of correlative, or at least similar, granite west of the main belt is unknown.

For a synthesis, broad terms are desirable, and of all the Highlands rocks names proposed, Storm King seems most likely to serve a useful purpose. The name Storm King is preferable to Byram because the Storm King granite is lithologically simpler and more sharply defined in the literature. Whether the name can or should be applied to hornblende granites outside the main belt, however, is speculative. Hague *et al* (1956), in describing the western side of the Highlands, use the term "Byram gneiss", slightly redefine it, and describe subdivisions. This not only perpetuates a dubious term, but also compounds the confusion. To avoid subjective interpretations of the equivalence of similar granites, recent workers have used the lithologic term "hornblende granite." I have adopted this usage, pending the establishment of the validity of the term Storm King.

Losee diorite gneiss: (Spencer, 1908)

More-or-less foliated medium- to coarse-grained rock resembling granite in texture. Mainly light in color, and in many weathered exposures nearly white. Differs from Byram in having dominant oligoclase; differs from Pochuck gneiss in having much quartz and only minor dark minerals. Cut by granite and pegmatite. Type locality: Losee Pond, Sussex Co., N.J.

Canada Hill granite: (Berkey, 1907, 1921)

Medium-gray, medium-grained rock varying from faintly to almost imperceptibly streaked. Composed of white and gray feldspar (dusty orthoclase, fresher microcline and sodic feldspar—presumably oligoclase, gray small, rounded, violet-red garnets. Also a coarser-grained pegmatitic facies, grading into true pegmatite. "Oldest and most vigorous" (presumably in its assimilation of, and metasomatic effects on, surrounding rocks) of invading granites. Type locality: Canada Hill, Putnam Co., N.Y.

Spencer's usage of Losee replaced and expanded the "Losee Pond granite" of Wolff to include essentially all light-colored plagioclase-rich rocks in the Highlands. The Losee gneiss was believed to be mostly of igneous origin, although its exact relationship to other rocks was nearly always obscure. In subsequent reports, it has been commonly suggested that the Losee may be equated generally with the Canada Hill granite and its contamination phases. Even if the Canada Hill and the Losee were valid and useful units, this would be an erroneous correlation of rocks with different feldspar proportions.

The Canada Hill at the type locality however, is not typical of the Canada Hill terrane as mapped by Berkey and Rice (1921). Moreover, the unit generally consists of coarse white granite interlayered in many places with sillimanitic quartz gneiss and rusty gneiss. The Canada Hill, as originally mapped, does not appear to be a valid unit, and redefinition of the lithology is necessary if the term is to used.

Application of the term Losee was diffuse originally and has become more so with each new study. The term probably no longer serves a useful purpose. Only one recent report (Hague *et al*, 1956) has used Losee as a unit name. Buddington and Baker (*in press*) have restudied the Losee type locality and applied the term quartz-oligoclase gneiss. I have followed other recent investigators in employing mineralogic names for the lithologic varieties that fall into the generalized "Losee" category. Quartz-oligoclase gneiss and quartz-microcline-plagioclase gneiss are the principal varieties (although the latter might also have been considered "dark facies Byram" by some of the earlier workers).

Pochuck gneiss: (Spencer, 1908)

Includes all gneisses of the region that contain hornblende, pyroxene, or mica as principal constituents. Some of these rocks may be of sedimentary origin, others may be altered igneous rocks, but in general the original nature cannot be ascertained. Usually the only light mineral is oligoclase, but some facies contain considerable scapolite. Microcline is observed in a few varieties, andesine and labradorite but rarely.

Bayley *et al* (1914) believed Pochuck included older dark gneisses invaded by the Byram and Losee gneisses and dark gneisses of igneous origin contemporaneous with the Byram and Losee gneisses. The two groups were not mapped separately because of the impossibility of discriminating them in the field.

Pochuck diorite: (Berkey and Rice, 1921)

Dioritic gneiss, intimately associated with streaked and banded rocks "of Grenville type." ("Grenville" used by Berkey and Rice referred to all metasedimentary rocks, on the basis that, as they were invaded by granites and diorites they must be part of the "ancient Grenville terrane"). Composed of hornblende, pyroxene, and oligoclase-andesine, but believed to vary in places even to the composition of soda granite. The occurrence of pegmatitic facies is judged to support the interpretation that igneous injection and impregnation of the original "Grenville" sediments by a magma of dioritic composition produced the observed variations. It is cut by granites.

The term Pochuck has not been used by anyone in recent years, and rightly so. In a general synthesis of Highlands geology, no single term for the dark gneisses will be practical, and even with detailed mapping, the equivalance or nonequivalence of these rocks in different parts of the Highlands will probably be very difficult to establish. Mineralogic names such as amphibolite, pyroxene gneiss, and hornblende-feldspar gneiss are used in this report, and it is believed that identical lithologic units may be of significantly different ages and origins within this small area. Taking the Highlands as a whole, this situation is undoubtedly magnified.

With possible exception of the Storm King granite, the only unit for which retention of a stratigraphic name seems warranted is the Franklin marble. Since homotaxis with other marble layers generally cannot be established, this name should be confined, however, to the prominent and essentially continuous belt of marble along the western margin of the Highlands, and to outliers of marble in the immediate vicinity (Code of Strat. Nomenclature, 1961, Art. 4c). The formation name is retained in this report.

Discussion of regional structure and correlation is reserved for a later section, but some mention of the term Grenville must be made. The name Grenville originally referred to high-grade metamorphic rocks in the vicinity of the town of Grenville in the Province of Quebec, Canada. Subsequently, the name has been freely applied to rocks of diverse character throughout southeastern Quebec and the Adirondack region of New York. Many workers have noted that rocks of the New York—New Jersey Highlands are more similar to the originally defined Grenville rocks than are many other rocks which have gradually been included in the term (e.g., Engel and Engel, 1953, p. 1018). Berkey and Rice (1921) in the Hudson Highlands, referred the obvious metasedimentary rocks ostensibly intruded by younger granites to an ancient "Grenville complex." By Adirondack usage, probably all Highlands rocks discussed in this report would be "Grenville." This would probably be a permissable extension if the term were used to describe, not specific rock-unit correlations, but rather a widespread orogenic episode such as the Taconian or Allegheny.

Against such usage, however, is recent evidence from radiometric dating of minerals in both the Highlands and the Adirondacks that two metamorphic events have occurred, and the term "Grenville" implies no distinction of rocks affected by one metamorphism from those affected by two. Moreover, the typical Adirondack sequence, with "Grenville" metasediments considered the oldest rocks, has recently been questioned by Walton and DeWaard (1962), who propose a metamorphic history in which these same metasediments are the youngest rocks. Because of these factors, and the uncertainties involved, the term "Grenville" appears to be of little real use.

CLASSIFICATION OF ROCK UNITS

The rock units described in this report are placed, by interpretation, into three categories:

1. **Metasedimentary rocks**
   - Franklin marble
   - Pyroxenic gneiss and related rocks
   - Biotite-quartz-feldspar gneiss
   - Quartz-microcline gneiss
   - Biotite-garnet-quartz-plagioclase gneiss
   - Graphitic quartz-plagioclase gneiss
   - Graphitic feldspar-quartz gneiss
2. **Rocks of uncertain origin**
   - Amphibolite and pyroxene amphibolite
   - Hornblende-feldspar gneiss
   - Quartz-microcline-plagioclase gneiss
   - Quartz-plagioclase gneiss
3. **Igneous rocks**
   - Alaskite and alaskite gneiss
   - Hornblende granite and hornblende granite gneiss
   - Hornblende-biotite granite
   - Basic dikes

In the mineralogic names of the rock units, as is customary, increasing abundance of mineral components is given by the word order, the last named component being the most abundant.

Throughout the report, quartz-microcline-plagioclase gneiss, quartz-plagioclase gneiss, and related rocks are referred to as charnockitic. Although these rocks are more sodic than many classical charnockites, they are of charnockitic aspect in that they are hypersthenic granitic or syenitic rocks of granulite facies characteristics. Use of the term charnockitic in describing such rocks follows the practice adopted for the new Geologic Map of New York State (Fisher *et al*, 1961), in which the pyroxene syenitic and granitic gneisses of the Adirondacks are called "charnockitic gneisses." References to rocks of presumed or inferred charnockitic aspect in the Franklin-Hamburg area mapped by Buddington and Baker are based on my interpretation of their manuscript data.

Metasedimentary rocks

Franklin Marble

Marble, predominantly calcitic, underlies a large part of the west structural block of Precambrian basement. It is part of a belt extending more or less continuously from Big Island, New York, to Andover, New Jersey. The marble has usually been referred to as the Franklin Marble (or limestone) or as white limestone, to distinguish it from the younger, blue Kittatinny limestone. Recent mapping however (Hague, 1956), has revealed that more than one band of marble is present. Hague defined a probable stratigraphic succession consisting of two thick layers of marble separated in places by a thin group of gneisses, overlain successively by a major group of gneisses, a thin marble layer, and another thick sequence of gneisses. The columnar section given (Hague, 1956, p. 468) is as follows:

> Pochuck Mt. gneiss series: A thick series of interlayered hornblende gneiss, microcline gneiss, and biotitic gneiss with thin bands of garnet gneiss, graphitic gneiss, pyroxene gneiss, and local quartzite. Intrusive (?) oligoclase gneiss in Pimple Hills.
>
> Wildcat marble: Indistinguishable from Franklin marble.
>
> Cork Hill gneiss zone: Similar to gneisses above. Graphitic gneiss, garnet gneiss and pyroxene gneiss at Mt. Eve.
>
> Franklin marble: Coarsely crystalline limestone with local banding of mica, tremolite, chondrodite, norbergite and other silicates. Abundant graphite.
>
> Median gneiss: Very few outcrops. Mostly biotite gneiss and quartz gneiss with local hornblende and microcline gneisses.
>
> Franklin marble
>
> Hamburgh Mt. gneiss series: Similar to Pochuck Mt. series. Local quartzite and graphitic gneiss. Byram gneiss intrusive into this series.

On Hague's map, the marble belt along the east margin of Pochuck Mountain is designated as the Wildcat band, separated from the marble band to the east by a thin layer of quartz-microcline gneiss. This gneiss was considered to represent the Cork Hill zone, but geologic relations are obscure and it appears just as likely to be the Median gneiss, so I have reverted to the broader usage of Franklin for both bands of marble on the accompanying map.

Despite fairly good outcrops, no regional structure has been discerned in the marble. In New Jersey, where the unit has received exhaustive attention in connection with mining operations at Franklin Furnace, detailed study of lithology, and minor mineral and trace element distribution have failed to reveal repetition by folding on a regional scale. Flow folding on a small scale is readily apparent, however, and makes any estimates of thickness for the marble bands mere speculation. An excellent exposure of such folding and rheid flowage may be seen at the Atlas quarry near Pine Island.

On the west bank of Pochuck creek at the northern limit of the marble is an exposure which led Ries (1895) and others to conclude that the white and blue (Paleozoic) limestones were gradational. The outcrop appears to be a blotchy mixture of white and blue dolomitic marble and typical finely crystalline, blue Paleozoic dolomite. In detail, however, the marble and dolomite are seen to be broken, angular fragments in a matrix of white calcite or limy mud. Siliceous boxworks, not seen elsewhere in the marble, and the broken, mixed, and recemented nature of the rock are almost certainly subsidiary effects of the adjacent fault which brings marble against Paleozoic dolomite.

The Franklin Marble is predominantly white and calcitic, but contains numerous gray or bluish dolomitic layers. Disseminated graphite is ubiquitous, in places occurring in flakes as large as a half-inch. Tremolite and phlogopite are very common varietal minerals. Exotic minerals abound throughout the marble, and the Amity-Edenville area has been a famous collecting locality for years. A partial list of minerals of museum quality found there is given in Table 1.

Layered structure is prominent in the rock, because of pronounced textural variation and lithologic differences. Commonly smooth-weathering layers of very fine-textured calcite alternate with coarse, crumbly layers of calcite rhombs ranging up to two inches in size. In some places the fine-grained layers are bluish, apparently because of the presence of minutely comminuted or smeared-out graphite in shear zones, and in such layers the texture is due to recrystallization during shearing. Where evidence of shear is lacking, the fine-grained and coarse layers may represent original sedimentary beds whose initial differences influenced the habits or recrystallization of the calcite during metamorphism. This interpretation is favored by the characteristic occurrence of tremolite and chondrodite in fine-grained layers, and their general paucity in coarse layers. Graphite and phlogopite occur in both.

Table 1.
Minor Minerals in the Franklin marble

albite	$NaAlSi_3O_8$	orpiment	As_2S_3
apatite	$Ca_4\ (CaF)\ (PO_4)_3$	orthoclase	$KAlSi_3O_8$
aragonite	$CaCO_3$	phlogopite	$K_2Mg_6(OH)_4Si_6Al_2O_{20}$
arsenopyrite	$FeAsS$	pyrite	FeS_2
chalcopyrite	$CuFeS_2$	pyroxene	$(Ca,Mg)SiO_3$
chondrodite	$2Mg_2SiO_4.Mg\ (F,OH)_2$	pyrrhotite	FeS
clinochlore	$Mg_5Al_2Si_3O_{14}.4H_2O$	quartz	SiO_2
corundum	Al_2O_3	rutile	TiO_2
edenite	$NaCa_2Mg_5(OH)_2Si_7AlO_{22}$	scapolite	$CaCO_3.3CAl_2Si_2O_8$
enstatite	$MgSiO_3$	scorodite	$(Fe,Al)AsO_4.2H_2O$
epidote	$Ca_2((Al,Fe)OH)$ $(Al,Fe)_2(SiO_4)_3$	serpentine	$Mg_6(OH)_8Si_4O_{10}$
fluorite	CaF_2	seybertite	$3H_2O.10(Mg,Ca)O.$ $5Al_2O_3.4SiO_2$
garnet	$Ca_3(Fe,Al)_2(SiO_4)_3$	sphene	$CaTiO.SiO_4$
graphite	C	spinel	$MgO.Al_2O_3$
hornblende	Ca,Mg,Fe silicate $(OH)_2$	talc	$Mg_3(OH)_2Si_4O_{10}$
ilmenite	$FeTiO_3$	tourmaline	Complex borosilicate
limonite	$2Fe_2O_3.3H_2O$	tremolite	$Ca_2(Mg,Fe)_5(OH)_2$ Si_2O_{22}
leucopyrite	Fe_3As_4	vesuvianite	$Ca_6(Al\ (OH,F))Al_2$ $(SiO_4)_5$
magnetite	Fe_3O_4	warwickite	$(Mg,Fe)TiO_2.B_2O_6$
molybdenite	MoS_2	yttrocerite	$(Y,Ce)F_3.CaF_2$
muscovite	$K_2Al_4(OH)_4Si_6Al_2O_{20}$	zircon	$ZrSiO_4$

Because of differential weathering, silicate minerals stand out in relief against the fine-textured calcite of the smooth fine-grained layers.

The layering is enhanced by mineral orientations in the marble. Parallelism of calcite rhombs, slightly flattened in places, and parallel or sub-parallel alignment of graphite, phlogopite, and bladed tremolite typically give the marble a distinct foliation. Mineral alignment parallels lithologic bands and might be thought to reflect original bedding. More likely, however, the mineral parallelism has resulted from plastic flow. Hague, for example, reports (p. 438) that banding and foliation in marble are parallel to all sides of included, completely detached competent blocks of gneiss or pegmatite.

Dolomitic layers have sometimes been ascribed to secondary dolomitization of calcitic marble, but the secondary dolomitization observed in this area is so distinctive, that the discrete dolomitic layers probably reflect original sedimentary composition. Secondary dolomitization is, for example, ideally displayed in a large outcrop area 2,000 feet south-southeast of Newport. The dolomite is conspicuous against the bare, white calcite marble because of its brownish weathered surface and a coating of minute grayish-brown lichens. Dolomite weathers less readily than calcite and stands out in slight relief. Rather than being in layers, the dolomite is localized by shear surfaces in very irregular patterns. Narrow zones of dolomite may follow individual shear surfaces for several feet, expanding abruptly where such surfaces intersect (figure 2).

On either side of these zones, small pockets of dolomite may occur, becoming less common away from the zones. This dolomitization possibly represents late-stage migration and redistribution of magnesia from dolomite already present in the rock. Introduction of magnesia by granitic emanations from a pegmatite dike (100 feet wide) only a few feet away is another possibility, although dolomitization shows no specific relation to the pegmatite.

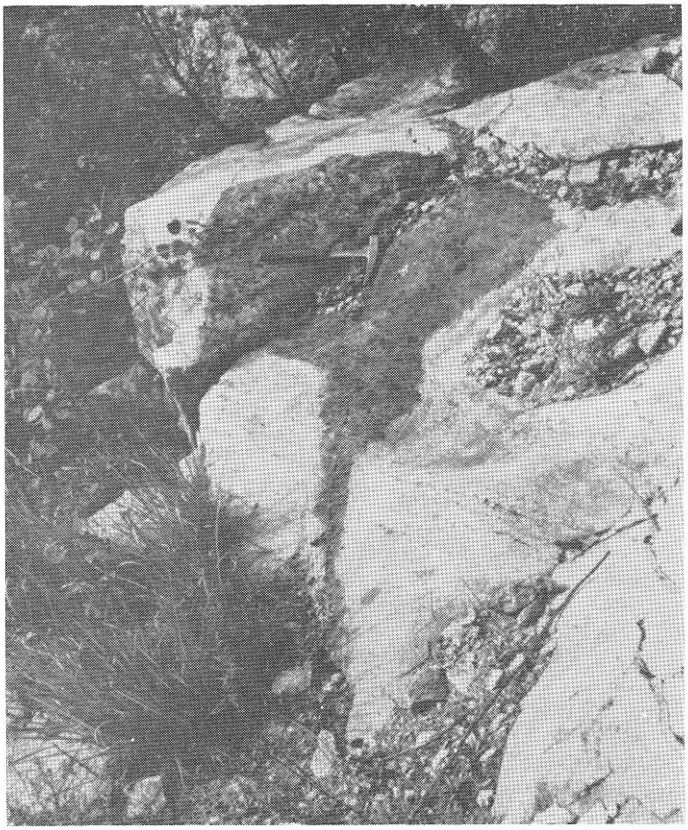


FIGURE 2. Secondary dolomite (dark) in calcite marble; note relation to joints and maximum development at joint intersection. Location, 2,000 feet south-southeast of Newport.

One siliceous zone was observed in which pods or nodules of granular fine- to medium-crystalline quartz were scattered along a single foliation surface. This almost certainly represents a sedimentary feature, perhaps a thin sandy layer pulled apart by flowage in the marble, or was perhaps originally discrete chert nodules.

Lenses, pods, and discontinuous layers of pyroxene rock and granite are scattered sparsely within the marble. The pyroxene rock is commonly composed of dark green, almost black, diopside, coarsely granular and mostly unfoliated. Sphene is a normal varietal mineral, and scapolite is common near contacts with marble. Lenses and pods of pyroxene rock appear to be boudins of competent layers which were fragmented and pulled apart by flowage in the surrounding marble. Granite pods and coarse pegmatites may be concordant or discordant to the structure of the surrounding marble. Contact effects are common, especially the scapolitization of plagioclase and development of diopsidic pyroxene in the granite, and the prominent fixation of fluorine in chondrodite as a contact halo in the surrounding marble.

Calcite dikes "intruding" granite also are developed in a few places at contacts with marble. The outcrop area at Newport, discussed above, exposes three such dikes intruding the pegmatite dike. Calcite extends into the granite in gently tapered slivers. One calcite dike is one inch wide at the marble-pegmatite contact and reaches three feet into the pegmatite (figure 3); another dike is one foot wide at its origin, and scarcely tapers in its exposed length of eight feet. The marble-pegmatite contact is slightly offset on opposite sides of the larger calcite dike. Clearly the calcite must have been injected under fairly high pressure into fractures which could only have developed after the pegmatite was fairly solid. Nevertheless, the temperature must have been rather high, because the calcite of the dikes has been partially converted to a rusty-weathering diopside-sphene mixture by contact metasomatism. The pegmatite also was capable of assimilating enough calcic material to form diopside-rich zones in the pegmatite surrounding the calcite dikes (dark border in figure 3).

Pyroxenic gneiss and related rocks

This lithologic group includes pyroxene-plagioclase gneiss, quartz-pyroxene gneiss, granular pyroxene rock, and pyroxene dikes.

Aside from pyroxene amphibolites, pyroxene-rich rocks are uncommon in the east block. Hotz (1953) shows three small layers, or lenses of a rock which he calls "skarn," in this area. One body of pyroxene rock ("skarn") shown at the northeast tip of Sterling Lake may be based on data from exploratory drilling, for a careful search of the area revealed no outcrops of pyroxene rock. Accordingly, it is not shown there on the accompanying outcrop map (plate 1). The other lenses of pyroxene rock mapped as "skarn" by Hotz are intimately related to amphibolite and have been included with amphibolite on this map. The "skarn" material consists of dark green, almost black, diopsidic pyroxene (salite: Hotz, p. 164), and is granular and unfoliated. Minor, rusty-weathering hornblende, and in places biotite, may be present in amounts up to 10 percent. On the northwest corner of Sterling Lake, dark pyroxene rock is gradational across strike on both sides into pyroxene amphibolite, which, in turn, becomes more feldspathic and grades into quartz-oligoclase gneiss. In the Sterling Lake area, pyroxene rock is subordinate to pyroxene amphibolite as host rock for the magnetite deposits. One fact of genetic significance revealed in underground working is the presence of marble lenses and intergranular calcite in the pyroxene rock.

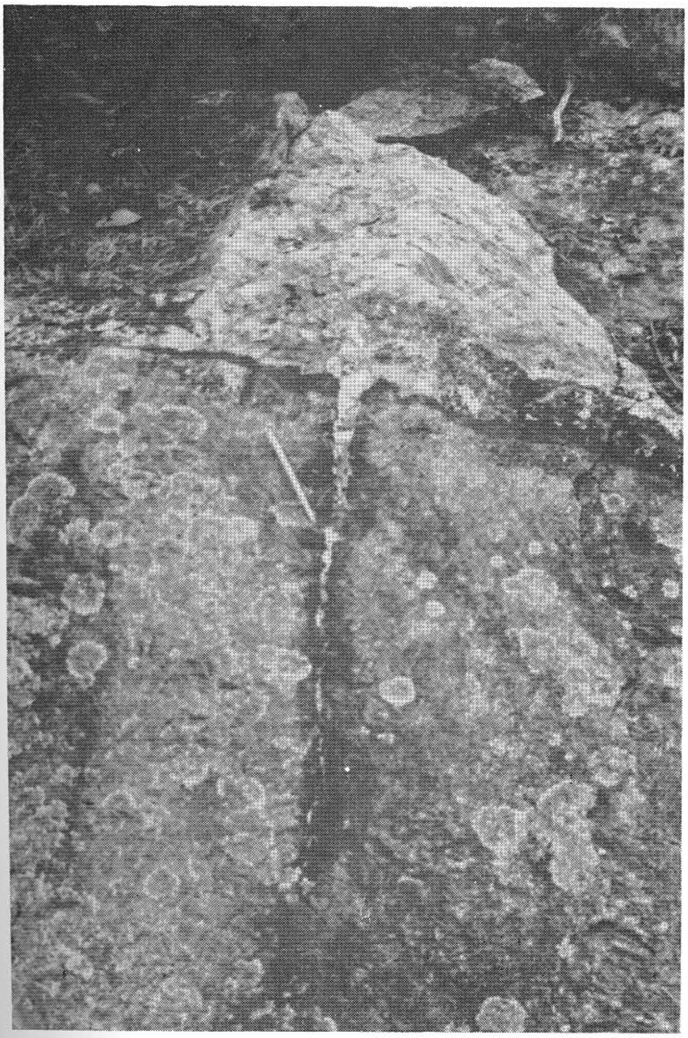


FIGURE 3. Marble-granite pegmatite contact, showing granite "intruded" by calcite dike; dark zone at contact is rusty-weathering diopside-sphene selvage. Location, 2,000 feet south-southeast of Newport. Note pencil for scale.

In the middle block, rocks in this category include pyroxene-plagioclase gneiss, quartz-pyroxene gneiss, and granular pyroxene rock. They are not abundant and primarily are associated with the belt of siliceous metasedimentary gneisses and alaskitic rocks along the west side of Bellvale Mountain.

Pyroxene-plagioclase gneiss occurs as minor layers in the amphibolite zone which crosses Route 17A between Bellvale and Bellvale Mountain. It is strikingly layered on a scale of inches or less, with bands of dark green or grayish green diopside or diopsidic augite alternating with smooth-weathering gray plagioclase layers commonly rich in scapolite. The dark bands may be either more or less resistant to weathering than the light bands, making ribs or furrows on the outcrops. Medium-grained even texture is the rule, with pyroxene a little coarser than plagioclase, but a few coarsely recrystallized clots or irregular lenses of pyroxene and plagioclase occur. These in places have halos or selvages of hornblende containing a minor percentage of very small red garnets. Probably such zones can be attributed to minor local variations in water-vapor pressure and influx of volatiles during metamorphism.

Retrograde phenomena include heavy sericitization and common scapolitization of plagioclase, alteration of pyroxene to form hornblende, and epidotization. Epidote commonly is sparsely scattered throughout the gneiss and is generally prominent in the coarse, recrystallized zones.

All three varieties of pyroxene-rich rocks are associated with alaskite and graphitic quartz gneiss along the west side of Bellvale Mountain, and at Sugarloaf Mountain to the north. West of Cindy Linda Lake is a structurally jumbled complex of alaskite, pyroxenic gneiss, and graphitic gneiss. Exposures are poor, but the distribution of rock types suggests intrusive and faulted relations. Alaskite typically has a garnetiferous margin at contacts with pryoxene gneiss. The pyroxenic rocks generally contain graphite and are gradational into, or interleaved with, graphitic quartzose gneiss. At the eastern base of Sugarloaf Mountain, pyroxene gneiss and associated graphitic quartz gneiss strike under an apparently flat thrust fault and appear again in the valley west of the mountain. Here, the pyroxene gneiss carries magnetite, locally rich enough that small prospect pits were opened.

Along strike of the middle block, four miles to the southwest in New Jersey, Buddington and Baker (ms.) find similar pyroxenic gneisses, (Table 2) primarily associated with metasedimentary gneisses. They are most abundant in a major syncline directly along strike from the zone just discussed.

TABLE 2.
Approximate modes (volume %) of pyroxenic rocks

	1.	2.	3.	4.	5.	6.
Plagioclase	42.1	54.0	48.7	53.0	65.8	39.6
Quartz		8.0	6.5		27.0	20.2
Microcline			13.6			24.3
Hornblende			3.1	1.9		12.0
Clinopyroxene	55.0	35.8	18.9	42.6	5.3	1.8
Sphene	2.4	1.0	5.4			
Magnetite	0.1	0.4	3.7	1.5	0.9	1.0
Apatite		0.6	0.3	1.0	1.0	0.5

1. F 4-14a. 2500 feet southwest of Cindy Linda Lake.
2. B 8-89a. Pyroxene-plagioclase gneiss, north end Mt. Eve.
3. Pyroxene-feldspar gneiss, Mt. Eve.
4. Franklin Quad., N.J., Buddington and Baker ms., Table 2, No. 1.
5. Franklin Quad., N.J., Buddington and Baker ms., Table 2, No. 5.
6. Franklin Quad., N.J., Buddington and Baker ms., Table 2, No. 6.

In the west block, sulphidic-weathering pyroxene-plagioclase gneiss is associated with quartz-microcline gneiss and graphitic gneiss, grading into both by increase in microcline, quartz and graphite. The rock may vary from 90 percent diopside to 80 percent feldspar, typically coarsely granular. On Pochuck Mountain, pyroxene-plagioclase gneiss is quite salic, and contains quartzitic layers. Biotite and garnet may be present in zones of coarsely recrystallized pyroxene and sphene in which pyroxene may occur in crystals as much as 1½ inches long. Weathered surfaces are rusty and pocked or off-white, and marked by dark-green pyroxene splotches. Scapolite is locally an important constituent of the gneiss, as at Mt. Adam, where it is probably an effect of the intrusion of granite into marble.

At the northeast corner of Mt. Adam, an outcrop along the country road exposes three sphene-bearing pyroxene dikes within granite. The largest one is 8 inches wide. Contacts are sharp and straight, although the granite is usually rich in pyroxene around the dikes. This is almost certainly an example of complete transformation of calcite dikes by contact metasomatism, as discussed in the preceding section on marble.

Pyroxenic rocks are also seen within marble; these are described in the section on Franklin marble.

Except for recrystallized zones or foliae, the pyroxenic rocks typically have medium to coarse granoblastic texture. Plagioclase (oligoclase-andesine) displays albite and minor pericline twinning and may be clear or completely altered. Pyroxene in some places is slightly altered to hornblende or chlorite, usually least in the east block. Except in the east block, sphene is locally an important constituent.

Magnetite replaces pyroxene and itself is replaced by rims of sphene. The titanium for the formation of sphene is presumably derived from ilmenite in solid solution in the magnetite. Apatite is a common accessory mineral in all of the pyroxenic rocks.

Biotite-quartz-feldspar gneiss

Biotite-quartz-feldspar gneiss occurs in minor belts in the middle block in the Taylor Mountain area south of Warwick and at Goose Pond Mountain, and also in the west block at Mt. Adam and Pochuck Mountain. In the middle block the gneiss is interlayered and gradational with graphitic quartz gneiss, pyroxene gneiss, and alaskitic rocks. In the west block biotite-quartz-feldspar gneiss is intimately associated with quartz-microcline gneiss. Here it was designated biotite gneiss by Hague (1956). To the south, in New Jersey, comparable rocks are present in thin bands in all three structural blocks.

Biotite-quartz-feldspar gneiss is a granular rock, buff- to white-weathering, or rusty in rough-surfaced, rather flaggy outcrops. Texture is extremely variable; fine and coarse foliae are commonly interleaved. Typical compositions are given in Table 3. Feldspar may be oligoclase alone (An_{28-30} in the middle block, An_{12-15} in the west block) or oligoclase and microcline. Plagioclase is variably clear or sericitized; albite twinning is sparse and pericline twinning is rare. Microcline is microperthitic in places. Dark-brown to red-brown biotite is well oriented, giving the rock an excellent foliation. In thin section, a lepidoblastic fabric is the rule, not only from the orientation of biotite, but also from strikingly elongated discs and blebs of quartz, microcline, and even garnet. Quartz occurs in large grains or aggregates of grains with intricately sutured boundaries; strain features generally

TABLE 3.
Approximate modes (volume %) of biotite-quartz-feldspar gneiss

	Middle Block			West Block	
	E9-13	F4-14	F3-8	B5-30	B5-31
Plagioclase	0.2	10.4	50.8	41.4	56.6
Quartz	58.4	28.4	28.1	18.4	14.4
Microcline		54.2		20.2	
Biotite	10.8	6.9	14.1	11.2	19.6
Hornblende	30.3			2.6	
Clinopyroxene					0.8
Magnetite		.1	0.1		7.4
Chlorite/epidote			6.6		
Apatite	0.3		0.1	0.4	1.0
Zircon			0.1		

E9-13. West slope, Bellvale Mt.
F4-14. 2,800 feet due west of Cindy Linda Lake.
F3-8. 700 feet southwest of southwest end of Cascade Lake.
B5-30. South end, Mt. Adam. Biotite gneiss of Hague (1956).
B5-31. South end, Mt. Adam. Biotite gneiss of Hague (1956).

are moderately developed but may be absent. Plagioclase-rich varieties commonly show complete lack of strain.

Pale pink or lavender garnet is an uncommon porphyroblastic accessory mineral which warps biotite foliae. Very fine-grained fibrolitic sillimanite is in places present in well-defined zones marked by rusty weathering and platy fracture. The rusty weathering is caused by breakdown of disseminated minute pyrite and pyrrhotite masses. Rarely, calc-silicate lenses are associated with the rusty metasediments, as in the vicinity of Cascade Lake. Rusty gneisses are distinctly subordinate to gneisses which are gray or white on fresh surfaces, although all the biotitic metasediments weather a mild rust color on foliation surfaces.

Interlayering and intergradation of minor lithologies in the biotite-quartz-feldspar gneiss and associated metasediments is conspicuous. There is little doubt that the layering, which is parallel to foliation, reflects original sedimentary bedding.

In many places, but not everywhere, stratigraphic and structural relations of metasediments to quartz-microcline-plagioclase gneiss and associated rocks may be construed as indicating the metasediments are younger than everything except various granites. This relationship is best displayed at the north end of the middle block. There, the biotite-quartz-feldspar gneiss and graphitic feldspar-quartz gneiss extend in narrow belts between ridges of charnockitic gneisses of the quartz-microcline-plagioclase gneiss-amphibolite association. The metasediment belts pinch out, or plunge out synclinally, southward and widen northward. Extent and continuity of the metasediments northward is evident from their appearance as the only rock types in the chain of inliers extending 25 miles northeast to Newburgh.

Just southwest of the State line, on the northwest corner of the middle block at Hamburg Mountain, Buddington and Baker have mapped two syncline-like areas of similar metasediments plunging northward under Paleozoic cover. These metasediments appear to overlie syenitic and granitic gneisses of charnockitic aspect. The westernmost group contains prominent pink, sillimanitic quartz-microcline gneiss such as occurs elsewhere only in the west block.

The implications of the relations of these metasediments to the adjacent gneisses are discussed at length in the section on structure of the middle block.

Quartz-microcline gneiss

Quartz-microcline gneiss has been recognized only in the west block except for the northwestern part of Hamburgh Mountain, as mentioned in the preceding section. The gneiss is intimately associated with amphibolite, pyroxene gneiss, and quartzose metasedimentary gneisses at both ends of Mounts Adam and Eve. At Pochuck Mountain, quartz-microcline gneiss makes at least two of the layers of the synclinal section invaded by granite. In the Glenwood (N.J.) syncline, the gneiss is interlayered with marble and amphibolite.

This is the unit designated by Hague (1956) microcline gneiss. His map shows a thin band of quartz-microcline gneiss separating two areas of marble southwest of Pine Island and for which surface data exist only at the north end. The band is shown on the accompanying map (plate 1) because its southern continuation shown by Hague apears to have been based on detailed geophysical data. Hague's map has been modified at the south end of Mt. Adam, however. The map showed graphite gneiss; this was a misprint and should have been Byram gneiss (Hague, personal communication). Except for a slightly larger percentage of plagioclase, this unit could not be distinguished from quartz-microcline gneiss, and I have mapped it as such.

Quartz-microcline gneiss is a fine- to medium-crystalline rock which most commonly weathers brownish-buff. The principal mineral components are quartz and microcline, and normally the rock is very light colored. The gneiss is gradational into mafic gneisses, however, and near contacts it may have several percent of hornblende, biotite, or pyroxene. Near graphitic pyroxene gneiss at the north end of Mt. Eve, quartz-microcline gneiss contains pyroxene, graphite, and considerable plagioclase, and is interlayered with the dark gneiss. In thin section, gradation into amphibolite may be seen in the minute alternation of plagioclase-hornblende and microcline-hornblende laminae.

Foliation is well developed by the planar orientation of biotite flakes and elongate quartz blebs. The most conspicuously foliated gneiss is a very light-colored variety consisting of alternating layers of pink microcline and white quartz. The quartz weathers as ribs and commonly is mixed with prominent amounts of bright yellow epidote. This variety is closely associated with granite.

Sillimanite locally forms conspicuous rods, clots, or sheaves, and in places crystals are several inches long. In the gneiss at Pochuck Mountain, sillimanite sheaves make up 5 to 10 percent of the rock in places, weathering as *en echelon*, oval porphyroblasts.

The fabric of quartz-microcline gneiss is crystalloblastic, generally not very strained. Replacement of plagioclase by microcline is ubiquitous, with albitic or myrmekitic rims in plagioclase against microcline but not against other minerals. In many thin sections, plagioclase is present only as ragged patches or films in slightly perthitic microcline, or as heavily sericitized islands in clear microcline. All microcline grains show excellent cross-hatch twinning. Red-brown biotite replaces medium-green hornblende and is itself partly replaced by microcline. Hornblende commonly has sieve structure filled with quartz and microcline. Two generations of quartz are present, the later quartz embaying all other minerals in large elongate blebs. Accessory minerals include apatite, magnetite, graphite, garnet, muscovite, and zircon. Zircons are small, rounded, and not specifically associated with any other mineral. Sericitization of plagioclase and chloritic alteration of mafic minerals are widespread.

Modes of several specimens are given in Table 4.

Biotite-garnet-quartz-plagioclase gneiss

Biotite-garnet-quartz-plagioclase gneiss is present in one thin layer between layers of graphitic quartz-plagioclase gneiss and quartz-microcline gneiss in the southern part of Mt. Eve. It is a dark, irregular textured rock which has foliation owing to aligned biotite and crudely aligned garnet porphyroblasts as much as half an inch in diameter. Wine-red garnet makes 20 to 30 percent of the rock. Quartz occurs in irregular lenses and clots, disrupting the foliation.

TABLE 4.
Approximate modes (volume %) of quartz-microcline gneiss

	B8-65	B8-78	15	*
Plagioclase		3.8	14.2	15.8
Quartz	36.4	39.0	28.4	37.5
Microcline	59.0	53.2	41.6	41.3
Hornblende		tr.	10.4	
Biotite/chlorite	4.6	0.4	2.0	3.9
Sillimanite				tr.
Garnet				0.3
Apatite				tr.
Magnetite				0.5
Muscovite				0.4
Epidote				tr.
Zircon				tr.

B8-65. Northeast Corner of Mt. Eve.
B8-78. North end of Mt. Eve, at contact with granite.
15. Northeast corner of Mt. Eve.
* Average of 10 modes, Table 1, Hague (1956).

Graphitic quartz-plagioclase gneiss

Graphitic quartz-plagioclase gneiss occurs in two belts of metasediments at the north and south ends of Mt. Eve. At the north end, the rock is interlayered and intergradational with graphitic pyroxene gneiss. These units are well exposed along the roads on the north and east sides of Mt. Eve and are conspicuous because of their rusty, flaggy character. The gneiss of the southern belt weathers less rusty. It is well exposed north of the granite at the bend in the road between Mounts Adam and Eve. Buddington and Baker (ms.) have mapped minor bands of similar gneiss as parts of metasediment belts near the east border of the middle block in New Jersey.

The gneiss has a fine-grained mosaic texture of equant plagioclase and smaller, interstitial quartz. The plagioclase (oligoclase-andesine) is gray-blue on fresh surfaces, and in thin section most grains show albite twinning. Abundant, perfectly oriented biotite disrupts the granular fabric to give the rock a conspicuous foliation. The biotite is light red-brown, with slight alteration to chlorite in a few places. Shreddy or skeletal flakes of graphite are orientated parallel to biotite. Generally, alteration and strain features are minor.

Graphitic feldspar-quartz gneiss

Graphitic feldspar-quartz gneiss makes up a large part of the Goose Pond-Sugarloaf-Snake Mountain inlier complex, and, together with biotite-quartz-feldspar gneiss, occurs in the syncline-like belts at the north end of the middle block, which were described in the section on biotite-quartz-feldspar gneiss.

The quartzose gneiss of the unit are interlayered with quartz-pyroxene gneiss, alaskite gneiss, and biotite-quartz-feldspar gneiss. With the advent of brown biotite and microcline, there is a complete gradation into biotite-quartz-feldspar gneiss. The gneisses are granular but foliated on discontinuous planes of feldspar, graphite, biotite, and elongate quartz grains. Foliation is invariably parallel with lithologic layering. Weathered surfaces are buff or white, with yellow specks of weathered interstitial feldspar. Fresh surfaces are glassy gray except for graphite and biotite.

The quartzose gneisses included in this unit may or may not have biotite, graphite, or microcline; quartz and subordinate plagioclase (oligoclase, An_{12-22}) are the essential minerals, although microcline may locally exceed plagioclase (Table 5). Graphite in flakes as large as three eighths of an inch is usually a conspicuous component. At the west edge of Goose Pond Mountain along Route 17M, graphite forms 15 percent of some layers.

TABLE 5.
Approximate modes (volume %) of graphitic gneisses

	Middle Block				West Block
	11	E8-47	F3-10g	F3-10f	B8-89
Plagioclase	6.5	22.5	6.4	10.8	58.2
Quartz	64.6	68.5	62.0	78.0	20.8
Microcline	14.5		25.5	9.8	
Biotite	2.8	0.1	3.7	0.4	18.4
Graphite	11.4		0.7	0.2	0.2
Magnetite		2.3		0.3	
Chlorite and alteration products		6.3		0.4	2.0
Garnet			0.7		
Zircon			0.1		

11. Graphitic feldspar-quartz gneiss, west contact of Goose Pond Mt. inlier, Route 17M.

E8-47. Plagioclase-quartz gneiss, minor layer in hornblende-feldspar gneiss, Brimstone Mt. inlier.

F3-10g. Graphitic feldspar-quartz gneiss, ridge west of Cascade Lake.

F3-10f. Graphitic feldspar-quartz gneiss, ridge west of Cascade Lake.

B8-89. Graphitic quartz-plagioclase gneiss, northeast side of Mt. Eve.

Hotz (1953) shows quartzite north of Route 17A and just west of the hornblende granite. This rock has not been shown on the accompanying map as quartzite or quartz gneiss because the rock is a granular mixture of quartz and epidote and probably is an epidotized quartz pod or stringer related to the nearby longitudinal fault.

Rocks of uncertain origin

Amphibolite and pyroxene amphibolite

Amphibolite is the general name for dark rocks consisting essentially of plagioclase and hornblende. Pyroxene is commonly present and locally in some rocks it may exceed hornblende in modal percentage. Such rocks are called pyroxene amphibolites because the percentage of hornblende is large, and because of the intimate association with amphibolites. Percentage of hornblende and general lithologic character distinguish pyroxene amphibolites from the pyroxenic gneisses discussed above.

Amphibolite and pyroxene amphibolite were not separated in mapping. It may be said, however, that pyroxene amphibolite is considerably more common in the east block than in the middle and west blocks. The two types may generally be distinguished in the field on the basis of color; amphibolite is very dark green to black, and pyroxene amphibolite is green or greenish gray. A third variety is dark, but very sharply layered, and might be called hornblende gneiss. The variety is amphibolitic, however, and the general term amphibolite has been used. Hague's (1956) unit hornblende gneiss has been renamed accordingly in this area.

Relations of amphibolites to adjacent rocks vary from place to place, even where the lithologic types involved are similar. Amphibolite in the east block may grade subtly into quartz-plagioclase gneiss by gradual changes in the ratio of light to dark layers. Amphibolite may occur as apparent inclusions or schlieren in quartz-plagioclase gneiss or hornblende granite. Layers or "schlieren" of amphibolite in quartz-plagioclase gneiss commonly have sharp contacts but show pulling apart as competent layers in a rheid medium. Butt-ends of the amphibolite fragments may be frayed and corroded by the gneiss or sharp and clean. Similar contact relations are observed against quartz-microcline-plagioclase gneiss and quartz-microcline gneiss in the other blocks.

The rocks typically are foliated by the planar orientation of hornblende or tabular feldspar. Foliation is especially prominent in biotitic varieties. Layering of the light and dark minerals gives the rocks a conspicuous gneissosity. The gneissic structure in places is accented by the presence of laminae or thin layers of coarse-textured white feldspar containing clots of recrystallized bright green hornblende. A few concordant layers of coarse alaskite or pegmatite carry bluish-gray peristeritic plagioclase; these have not been observed in the west block.

Amphibolites everywhere in the area are generally similar. The principal difference is in the percentage of pyroxene amphibolites, but other comparisons of amphibolites from the three blocks can be made (Table 6). In the east block, hypersthene is common in amphibolite, occurring in sharp, clear grains. Sericitization of feldspar is minor or lacking; sphene, epidote, and scapolite are almost completely absent. In the middle block, hypersthene is less common and is corroded or entirely replaced by uralite or a fibrous aggregate. Plagioclase alteration is ubiquitous; epidote is common in discrete grains, clots, or veins. Sphene and scapolite are common accessory minerals and locally may be important constituents. The description of the middle block amphibolites applies to those of the west block, except that hypersthene is found only in amphibolites within or closely associated with the quartz-plagioclase gneisses, and not in amphibolites of the metasediment sequences.

Petrographically, amphibolites are crystalloblastic intergrowths of plagioclase and hornblende with or without pyroxene. Hornblende (bright green uralite) in some thin sections partially replaces pyroxene, and both may be replaced in part by biotite. Magnetite is present in nearly all sections, commonly as a replacement of mafic minerals.

Interstitial grains of sphene and apatite are present in accessory amounts. Scapolite in large, clear grains in places occurs in discrete grains or in irregular replacement of plagioclase.

Plagioclase varies from An_{28} to An_{40}, and is generally andesine, but in leucocratic bands of the layered varieties the plagioclase may be oligoclase (An_{20-30}).

Albite twinning is prominent, and some grains also display pericline twinning. The hornblende is a green or brownish-green variety of hastingsite which has marked

TABLE 6.
Approximate modes (volume %) of amphibolite
and pyroxene amphibolite

	East Block				Middle Block			West Block	
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Plagioclase	36.9	56.6	51.0	47.0	21.0	47.2	39.5	29.9	50.3
Hornblende	52.7	22.2	9.0	33.0	58.7	16.8	53.0	58.7	21.1
Clinopyroxene		15.9	28.0	2.0		25.7			1.9
Orthopyroxene	0.3	5.1		16.0		6.7			
Biotite	0.2	0.1	0.5	2.0			7.5	0.6	4.0
Magnetite	9.4		10.0		0.1	3.4		1.9	
Quartz								8.5	5.7
Apatite	0.3	0.1	0.5		1.7	0.2		0.5	
Orthoclase								tr.	16.7
Chlorite	0.2		0.5		0.7				
Epidote			0.5						
Scapolite					7.9				

(1) F8-2d. Darkamphibolite, east side of Sterling Lake.
(2) F8-61. Layered amphibolite, 2,100 feet south of Sterling Lake.
(3) Pyroxene amphibolite, Boonton, Quadrangle, N.J., Sims (1958) Table 3, No. DG1-1.
(4) Amphibolite associated with metasediments, Boonton Quadrangle, N.J., Sims, Table 3, No. DA13-1.
(5) F4-1a. "Hornblende gneiss", 3700 feet east-northeast of Bellvale.
(6) Franklin Quadrangle, N.J., Buddington and Baker ms., Table 20, No. 543.
(7) Wawayanda Quadrangle, N.J., Buddington and Baker ms., Table 20, No. 1964-b.
(8) Hornblende gneiss associated with metasediments, Franklin area, N.J., Hague (1956) Table 2, No. V35.
(9) Hornblende gneiss within undivided "Byram" gneiss, Franklin area, N.J., Hague (1956) Table 2, No. V491.

pleochroism. Pyroxene includes both pale-green nonpleochroic augite and hypersthene pleochroic from pink to pale green. Both varieties occur as discrete grains or intergrown so as to suggest simultaneous crystallization. Either type of pyroxene may be present to the exclusion of the other locally.

Hornblende-feldspar gneiss

In the east block, hornblende-feldspar gneiss makes the core of a large syncline west of Sterling Lake, (plate 1) and at Sterling Lake partly outlines another syncline as a belt within amphibolite. It occurs in two belts north of Route 17A and in smaller layers in the vicinity of Sterling Forest Lake. In the middle block, the gneiss has been recognized on Warwick and Taylor Mountains and in the Sugarloaf inlier complex.

Recognition of this unit is relatively subjective, for in most belts it varies in character between quartz-plagioclase gneiss (gnq) and amphibolite (am) or between quartz-microcline-plagioclase gneiss (qmp) and amphibolite. It is often easy in mapping to dismiss any single outcrop of hornblende-feldspar gneiss as a minor variant of one of the end-member lithologies. Hotz (1953) for example, mapped the core unit of the syncline west of Sterling Lake as amphibolite, but the rock is considerably different from the dark amphibolite of the syncline just to the east at Sterling Lake, and setting up a unit of an intermediate lithology seems useful in working out structural, stratigraphic, and petrologic relationships.

In the east block, hornblende-feldspar gneiss weathers pale-brown, and commonly has an irregular ribbed or corrugated surface. The ribs are formed by coarse pegmatoid or alaskitic layers generally concordant to the foliation but which show marked pinch-and-swell and warping of the adjacent foliation. Generally the coarse material consists of gray-white plagioclase and quartz and has minor coarse hornblende and biotite in clots or as irregular selvages. Near contacts with hornblende granite, the alaskitic layers are slightly pink and of granitic composition. Such invasion by granite, without visible modification of the hornblende-feldspar gneiss can be seen along the gneiss-granite contact west and southwest of the Sterling Forest lookout tower.

The gneiss is very well foliated by the orientation of blebs and streaks of hornblende and biotite. Alternation of dark hornblendic and light salic layers gives the gneiss a banded appearance and a characteristic flaggy cleavage. Layering is variable, however, and the rock may be all light or all dark, and relatively massive.

Typical compositions of hornblende-feldspar gneiss are given in Table 7. Except for discrete leaves of quartz-plagioclase gneiss, quartz is minor or absent in hornblende-feldspar gneiss. Feldspar percentages vary sharply between the east and middle blocks. In the east block, potash feldspar is absent or is present only in minor interstitial grains; in the middle block, potash feldspar always exceeds 20 percent and locally greatly exceeds plagioclase. As shown in Table 7, the mafic content also differs considerably from east block to middle block. Two units might have been defined on the basis of these differences, but as the distinction in the field commonly is vague or undiscernible, the simpler and more inclusive term is preferred for both lithologic types.

Textures are crystalloblastic; biotite is the only mineral which everywhere is obviously oriented. Plagioclase is generally unclouded, and albite and pericline twinning are nearly ubiquitous; in the middle block it is oligoclase (An_{22}-An_{26}) and in the east block it is oligoclase-andesine (An_{25}-An_{40}). Potash feldspar is most commonly microcline or microcline microperthite, in which twinning is only incipient or poorly developed. Microcline typically replaces plagioclase; myrmekitic intergrowths and bleached rims in plagioclase are common at grain boundaries with microcline.

Medium-green hornblende of hastingsite type occurs in equant grains in places partly altered to chlorite. There is no evidence that hornblende is secondary after pyroxene. The few examples of secondary hornblende showed bright-green uralite incompletely replacing pyroxene. Biotite is reddish brown, in places altered to chlorite. The biotite is bronze or purple on weathered surfaces.

Magnetite is an abundant accessory, generally in discrete anhedral grains, but in places as irregular replacements of hornblende or biotite. In alaskitic layers or lenses, coarse magnetite may form rims around clots of recrystallized hornblendes. Graphite in tiny disseminated flakes occurs in the gneiss at Sugarloaf Mountain.

Except for the difference in potash feldspar content the two series, a) quartz-plagioclase gneiss—hornblende-feldspar gneiss—amphibolite, and b) quartz-microcline-plagioclase gneiss—hornblende-feldspar gneiss—amphibolite, are very much alike. In both series, the intermediate member is gradational in both directions, both by rather subtle changes in the total rock, and by changes in relative percentage of interleaved component lithologies.

In the east block, this transition is well displayed on a traverse across strike east from Route 17A just north of cross-section line D-D (plate 1). Here the relationship is fairly clear, although it is uncertain if the transitional series results from original sedimentary compositional change, contamination of magmatic rocks, or complex metasomatic modifications. In the middle block, north of the State line on Taylor Mountain, quartz-microcline-

TABLE 7.

Approximate modes (volume %) of hornblende-feldspar gneiss (hfg)

	East Block				Middle Block				
	F8-60	F8-59	F8-52	F8-2b	TM5	F1-22	F4-1b	F3-10b	E8-71
Plagioclase	57.1	60.4	65.2	73.4	21.4	34.5	44.4	54.9	24.0
Microcline	0.1	2.4			44.1	23.1	32.2	24.3	49.9
Quartz		2.16			6.4	2.8		0.9	17.0
Hornblende	9.8		4.7	4.8	25.6	21.2	17.6	14.2	7.7
Clinopyroxene	11.3						0.2		
Orthopyroxene		8.8	26.5						
Biotite		0.1		8.7		1.8		.1	0.4
Magnetite	7.5	6.2	3.4	3.0	1.1	3.5	3.6	1.5	1.0
Sphene					0.3	0.1			
Apatite	0.3	0.5	0.2	0.3	tr.	2.5	0.9	0.2	
Chlorite/ Epidote	6.7				1.0	.4	1.0	3.9	
Zircon	tr.	tr.			tr.				tr.
Scapolite				9.8					

F8-60. From hornblende-feldspar gneiss within amphibolite west of Sterling Lake.
F8-59. From hornblende-feldspar gneiss between amphibolite and quartz-plagioclase gneiss, gradational into both, west of Sterling Lake.
F8-52. From hornblende-feldspar gneiss in contact with granite 1,000 feet west of Sterling Lake fire tower.
F8-2b. From hornblende-feldspar gneiss gradational into quartz-plagioclase gneiss, west shore of Sterling Lake.
TM5. From near top of Taylor Mt. along Appalachian Trail.
F1-22. West side of Taylor Mt., 300 feet south of Appalachian Trail.
F4-1b. Interlayered with amphibolite ("hornblende gneiss"), 3,700 feet east-northeast of Bellvale.
F3-10b. Ridge west of Cascade Lake.
E8-71. Brimstone Mt. inlier.

plagioclase gneiss appears to change into hornblende-feldspar gneiss along strike. Exposures are poor, however, so the nature of this apparent change is not clear.

Quartz-microcline-plagioclase gneiss

Quartz-microcline-plagioclase gneiss forms the bulk of the ridges of Warwick and Taylor Mountains and the anticline southwest of Warwick. Table 8 shows the range of composition of the gneiss. Two major sub-types are apparent, and subdivision would be warranted if they could be recognized in the field. The two types are quartz-plagioclase gneiss with minor potash feldspar, and potash feldspar-plagioclase gneiss with minor quartz.

The quartz-plagioclase and potash feldspar-plagioclase sublithologies are very similar in outcrop and are rather intimately associated. Bright-green altered augite and raised blebs of pale lavender-gray quartz on a smooth gray-white outcrop surface generally serve to distinguish the quartz-plagioclase variety. Outcrops are rather massive but aligned quartz and mafic minerals impart a faint foliation. The potash feldspar-plagioclase variety is distinguished in some places by more biotite and buff weathering. All gradations between the two exist, however.

Quartz-microcline-plagioclase gneiss is nearly everywhere interlayered with amphibolite to some extent. The best example is the three amphibolite layers which outline the anticline west of Taylor Mountain. Contacts there between gneiss and amphibolite range from extremely sharp to completely gradational through a distance of several feet. The gradations may involve subtle change in percentage of disseminated hornblende, or change in abundance of hornblende-rich schlieren in the gneiss away from the amphibolite.

Plagioclase alaskites are abundantly associated with the quartz-microcline-plagioclase gneiss and they commonly are hard to distinguish from leucocratic members

TABLE 8.
Approximate modes (volume %) of quartz-microcline-plagioclase gneiss

	F4-26	PM-1	C7-34	F1-20	F1-12	C7-40	F4-3	2	3	4	30
Plagioclase	49.9	52.5	25.0	48.0	52.7	52.1	43.4	28.8	52.0	61.1	52.2
Quartz	3.9	37.9	31.6	0.1	4.4	13.0	25.8	0.7	1.1	25.0	21.4
Potash feldspar	31.8[1]	4.9	40.8[1]	26.1[1]	36.8[1, 2]	3.4	23.4[2]	61.1[1]	32.9[1]	6.5	14.4
Hornblende		1.0									5.2
Clinopyroxene		0.3		17.6	0.3	15.3		5.3	4.2	4.8	
Orthopyroxene	3.0	0.1									
Biotite		01				14.5	0.2	0.3			5.0
Magnetite	7.4	1.6	1.6	2.6	1.0	0.2	1.8	0.4	1.2	0.5	1.8
Sphene	tr.	0.3		4.5	1.3			1.2	2.7	0.9	
Chlorite/alter.	4.0	1.2	0.8		0.8	1.4	4.8	1.3	2.7	0.9	
Apatite				0.1	0.3	0.1	0.4	0.8	0.8	0.3	tr.
Epidote									2.4		
Zircon		0.1	0.1		0.1		0.1		tr.		tr.

[1]Microperthite, chiefly microcline microperthite, some microantiperthite.
[2]Microcline.
F4-26. East ridge of Warwick Mt., 9,000 feet southwest of Bellvale.
PM-1. Parrott Mine, hill south of Warwick Mt., 600 feet north of Cascade Lake Road.
C7-34. 1,200 feet east-northeast of intersection of Moe Rd. and Conklin Rd.
F1-20. 1,600 feet east-northeast of intersection of Bowen Rd. and road south from Warwick.
F1-12. Warwick Mt., 3,000 feet due east of crest of Rocky Hill.
C7-40. 2,700 feet west-northwest of intersection of Moe Rd. and Conklin Rd., at "R" of "Reservoir".
F4-3. 2,000 feet northwest of intersection of Buttermilk Falls Rd. and Cascade Lake Rd.
2,3,4. Interlayered series, west slope of Warwick Mt., southeast of Rocky Hill.
30. Bowen Road at west boundary of Greenwood Lake Quadrangle.

of the gneiss except where alaskite cuts across or embays layers of gneiss. One fairly certain example of cross-cutting and assimilation of amphibolite by the gneiss, however, was noted near the south end of the east ridge of Warwick Mountain (figure 4).

In the southern part of Taylor Mountain, a change along strike from quartz-microcline-plagioclase gneiss to hornblende-feldspar gneiss is shown schematically on the map. The transitional area is poorly exposed except for lenses and pods of plagioclase alaskite, but to the north, the alaskite clearly is associated with quartz-microcline-plagioclase gneiss, and to the south it is interleaved irregularly with the darker gneiss. Modes of samples from this area are given in Table 9. The nature of the transition is uncertain; it may be an igneous contact relationship, or an original sedimentary transition, or an apparent change due to infolding. As minor structures indicative of complex folding were not observed, the last possibility is considered remote.

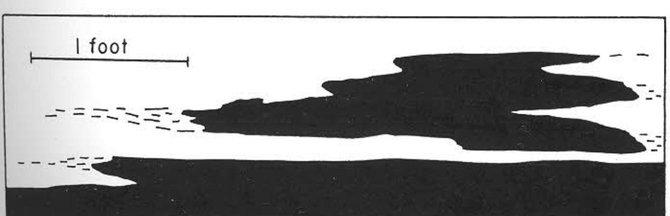


FIGURE 4. Amphibolite layers or schlieren in quartz-microcline-plagioclase gneiss; layers parallel a faint foliation in the enclosing gneiss. East ridge of Warwick Mountain, 2½ miles west of Cindy Linda Lake.

Under the microscope, most specimens of quartz-microcline-plagioclase gneiss have granoblastic fabrics of quartz, microcline or microcline microperthite, and plagioclase. Quartz commonly occurs in long, thin leaves or large grains characteristic of a recrystallized fabric. Microcline and clear plagioclase typically form the mosaic granoblastic fabric, but in some specimens microperthite exceeds nonperthitic microcline in abundance. The mi-

TABLE 9.

Approximate modes of transitional series between quartz-microcline-plagioclase gneiss and hornblende-feldspar gneiss of the middle block.

	TM-1	TM-2	TM-3	TM-5
Plagioclase	15.1	14.7	45.3	21.4
Quartz	17.7	1.9	5.4	6.4
Microperthite[1] and Microcline[2]	61.1[1]	66.9[1]	35.6[2]	44.1[2]
Hornblende	0.8	4.4	6.5	25.6
Biotite		0.4	1.4	
Clinopyroxene	3.6			
Orthopyroxene		6.4		
Magnetite	1.2	2.6	3.2	1.1
Sphene	0.3	1.0	0.5	0.3
Chlorite/alter	0.2	1.7	2.1	1.0
Apatite		0.1		tr.
Zircon		tr.		tr.

Series of samples taken from north to south as nearly as possible along strike of a single zone south of Appalachian Trail on Taylor Mt. TM-1 is quartz-microcline-plagioclase gneiss; TM-5 is hornblende-feldspar gneiss; TM-2, TM-3 are transitional types.

croperthite may occur in separate grains or as irregular patches within clear plagioclase. It is characteristic of specimens with irregular fabrics. Plagioclase is antiperthitic in some specimens, with poorly twinned microcline occurring in tiny blebs or large patches (figure 5) suggestive of an exsolution mechanism. Rarely, some feldspar grains are mesoperthite (plagioclase and potash feldspar in equal amounts) with plagioclase the host. Microcline commonly replaces plagioclase, perhaps in a continuation and extension of the reorganization seen in the exsolution antiperthites.

Pyroxenes may be present in varying amounts; hypersthene is usually very subordinate to clinopyroxene. Hypersthene is everywhere much altered to shreddy mats of antigorite and chlorite. Biotite is prominent in the first type; and sphene is common to abundant throughout.

In the middle block to the south, Buddington and Baker (ms.) have been able to differentiate among several lithologies which, from the modal data available, seem to fall roughly within the broader compositional range of quartz-microcline-plagioclase gneiss. Their units (Table 10) in this category include hornblende and pyroxene syenite gneisses, hypersthene-quartz-plagioclase gneiss, and bio-

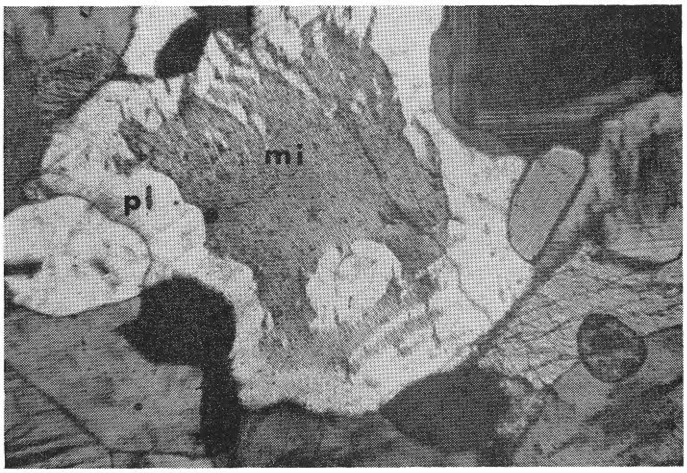


FIGURE 5. Photomicrograph of microcline within plagioclase in quartz-microcline-plagioclase gneiss, probably the result of reorganization of mesoperthite.

tite-quartz-oligoclase gneiss. Representative modes of these units are given in Table 10, but their compositions vary considerably and accurate sampling and comparison are difficult. Buddington interprets the syenites as igneous and metaigneous rocks, the hypersthene-quartz-plagioclase gneiss as metasedimentary because it contains disseminated graphite, and the biotite-quartz-oligoclase gneiss as uncertain in origin.

Buddington and Baker observed petrographic features in the syenitic rocks similar to those just described for quartz-microcline-plagioclase gneiss. They found two unrecrystallized specimens composed of mesoperthite, which they regarded as relicts of the original igneous fabric. The remainder of the syenite specimens provided a textural series from which Buddington and Baker inferred that the breakdown of mesoperthite to form discrete grains of microcline and oligoclase increased with degree of recrystallization. They suggested that sodic fluids probably promoted the reorganization.

In the rocks described here, a similar relationship seems to hold generally, but irregularities on a small scale tend to obscure it. Both replacement of plagioclase by potash feldspar and of potash feldspar by plagioclase were observed. Probably the mutual replacement occurred as a result of reorganization of microperthite.

The term "recrystallization" has been used. This is based on assumption of an older igneous or metamorphic texture which has been modified at some later time. This is justified if mesoperthite indicates magmatic crystallization, and if the mesoperthite specimens are indeed relicts of an older texture. An alternate, but less likely supposition is that mesoperthite formed by very local

TABLE 10.

Approximate modes of rocks in Franklin-Hamburg area, N.J., comparable in part to quartz-microcline-plagioclase gneiss.*

	1.	2.	3.	4.
Microcline and microperthite	41.3	42.4	6.3	18.4
Oligoclase	44.9	45.2	67.0	51.1
Quartz	2.5	3.9	18.0	17.5
Hypersthene			4.3	
Augite	2.1	3.9		
Hornblende	7.4	0.5	2.1	
Magnetite/Ilmenite	1.3	1.2	0.4	
Apatite	0.3	0.4	0.3	
Zircon	0.1	0.1		
Sphene	0.1			
Epidote/chlorite		2.4		
Biotite			1.4	2.9
Graphite			0.2	

1. Average of 2 sections of hornblende syenite gneiss a mile north-northeast of Summit Lake.
2. Average of 2 sections of pyroxene syenite gneiss within a mile north of Edison.
3. Hypersthene-quartz-plagioclase gneiss, east border of Franklin Quad., 1.4 mi. north of Pacock Brook.
4. Biotite quartz-plagioclase gneiss, about 900 feet northwest of Russia.

* Data from Buddington and Baker ms., Tables 3, 11, 22.

partial melting during high-grade metamorphism. It is also possible that the mesoperthite formed slightly below melting temperature under granulite facies conditions of metamorphism. Experimental evidence does not favor metamorphic origin for mesoperthite, but the possibility is not ruled out, because the complexities of a natural metamorphic environment have not yet been duplicated in experimental work.

Quartz-plagioclase gneiss

This gneiss, mapped by Hotz (1953) as quartz-oligoclase gneiss, is one of the major units of the east block. To the south, Sims found it present only in minor layers; he mapped a unit equivalent in areal extent and very similar in outcrop as quartz diorite because it carried andesine rather than oligoclase. The two units are so much alike, that quartz-plagioclase gneiss may simply become more calcic southward, but the intervening area has not been mapped and no connection has been established, so that the gneiss may die out within eight miles south of the State line.

Comparable quartz-oligoclase gneiss, mapped by Hague (1956) as Losee gneiss, occurs in the cores of two large anticlines, one at the west edge of the middle block and the other in the west block, separated by a synclinal sequence of west block metasediments.

Quartz-plagioclase gneiss is gray-green to medium green on fresh surfaces, and weathers gray-white in smooth, rounded outcrops. In part, the rock is so massive that foliation and lineations are not apparent, but generally alignment of mafic minerals or slightly elongate quartz can be discerned. Some zones contain numerous schlieren or septa of amphibolite oriented parallel with the foliation of the gneiss. These zones have rough, corrugated, brown weathered surfaces. Amphibolitic material is only locally abundant within the gneiss and hence cannot be readily shown at the scale used for the map. Distinction between "gnc" and hornblende-feldspar gneiss in the field is in places fairly subjective, but generally the inclusionlike nature of amphibolitic material in a more leucocratic matrix serves to distinguish "gnc" from the other, more uniformly hornblendic gneiss.

In proximity to hornblende granite at the north and south ends of the map area, quartz-plagioclase gneiss commonly is cut by small, irregular veins of pink and white alaskite or pegmatite. Such zones are marked by rough surfaces which weather more buff than the usual gneiss.

Contact effects against amphibolite range from none to crosscutting and intermingling on a considerable scale. In some places amphibolite layers are pulled apart, and embayed by the enclosing gneiss only on the butt ends of the fragments. Commonly, though, the relations depicted in figures 6 and 7 may be observed. Recrystallized selvages of hornblende and feldspar are common at contacts, but in only one place was finely crystalline border facies

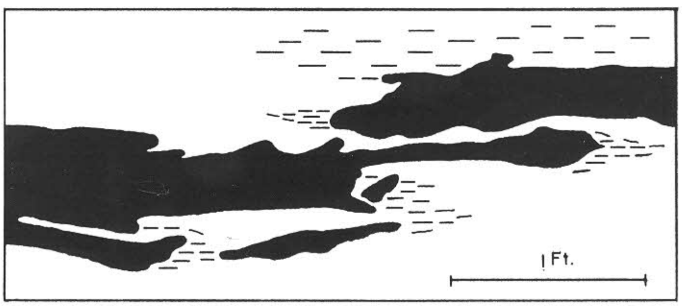


FIGURE 6. Amphibolite layers or schlieren in quartz-plagioclase gneiss; layers parallel a faint foliation (not shown) in the enclosing gneiss; 5,500 feet due west of Sterling Forest lookout tower.

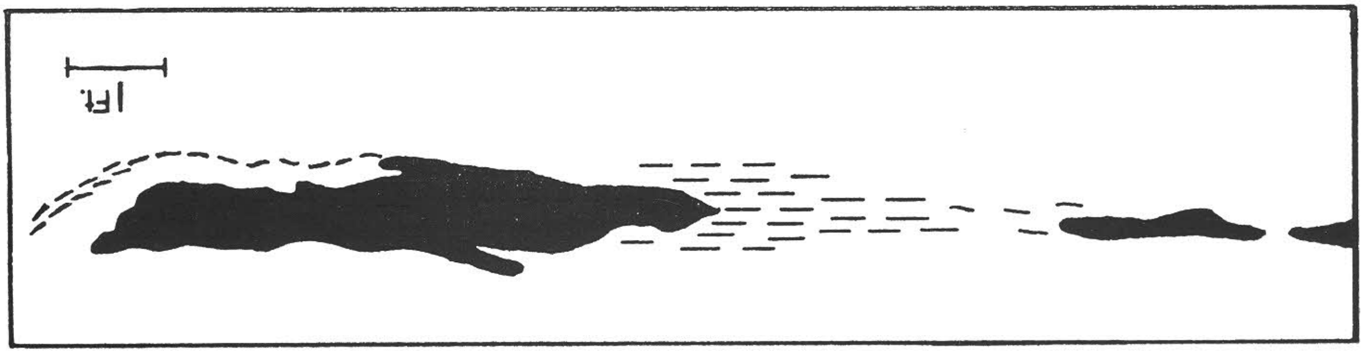


FIGURE 7. Amphibolite layer or schlieren in quartz-plagioclase gneiss; at power line 6,000 feet west-northwest of northeast corner of Sterling Lake.

observed that might be construed as a chilled margin in the gneiss.

In several places (e.g., around the south end of Sterling Lake) an apparently gradational series from quartz-plagioclase gneiss through hornblende-feldspar gneiss to amphibolite can be observed. Mineralogic composition, texture and foliated character change subtly in the transition. A similar series was described for the quartz-microcline-plagioclase gneiss of the middle block. The leucocratic and intermediate members of the two series bear strong resemblances, the only important difference being potash-feldspar content.

In thin section, quartz-plagioclase gneiss is even textured, with a hypautomorphic-granular fabric. Granulation and strain features are uncommon. Tables 11 and 12 give modal compositions of the gneiss and of comparable rocks

TABLE 11.
Approximate modes (volume %) of quartz-plagioclase gneiss

	17	F8-38	F8-36	F8-45	F8-35	F5-2	F7-18	F7-31	F7-26
Plagioclase	60.7	34.9	56.4	63.4	56.4	68.5	69.0	66.0	60.4
Quartz	3.4	45.8	42.6	23.9	36.5		16.7	28.4	28.2
Potash feldspar	0.2	15.9	1.0	1.3	1.9		1.4	1.5	5.2
Hornblende					1.3	7.0	7.8		1.4
Biotite		1.5			3.4	0.4	0.7		0.4
Clinopyroxene	3.8			8.9	0.1	22.4	2.6		
Orthopyroxene								2.7	3.2
Magnetite	1.0			2.2	tr.	0.2	1.1	1.3	0.2
Sphene				0.1					
Chlorite/alter.		1.0			1.0	1.4	0.4	0.1	1.0
Zircon	tr.	tr.		tr.	tr.		tr.	tr.	
Apatite	0.2			0.1	0.2		0.1		

17. Route 17A, 700 feet east of BM 839, at Greenwood Lake town line.
F8-38. 8,000 feet due west of Lakeville.
F8-36. 2,000 feet N. 50°E. of word "Creek" in "Jennings Creek".
F8-45. East border of Greenwood Lake Quad., north edge of McKeags Meadow.
F8-35. 1,600 feet from shore due west of word "Lake" in "Sterling Lake".
F5-2. West side of Jennings Creek 1,200 feet north of State line (gnc).
F7-18. 1,800 feet due north of northernmost tip of Sterling Lake.
F7-31. 800 feet from shore at hill 1000, northwest corner of Sterling Lake.
F7-26. 3,000 feet northwest along powerline from northeast tip of Sterling Lake.

in the New Jersey Highlands. The plagioclase is clear; albite twinning is abundant, and pericline twinning is also present. Plagioclase composition ranges from An_{20} to An_{40} if mixed varieties are considered, but is An_{28-32} in the principal type. It is slightly antiperthitic in some specimens, but the very small percentage of potash feldspar shown in the modes is orthoclase which occurs in tiny, interstitial grains or partial replacements of plagioclase.

TABLE 12.

Approximate modes of New Jersey Highlands rocks comparable to quartz-plagioclase gneiss.

	V775	V.847-F	1315	1	2
Plagioclase	78.3	62.2	58.7	59.0	64.8
Quartz	15.4	33.4	30.8	36.0	32.2
Potash feldspar	1.9	1.0			0.5
Hornblende	3.6		4.4	2.6	
Biotite		3.3		1.5	
Clinopyroxene	0.6				
Orthopyroxene			4.7		
Magnetite			1.3		0.3
Other	tr.	tr.	0.1	0.9	2.2

V775. Losee gneiss, 8,400 feet due south of Sparta (middle(?) block); Hague (1956), Table 3.

V.847-F. Oligoclase gneiss 7,800 feet S.85°W. of Ogdensburg (west block); Hague (1956), Table 3.

1315. Hypersthene-quartz-plagioclase gneiss 1,100 feet northwest of lake southwest of Mt. Paul (middle block); Buddington and Baker ms., Table 3.

1. Average of 12 sections of Losee gneiss, Losee Pond belt (middle block); Buddington and Baker ms., Table 21.
2. Quartz-oligoclase gneiss, average of 2 sections from north of Sickle Pond (middle block); Buddington and Baker ms., Table 21.

Quartz is mostly in irregular, small, interstitial grains, but it also occurs as larger, elongate blebs. Both varieties partially embay plagioclase. Diopsidic augite and hypersthene are generally present, but none of the sections examined contained both. The augite is pale green to colorless in thin section, and is marked in hand specimen by characteristic bright-green weathering. Hypersthene is pleochroic pink and green, and is more common than augite. It is almost everywhere unaltered but in places it is partly altered to a shreddy antigoritic mat along fractures. Green hornblende and brown biotite may be prominent constituents locally. They do not have replacive relationships with pyroxene or with each other. Interstitial magnetite is present in nearly all sections.

Observed contact effects are minor. West of Cindy Linda Lake, alaskite locally has a finely crystalline border facies as much as six inches wide, and sprinkled with tiny red-brown garnets. This facies occurs next to pyroxene gneiss, the alaskite apparently having extracted components necessary to form garnet, probably almandine. At Sugarloaf Mountain, in the power line cut, quartz-plagioclase rocks in contact with sodic alaskite show heavy epidotization, chloritization, sericitization, and contain large, pink albite porphyroblasts. A large part of these effects is probably due to retrograde metamorphism induced by late intrusion of water-rich alaskite, but the inlier rocks have been so badly sheared during faulting that it is difficult to separate the retrograde effects induced by shearing. Late faulting elsewhere in the Highlands, however, has not resulted in retrograde phenomena other than chlorite-epidote fracture-fillings, so the effects described are believed to be contact effects for the most part.

Alaskite normally is unfoliated, because of the absence of dark minerals, but gneissic foliation is, in places, well developed by the alignment of quartz blebs in discontinuous planes. In the "pseudoalaskites," foliation consists of aligned biotite and quartz blebs, and quartz-rich layers. Outcrops weather pale-brown or pinkish and have rough, rubbly surfaces. Quartz blebs stand up in relief and rusty pocks may develop from weathering of magnetite or pyroxene.

Textures are coarsely hypautomorphic-granular in most of the plagioclase alaskites and granoblastic in the normal alaskites. Typical modal compositions are given in Table 13. Potash feldspar is microcline, commonly very perthitic. In the plagioclase alaskites, the plagioclase is albite-oligoclase, clear or sericitized and albite twinned. In the pyroxenic alaskites, plagioclase is extremely antiperthitic (figure 8). As much as 60 percent of individual antiperthite grains may be potash feldspar present as sharp-bordered anastomosing stringers in plagioclase. Replacement of plagioclase by potash feldspar is evident in most thin sections, but the perthitic textures suggest exsolution (figure 8). It is possible that the replacement features are the result of fairly late-stage reorganization of exsolved potash feldspar.

Hornblende or biotite is generally present in minor amounts. Magnetite in disseminated equant grains is a frequent accessory, and often makes up 4 to 5 percent of the rock.

TABLE 13.
Approximate modes (volume %) of alaskite and alaskite gneiss

	F3-10d	F3-10e	F3-11	E8-7	7	F4-6	C7-20	C7-15	C7-47
Plagioclase[1]	20.6	55.9	16.4	65.0	22.7	40.6	9.2	12.0	32.0
Quartz	41.3	39.0	33.7	35.0	51.3	11.8	33.6	27.2	23.0
Potash feldspar[1]	35.6	1.1	46.8		12.5	34.4	52.0	54.4	40.4
Hornblende						0.8	2.8		2.6
Biotite	2.0	2.6					0.8	5.4	
Magnetite	0.1	0.2	tr.		5.4	4.1	1.2	0.8	0.2
Other	0.3	1.1	3.3		8.6	8.3	0.4		1.8

[1]Feldspars generally perthitic or antiperthitic up to 50-50 mix (mesoperthite).
F3-10d. Ridge west of Cascade Lake.
F3-10e. Ridge west of Cascade Lake.
F3-11. Ridge west of Cascade Lake.
E8-7. Snake Mt. thrust block.
7. Route 17A just west of faulted contact with Bellvale sandstone.
F4-6. 900 feet south-southwest of No. 7.
C7-20. Pyroxenic alaskite, west side of ridge south of Hoyt Road.
C7-15. Pyroxenic alaskite, east border of Wawayanda Quad., 1,300 feet north of Black Rock Rd.
C7-47. Pyroxenic alaskite, at State line 1,900 feet east of Iron Mt. Road.

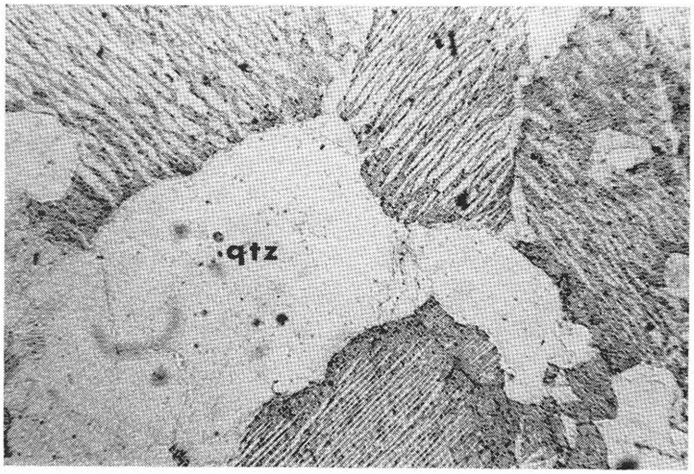


FIGURE 8. Photomicrograph of variations in mesoperthite development in pyroxenic alaskite. Dark stringers and patches are microcline, light stringers are plagioclase.

Igneous rocks

Alaskite and alaskite gneiss

Alaskite is a granitic rock containing less than five percent mafic minerals. It is prominent in certain areas of the hornblende granite of the east block, but only a few rather isolated masses are shown as alaskite. The main development of alaskite is in the middle block, in narrow belts or zones generally concordant to the surrounding gneisses.

One prominent zone is that along the east border fault of the middle block. Here, alaskite occurs in layers and large pods associated with amphibolite and quartzose metasediments. It is quite concordant except at the sharp hill west of Cindy Linda Lake, where the relationship to metasedimentary rocks is obscure. This may be an area of discordant intrusion of alaskite, or of intrusion phacolithically into a fold whose form is now obscure, or where unrecognized faulting has altered original relationships. The alaskite along the border fault is shattered; epidote and chlorite fracture filling is extremely common.

The alaskites associated with metasediments at Rocky Hill south of Warwick, and on the ridge west of Cascade Lake are very granular and quartz-rich. This variety is mostly granitic in composition but almost certainly represents somewhat modified original sedimentary layers. In places it contains thin bands of which 90 percent is granular quartz. The amount of metasomatic addition of potash, soda or other material, if any, to form these "pseudoalaskites" could not be ascertained.

On Warwick Mountain, the term alaskite is perhaps overextended to include granite pegmatite which makes the long, narrow layers on the east side of the ridge and the two lenses (actually the outcrop patterns of horizontal cross-cutting sheets) on top of the ridge. These pegmatites are associated with magnetite-uraninite mineralization, although no genetic connection has been shown.

In the inlier complex, alaskite is pink and white like a normal alaskite, but consists of plagioclase and quartz. Plagioclase alaskites are common elsewhere in the area, but they are white. The origin and significance of the local pink color of plagioclase (albite-oligoclase) are not known, nor is the origin of the plagioclase alaskites in general.

West of the anticline southwest of Warwick, alaskite is abundant, and differs from the remainder of the alaskites by containing small, scattered clots of pyroxene which alters to bright green on weathered surfaces. This variety of alaskite probably matches Buddington's pyroxene granite or pyroxene alaskite in New Jersey.

Hornblende granite and hornblende granite gneiss

In the present area, hornblende granite is confined to the east block, but available maps of the middle block show prominent belts of hornblende granite or Byram gneiss to the south in New Jersey. Eight miles south, in the east block, Sims' map shows rocks of this general character to be the most abundant lithologies.

The main body of granite is the hook-shaped mass which follows the west limb and the keel of the syncline west of Sterling Lake (plate 1). South of the syncline the granite broadens into an irregular shape. This body, which has the shape of a typical phacolith (an intrusive mass filling a dilatant space in the keel or crest of a fold), consists of both hornblende granite and hornblende granite gneiss. Granite gneiss occupies the attenuated west limb of the syncline. Planar structures fade in the keel of the syncline, and unfoliated granite, rather than granite gneiss, occupies the keel and the short east limb. Distribution of the two lithologic types is inconsistent in the rest of the body. Granite gneiss is a contact facies only locally, and commonly occurs in ill-defined areas within unfoliated granite.

Northwest of the granite gneiss of the west limb of the syncline is a symmetrical repetition of rock units. In Monroe Quadrangle, northeast along strike, an anticlinal axis was observed in the quartz-plagioclase gneiss. Thus the two narrow layers of granite appear to define an anticline west of, and complementary to, the large syncline. The layers and the nearly vertical structure are continuous northeastward to the Paleozoic onlap south of Monroe.

The extent southward, and geological relations of the large mass of granite at Sterling Forest Village are unknown. On its east contact, the granite is subtly interfingered on a small scale with quartz-plagioclase gneiss; the type of granite involved is pink alaskite, almost pegmatitic in coarseness.

Such interfingering at contacts is uncommon. Typically, contact effects are negligible, as at the upper contact of the granite gneiss on the southwest corner of the large syncline. There, granite and hornblende-feldspar gneiss are separated by only a 1-foot covered interval, and the only effect observed was a few thin concordant stringers of coarse, white alaskite in the bottom few feet of the upper unit. These stringers were also present in the adjacent granite and may be very late-stage phenomena, not directly attendant upon intrusion of the granite. Similar pink or white pinch-and-swell stringers are seen elsewhere, principally in amphibolite next to granite.

At the contacts of granite and amphibolite in the power line cut four miles north of Greenwood Lake and east of Little Cedar Pond, the granite contains numerous schlieren of amphibolite which decrease in number into the granite. Coarse alaskite or pegmatite may cross-cut amphibolite layering very slightly. On the hill east of Sterling Cemetery, disoriented, "floating" blocks and short layers of amphibolite occur within essentially structureless hornblende granite. Corrosion and assimilation of amphibolite is minor.

Relations of granite to quartz-plagioclase gneiss are more obscure, but the presence of coarse alaskite extending in sharp fingers into the gneiss at the north end of Jennings Brook, the previously mentioned minor interfingering at contacts, and the intrusive relation of granite to amphibolites often interlayered with quartz-plagioclase gneiss all suggest that granite intrusion or mobilization was late with respect to formation of the gneiss.

Hornblende granite weathers buff-pink and is a medium-crystalline, poorly foliated rock. Throughout the granite are areas of unfoliated medium- to coarse-textured pink and white alaskite. The alaskite is virtually mafic-free; magnetite is present in minor amounts. A poor lineation is in places developed on elongate blebs of gray-white quartz.

With increase of hornblende and streaking-out of the mafic mineral to form a planar structure, hornblende granite grades into hornblende granite gneiss. The gneissic facies is fine- to medium-textured, generally a little finer than the granite. The gneiss weathers more buff and is smoother on outcrop surfaces than the granite. Extremely fresh surfaces of both varieties are medium green.

Modal compositions of representative specimens of both phases are given in Table 14. Microperthite, quartz, and plagioclase make up the bulk of the rock; hornblende and magnetite contribute 10 percent or less by volume. The potash feldspar is largely microperthite, but microcline

TABLE 14.

Approximate modes (volume %) of hornblende granite (gh) and hornblende granite gneiss (hg)

	F8-34	F8-53	F7-30	F5.7	F5-7a	F8-49a	F8-49b	F8-51	F5-15
Plagioclase	7.4	20.5	27.6	34.9	16.2	27.3	17.7	25.4	20.8
Quartz	34.2	24.5	31.3	31.3	35.6	27.2	27.3	20.5	31.7
Microperthite	52.9	54.4	40.4	29.7	42.2	39.9	50.2	44.9	40.3
Hornblende	3.4			3.7	6.0	3.1	0.6	7.9	3.1
Biotite				0.1		0.2			0.3
Orthopyroxene						0.3	1.3		
Magnetite	1.4	0.3	0.7	0.2		1.2	2.4	1.1	0.8
Zircon	0.2	tr.				0.1	0.2	0.1	tr.
Apatite	0.3		tr.			0.1	tr.	0.2	0.2
Chlorite/alter.	0.3	0.3				0.6	0.2	0.1	1.7

F8-34. (gh) 6,000 feet due west of northwest end of Sterling Forest Lake.
F8-53. (gh) 100 feet below contact with hornblende-feldspar gneiss, 1,000 feet west-southwest of Sterling Forest Lookout tower.
F7-30. (gh) 4,300 feet S. 20°E. of Chapel Island (in Greenwood Lake).
F5-7. (gh) 4,000 feet due east of Sterling Forest Village.
F5-7a. (hg) 4,000 feet due east of Sterling Forest Village.
F8-49a. (hg) 2,600 feet due east of southeast corner of Little Cedar Pond.
F8-49b. (gh) 2,600 feet due east of southeast corner of Little Cedar Pond.
F8-51. (hg) North-central edge of Little Cedar Swamp.
F5-15. (hg) On highway 6,000 feet northeast of Sterling Forest Village.

is locally prominent, especially in the gneissic phase. Plagioclase is sodic oligoclase (An_{12-18}), which has minor albite twinning. Against grains of potash feldspar, plagioclase may have bleached albitic rims or myrmekitic quartz intergrowths. Green hornblende is in a few places slightly altered to chlorite, and near shear zones, both biotite and chlorite replace hornblende.

Textures are hypautomorphic-granular and strain features are uncommon. In some specimens, the fabric is interrupted by large, elongate quartz grains or accumulations of magnetite.

Modal feldspar and quartz percentages are plotted on a triangular diagram in figure 9. The resulting cluster is more removed from the plagioclase corner than are average granites. The plot resembles that for the high-temperature Skye granites discussed by Tuttle and Bowen (1958, cf. figure 55, p. 110), and for which they showed the discrepancy to be related to plagioclase held in solid solution in the alkali feldspar. In the present example, it appears that orthoclase of a high-temperature granite contained considerable amounts of plagioclase components and that exsolution of the two phases occurred during cooling. In figure 10, the exsolved plagioclase has been subtracted from the modal percentage of microperthite for the compositions plotted in figure 9. The result is a cluster which corresponds more nearly with the average granite.

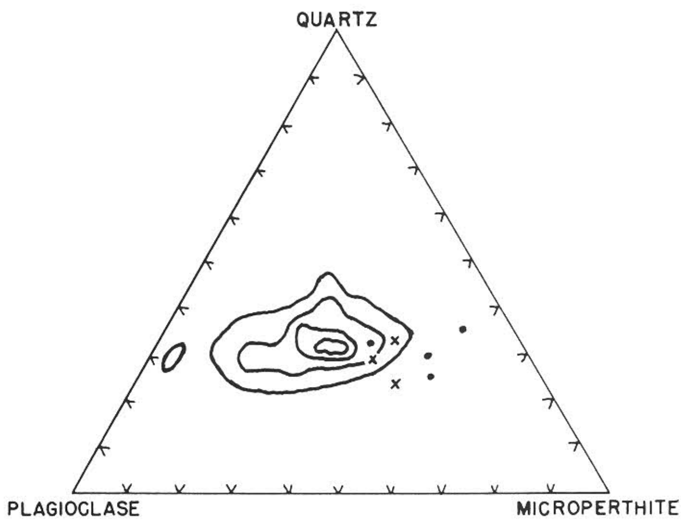


FIGURE 9. Modal plagioclase, microperthite, and quartz in hornblende granite (●) and hornblende granite gneiss (x). Contours show compositional fields of 260 granite samples from eastern United States (Tuttle and Bowen, 1958, figure 56).

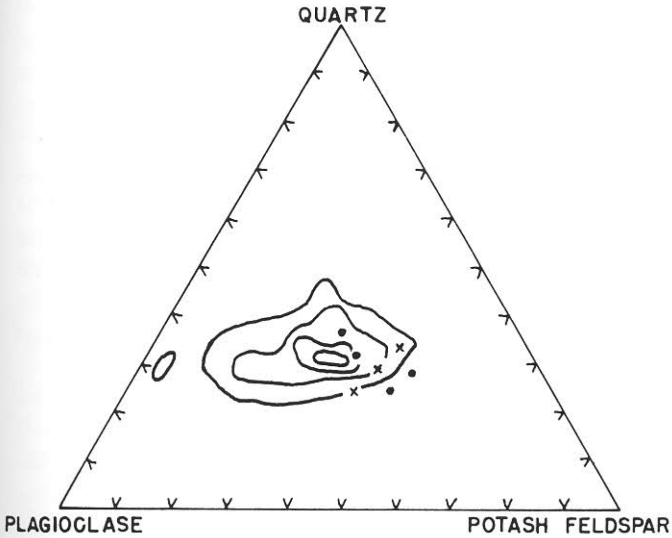


FIGURE 10. Modal plagioclase, potash feldspar, and quartz in rocks of figure 9, with microperthite components plotted separately. Contours show compositional fields of 260 granite samples from eastern United States (Tuttle and Bowen, 1958, figure 56).

Hornblende-biotite granite

Hornblende-biotite granite is associated with the folded series of metasediments at Mounts Adam and Eve, and Pochuck Mountain. It also occurs in isolated lenses and pegmatitic dikes throughout the Franklin marble.

The granites of Mt. Adam and Pochuck Mountain are identical, consisting of buff-gray feldspars, gray quartz, and dark-brown biotite in a medium- to coarse- hypautomorphic-granular fabric. Microcline displaying sharp twinning and albite-oligoclase which has Carlsbad and albite-pericline twinning are the feldspars. Irregular networks and islands of plagioclase within microcline are common; plagioclase typically shows a light-colored, slightly more sodic rim against microcline grains. Biotite occurs in disseminated flakes and clusters, and is secondary after hornblende in part. Greenish-brown hornblende is commonly present in accessory amount, and in places is a varietal mineral. Allanite is a common accessory mineral; its rusty weathering discolors and weakens the granite which would otherwise be an excellent building stone. Allanite in the isolated pegmatites is suggestive of a genetic relation with the main granite. Trace amounts of interstitial fluorite were observed in thin section. Sharply euhedral, doubly terminated zircon occurs in accessory amounts. Euhedral magnetite is also present.

The Mt. Eve granite is similar, (Table 15) but is finer grained and weathers buff. It is nearly structureless within the mass, but becomes foliated near its contacts with the metasediments. Microcline microperthite is characteristic of the granite except at the margins, where sharply twinned, clear microcline is present. Allanite is not common. Quartz is anhedral throughout, apparently replacing microcline in part; it occurs as myrmekitic blebs and hooks in plagioclase in the marginal facies of the granite. Biotite partly altered to chlorite and containing skeletal grains of leucoxene is a common feature of the marginal facies.

TABLE 15.
Approximate modes (volume %) of hornblende-biotite granite.

	B8-92	B8-92a	27	B5-26
Plagioclase	14.8	8.8	38.8	15.8
Quartz	24.1	34.1	22.5	20.6
Microcline[1]	48.1[2]	53.8	30.8	55.0
Hornblende	12.2		2.5	
Biotite		1.1	3.2	0.4
Magnetite	0.7	2.1	0.5	3.4
Sphene			0.7	
Zircon	tr.			0.1
Apatite	tr.			0.1
Chlorite/alter.			0.5	4.4

[1] Slightly microperthitic in part.
[2] microperthite.
B8-92. Mt. Eve, center of area between metasediment belts.
B8-92a. Mt. Eve, contact facies against microcline gneiss.
27. Quarry, along road on east side of Mt. Adam.
B5-26. Northwest corner of Mt. Adam.

Both varieties of granite have greenish-brown hornblende in minor amounts, commonly containing euhedral grains of zircon. In the Mt. Eve mass, hornblende in places exceeds biotite in percentage or even occurs exclusive of biotite. Near marble, plagioclase may be scapolitized and clots of bright green pyroxene are characteristic. Hornblende and biotite alignment imparts foliation near contacts and lineations throughout. Fabrics show no features of strain or recrystallization, except for minor granulation in border facies at a few places.

Effects of granite intrusion on the surrounding marble were discussed in the section on Franklin marble. The abundance of volatiles (water, fluorine, chlorine, etc.) introduced with the granite is evident from the aureoles rich in chondrodite, scapolite, and various hydrous phases.

Basic dikes

Basic dikes, all basaltic and nearly aphanitic in texture, have been observed in only three places. One is a 5-inch dike, which fills a fracture and pinches out on one end, in quartz-plagioclase gneiss 6,800 feet due west of the center of Sterling Lake. A similar narrow dike, with flecks of biotite, and tiny "eyes" of calcite, occurs in the northeast corner of Greenwood Lake Quadrangle, 1,800 feet west-southwest of BM 1215. The third dike is a series of sheared, broken, and disconnected pieces at the crest of the hill just west of the power line crossing the east side of Sugarloaf Mountain.

The dikes are tentatively assigned to the Precambrian. At least the one at Sugarloaf Mountain must be older than the faulting of the inlier block. Hague showed a dike cutting Cambrian dolomite 1.4 miles southwest of Pine Island, but in three visits to the locality, I was unable to find it. Similar dikes, however, cut the Wappinger dolomite along the New York State Thruway south of Harriman.

PETROGENESIS

Metasedimentary rocks

Marble

The Franklin marble is the result of regional metamorphism of rather pure limestone with minor dolomitic layers. Simple recrystallization was predominant, during which minor amounts of carbonaceous material became graphite, and minor silica combined with other elements to form various silicate minerals. Pervasive metasomatism involving water, fluorine, and chlorine is evident throughout the marble but is developed to a striking degree in proximity to granitic intrusive bodies. Even minor pegmatites develop aureoles of chondrodite, fluorite, scapolite, and many exotic silicates in the surrounding marble. Skarn assemblages of pyroxene and sphene at contacts and in isolated lenses within marble probably indicate local metasomatic introduction of silica, magnesia, and titanium which reacted with calcium from the marble, but may in part be original mafic intrusive material which was metamorphically reconstituted. Potash-soda metasomatism is indicated by the presence of orthoclase-scapolite laminae in a foliated amphibolite layer in marble at the Atlas quarry near Pine Island.

Pyroxenic rocks

Pyroxenic lenses in marble may be metasomatic products, as just discussed, or they may be recrystallized mafic intrusive rocks or impure dolomitic sediments of appropriate composition. The presence of such assemblages, often wholly anhydrous, in a unit characterized by accessory hydrous silicate minerals perhaps suggests recrystallization of water-poor sediments or intrusive rocks more than metamorphic reactions in the presence of water-rich metasomatic fluids.

Quartz-pyroxene gneisses or graphitic pyroxene gneisses associated with metasedimentary series almost certainly originated by recrystallization of sandy dolomite layers with little or no modification by metasomatism. Probably a similar origin holds for the skarn-type layers of the east block not specifically associated with granite or pegmatite.

Quartzo-feldspathic gneisses

This group includes graphitic quartz gneiss, graphitic quartz-plagioclase gneiss, biotite-garnet-plagioclase gneiss, quartz-microcline gneiss, and biotite-quartz-feldspar gneiss. A metasedimentary origin is indicated for these lithologies by their heterogeneous layered character, the abundance of quartz, and the common occurrence of graphite. Garnet and sillimanite are also characteristic of metasediments.

The quartzose gneiss undoubtedly represent metamorphosed impure sandstones with aluminous and carbonaceous layers now marked by sillimanite and graphite, respectively. Other gneisses poorer in quartz probably formed by reconstitution of shales or graywackes. However, in many of the gneisses, the plagioclase percentage indicates soda content in excess of that of average shales or graywackes. Although these gneisses show some evidence of metasomatic introduction, or at least reorganization, of potassic material, convincing evidence of sodic metasomatism to alter K:Na ratios is lacking. Engel and Engel (1953) have intensively investigated similar rocks in the northwest Adirondacks and conclude that the parent sedimentary material was probably sodic shale or tuff. Other possible parent rocks of appropriate composition are bedded cherts, common in many clastic sequences, which may carry more than 50 percent sodic plagioclase. These and any parent tuffs would be layers of pyroclastic origin, but metamorphic recrystallization would render them indistinguishable from rocks derived from ordinary sediments.

Quartz-microcline gneiss, interlayered in places with graphitic pyroxene gneiss, probably represents shales dynamothermally metamorphosed, with aluminous layers marked by development of sillimanite. The pink and white variety with layered quartz, feldspar and considerable epidote indicates an unusual degree of reorganization, perhaps in the presence of introduced granitic material. As sillimanite is best developed in quartz-microcline gneiss closely associated with granite, it is possible that some or all of the alumina in sillimanite is of metasomatic origin.

Addition of granitic material to the metasediments is also suggested by the character of the "pseudoalaskite" layers. They contain graphite and sharp bands of quartzite, but have coarse, hypautomorphic-granular texture quite different from the adjacent metasediments. The irregular potash feldspar distribution probably is the result of uneven introduction of material into these layers. It is believed that coarse recrystallization was promoted in the "pseudoalaskites" by the presence of a water-rich granitic interstitial phase, in part locally derived, and in part introduced during the pervasive introduction of alaskitic material throughout the area.

Rocks of uncertain origin

Amphibolite and pyroxene amphibolite

The origin of amphibolites is difficult to ascertain. Metamorphism of impure dolomitic sediments, basic volcanics, and mafic igneous rocks may produce amphibolites identical in composition and texture. Walker *et al* (1960) have shown that such convergence toward identical character is essentially complete in most terranes of upper greenschist facies, and that conditions of less intense metamorphism will suffice if substantial transfer of material by metasomatism occurs during metamorphism. They studied lithologic character, composition, trace element distribution, plagioclase twinning, and magnetic properties, and found that known para-and ortho-amphibolites were indistinguishable except in very local instances.

In the present area, all the amphibolites are products of high-grade metamorphism and cannot be traced into a lower grade terrane where the original nature might be determined. Metasomatic modification is apparent from the occasional abundance of scapolite and the prevalent association of magnetite deposits and amphibolite. An excellent example is the "uranium quarry" atop Warwick Mountain, where pyroxene amphibolite contains zones of pyroxene-scapolite-magnetite with scattered uraninite and abnormally high (70 ppm) tin content.

Evidence of original character is slight indeed. No relict igneous textures were observed, although Hague reported possible pillow structures in amphibolites of the west block in New Jersey, suggesting volcanic flows. The main evidence to be considered is the interlayering of amphibolite with other rocks, and its gradational contacts in a few places. This is suggestive of a metasedimentary origin but metamorphosed tuffs might have similar relations. Some of the amphibolites of the east block and west block are intimately associated with minor lenses of marble and pyroxene rocks and are almost surely metasediments. Others, in the east and middle blocks, are interlayered with charnockitic rocks of equally doubtful origin; these sequences may be metasedimentary or metavolcanic, but probably not meta-igneous.

Hornblende-feldspar gneiss

The transitional nature of this unit between charnockitic gneisses and amphibolite may mean a common origin, presumably metasedimentary, of all three lithologies where this relationship prevails. Such interlayering could also be produced by mixed volcanic and sedimentary processes. If the charnockitic member is igneous, however, the transitional contact may be a function of mixing and assimilation.

The hornblende-feldspar gneiss of the inlier complex contains quartzose zones and a few minute flakes of graphite. At least this variant is almost surely metasedimentary.

The sodic alaskitic layers so common in the hornblende-feldspar gneiss of the east block are a special problem. They do not occur in any specific relation to quartz-plagioclase gneiss or any other likely sodic source rock and thus are believed to be locally derived by sweating-out and reorganization of salic components during metamorphism. However, no particular argument can be raised against *lit-par-lit* introduction of far-traveled sodic material. The coarse material in some places transects the surrounding gneiss at a slight angle to foliation, but this may denote greater mobility of the alaskite than the enclosing gneiss during metamorphism, rather than forceful cross-cutting by injected material.

Quartz-microcline-plagioclase gneiss

Buddington has interpreted similar rocks in New Jersey to be magmatic in origin on the basis of relict mesoperthite and ilmenomagnetite composition (as much as 7.97 percent TiO_2 in solid solution) indicative of $\pm 800°C.$ temperature of formation. The quartz-microcline-plagioclase gneiss is rather uniform in composition and texture within each of the two sub-types recognized, and probably was in part highly mobile or magmatic at some stage of its formation. Substantial homogenization of moderately uniform material, and perhaps development of mesoperthite, is possible under conditions of granulite facies metamorphism, however, so that a magmatic interpretation is not unassailable.

Concordant interlayering with amphibolite, apparent change along strike into hornblende-feldspar gneiss, and interlayering of the two sub-types are suggestive more of sedimentary or mixed volcanic and sedimentary origin than of magmatic origin. Where contacts with amphibolite are gradational, the mixing is by mechanical layering rather than by variable assimilation. If the syenitic varieties are, as Buddington suggests (1939; ms.), facies of pyroxene granite contaminated by reaction with mafic gneisses, the reaction zones were never observed. Pyroxenic alaskites, for example, show no reaction with amphibolites.

If the mesoperthite grains are relict, their rarity suggests that the bulk of the lithology has been modified by recrystallization and granulation. This would have caused incomplete reorganization of perthite components into discrete grains of oligoclase and microcline. If this has occurred, the common paucity of potash feldspar probably indicates that it has migrated from some parts of the rock. Buddington has observed this in mesoperthitic syenite gneisses of New Jersey and the Adirondacks, and suggests that they have suffered later deformation. Further interpretation of this is offered in the section on metamorphism.

Quartz-plagioclase gneiss

In gross character and field relations, quartz-plagioclase gneiss is rather similar to quartz-microcline-plagioclase gneiss, and the same problems of origin arise. The sharpness of contacts with most amphibolite layers suggests original sedimentary or volcanic origin. Graywackes or sodic tuff would provide approximately the right composition, and occasional mafic volcanic admixture would result in associated amphibolites in the metamorphosed sequence. Such parent material could be quite homogeneous, so uniformity of the gneiss need not argue for magmatic origin.

From the homogeneity of the unit and its sometimes transgressive relation to amphibolite, an argument of equal uncertainty can be presented for a magmatic origin Indeed, under conditions of granulite facies metamorphism, it is probable that melting took place at least locally, even if the unit were of ultimate sedimentary or volcanic origin.

Unlike the quartz-microcline-plagioclase gneiss, the quartz-plagioclase gneiss has no mesoperthite and does not show crushing and recrystallization except very locally. An interpretation of this is given in the section on metamorphism.

Igneous rocks

Alaskite and alaskite gneiss

The alaskitic rocks are characterized by unrecrystallized hypautomorphic-granular fabrics and mesoperthitic feldspars, suggestive of crystallization at high temperatures from a melt or highly mobile material. Magmatic origin may further be inferred from the character of zircons, mostly euhedral with slight rounding, except in the "pseudoalaskites," where rounded zircons with overgrowths occur. Buddington reports similar hornblende and pyroxene alaskites in New Jersey to contain 2.76-3.60 percent TiO_2 in solid solution in magnetite. He suggests that this indicates temperatures of formation in the range 700°-750°C.

The pyroxene of the alaskites appears to have been an initial component, because it would not have been produced by reaction between a water-rich granitic melt and amphibolitic host rocks.

Hornblende granite and hornblende granite gneiss

Cross-cutting relations and overall homogeneity of the granite bodies indicate magmatic origin. Additional evidence is the euhedral character of zircons and the ilmenomagnetic solid solution reported by Buddington for comparable New Jersey rocks falling in the range mentioned above. Also, magmatic or highly mobile character is shown by the phacolithic shape of the main body, which has gneissic structure on the confined and attenuated west limb (as might be expected if the foliation were a primary flow feature caused by streaking-out of minerals in areas of constriction of magma during intrusion) and poorly defined structure in the keel where the granite appears to have broken through the confining gneisses. Elsewhere in the granite, if foliation relates to drag of magma against enclosing rock, the irregular distribution of the gneissic facies is puzzling. Unseen projections of floor or roof rocks into the granite layer might be invoked, but there is no supporting evidence, and this does not explain the general lack of foliation as a contact phenomenon throughout the granite.

The ultimate origin of the granitic material is unknown. Perhaps it was intruded from a deeper source, or possibly it is an ultrametamorphosed sedimentary layer, mobilized but still essentially in its original stratigraphic position. Reconnaissance throughout the Highlands has shown that hornblende granite consistently behaves as layers concordant with folded host gneisses. This is exhibited to a remarkable degree in the Dover area mapped by Sims. The magmatic explanation calls for quiet, late syntectonic intrusion into dilatant portions of fold structures. Lineations and foliations are regarded as primary flow features. By this explanation, of course, the granite layers have no stratigraphic significance. This probably applies to granites of the present area, although they may not have moved far in arriving at their present positions. On the other hand, ultrametamorphic origin may be regarded as favored by the fact that, if all granitic and other rocks regarded as intrusive are removed from Sims' area, almost nothing is left, whereas if they are regarded as sedimentary layers, the entire area would represent a rather typical clastic sequence.

Hornblende-biotite granite

This granite appears to have been emplaced in a highly mobile condition, apparently as a magma. Large quantities of metasomatic fluids or vapors were associated with, although not necessarily derived entirely from, the granite. It seems clear that the granite furnished silica, fluorine, and chlorine to the surrounding marble. Sheet-like and cross-cutting granite bodies indicate high mobility. As the granite material is not ostensibly of local derivation, presumably it migrated as magma, upward from a deeper level. The magmatic character, however, is not entirely clear. Assimilation or considerable mixing of granite with quartz-microcline gneiss might be expected at contacts, yet this is not apparent, and the gneiss instead appears to have been simply shouldered aside by the upbulging granite. Such relations may show that the granite had reached a cooler level where it behaved as a rather coherent mass; this is also reminiscent of a mantled gneiss dome configuration in which an older granitic basement may be remobilized locally and push up in a domical form through the younger mantling sediments during metamorphism.

METAMORPHISM

Metamorphic character of the east block

The rocks of the east block display features typical of the hornblende granulite subfacies and possibly locally of the pyroxene granulite subfacies of regional metamorphism; criteria of retrograde metamorphism are virtually absent:

1. Hypersthene is a prominent constituent of quartz-plagioclase gneiss, hornblende-feldspar gneiss, and amphibolite. It is corroded or replaced by antigorite and chlorite slightly or not at all. Anhydrous ferromagnesian minerals in all rocks except amphibolite and granite typically exceed hydrous ones in abundance.
2. Plagioclase is slightly antiperthitic.
3. Orthoclase and microperthite are the principal varieties of potash feldspar; microcline is nearly absent, except in hornblende granite and pegmatite.
4. Sphene is virtually absent from mafic rocks; titanium is present in rutile.
5. Host rocks and intrusives appear to have been held at similar temperatures; contact effects and disharmonic relations are absent.

Diagnostic mineral assemblages are: Quartz-orthoclase-plagioclase-rutile; plagioclase-diopside-hypersthene-quartz; plagioclase-hypersthene-microperthite-quartz.

Metamorphic character of the middle block

The rocks of the middle block have characteristics which suggest that the original degree of metamorphism was somewhat less than that of the rocks of the east block, possibly of lowest hornblende granulite subfacies or uppermost almandine amphibolite facies; abundant retrograde and possibly late metasomatic effects are complicating factors which are discussed in the section on interpretation. Significant characteristics are:

1. Hypersthene is present but uncommon, and it is everywhere corroded and replaced by shreddy mats of antigorite and chlorite. Hydrous ferromagnesian minerals greatly exceed anhydrous ones in amount.
2. Plagioclase is typically antiperthitic or mesoperthitic.
3. Microcline and microperthite are both prominent.
4. Sphene is common or locally abundant; rutile is uncommon or absent.
5. Host rocks and intrusives appear to have attained the same levels of temperatures; contact effects are minor or absent.

Diagnostic mineral assemblages, at least of the more mafic rocks, exclusive of retrograde features, are: plagioclase-microcline microperthite-quartz; plagioclase-(hypersthene)-hornblende-diopside; plagioclase-hornblende-diopside; plagioclase-hornblende-diopside-(hypersthene).

Metamorphic character of the west block

In the west block, the heterogeneous metasediments display features of the sillimanite-almandine subfacies of the almandine amphibolite facies of regional metamorphism:

1. Hypersthene is absent except in anticlinal-core masses of quartz-oligoclase (Losee) gneiss.
2. Sillimanite is common in quartz-microcline gneiss.
3. Wollastonite is not present in marble; tremolite is common.
4. Non-perthitic microcline as the dominant potash feldspar and non-antiperthitic oligoclase suggest amphibolite facies as the upper limit of metamorphism.
5. Granite or alaskite is uncommon, nearly absent, except at the north end of the block. Granite bodies show disharmonic relations and contact effects with their host rocks.

6. Anhydrous assemblages are uncommon or absent except in the quartz-oligoclase (Losee) gneiss.

Diagnostic mineral assemblages are: Quartz-microcline-sillimanite-almandine-biotite; calcite-diopside-tremolite; hornblende-plagioclase; hornblende-plagioclase-diopside-quartz.

Discussion and interpretation

Metamorphism in the west block is relatively simple; the facies criteria are straightforward and there is no evidence of polymetamorphism; however, the quartz-oligoclase gneiss (Losee) of the anticlinal cores is more like rocks of the middle block. The east block also presents a rather simple metamorphic aspect without obvious overtones of polymetamorphism.

In comparison, the metamorphic character of the middle block is complex. Fyfe, Turner, and Verhoogen (1958, p. 232-233) point out that metamorphic assemblages produced by prograde and retrograde metamorphism may overlap in character. Retrogressive phenomena may result if water is available as metamorphic temperature declines, but developed on a large scale, they usually indicate a superposed metamorphism.

Common epidotization of various rocks, and corroded and replaced hypersthene in the middle block suggest that hornblende granulite subfacies rocks have been retrograded on a large scale. Further evidence of polymetamorphic character is the apparent unconformity at the north end of the block (discussed in the section on structures of the middle block), and the complex nature of the feldspars. The presence of mesoperthites together with granulated mixtures of microcline and oligoclase is regarded as highly significant. Of this relationship in middle-block syenitic rocks in New Jersey, Buddington (ms., p. 100) comments:

> Although the feldspar of the gneiss is now almost exclusively slightly microperthitic microcline and oligoclase, there are locally enough relics of mesoperthite and types transitional between mesoperthite and granoblastic aggregates of microcline and oligoclase to indicate that the latter is derived by crushing and recrystallization of the former. This would necessarily mean deformation and metamorphism with some plastic flow in the solid state at temperatures of around 450° C ± 100°.

Buddington does not specify where this deformation would fit in a petrogenetic sequence; he presumably would regard it as a late stage of a metamorphic event in which magmatic syenites were emplaced, or as part of a metamorphism which affected premetamorphic syenites. Walton, however, (unpublished manuscript; Walton and De Waard, 1963; Berry and Walton, 1961) has used similar evidence in the eastern Adirondacks, together with other data gathered during a ten-year study of a large area, to build a convincing case for a polymetamorphic history. Charnockites, syenitic and granitic gneisses, and other rocks of a granulite facies metamorphic terrane are inferred to have been a basement for deposition of a sequence of carbonate and clastic rocks. In a later metamorphism (amphibolite facies), the basement rocks with lowest melting points were locally remobilized, doming up and intruding to a minor degree the so-called Grenville metasediments. During this episode the charnockitic basement rocks were retrograded in places, particularly where water was available. But in dry granulitic syenites and similar rocks, simple granulation and recrystallization were the main effects of the later, lower grade metamorphism.

This interpretation seems to fit admirably the present area. Quartz-microcline-plagioclase gneiss, quartz-plagioclase gneiss, some amphibolites, and probably some hornblende-feldspar gneiss and metasediments would constitute the granulite facies basement complex exposed by long erosion. Upon this basement were laid sediments subsequently metamorphosed to amphibolite facies in the present area and apparently to lower grades elsewhere in the Highlands. These metasediments are presumed to have their base exposed in the synclinelike belts at the north end of the middle block and around the anticlinal core of Losee gneiss mapped by Hague (1956) at the west side of the west block. Atop basal quartzose and argillaceous rocks would come the Franklin marble and any metasediments beneath it. The gneisses of Cork Hill and Pochuck Mountain then would be sediments (clastics and impure carbonates), with possible volcanic layers within and above the marble. Thus, the stratigraphic sequences proposed by Hague (1956) and Buddington and Baker (ms.) are modified only in the respect that the gneiss series of Hamburg Mountain is considered largely to be older basement for the overlying section. The basement anticline-and-cover relationship of quartz-plagioclase (charnockitic) gneiss and various metasediments holds for eight of ten major occurrences of the quartz-plagioclase gneiss (figure 11). The two remaining occurrences are synformal masses (oligoclase gneiss in the Pimple Hills syncline of Hague and quartz-diorite at the east edge of Sims' area) partly or entirely within metasediments of the "cover" type. These reversals of the typical anticlinal relationship may possibly be explained by structural overturning, but must be regarded as unexplained by the present hypothesis.

Additional evidence of polymetamorphism seems clear from the occurrence of clinozoisite-rich gneisses near the east margin of the middle block in New Jersey (Budding-

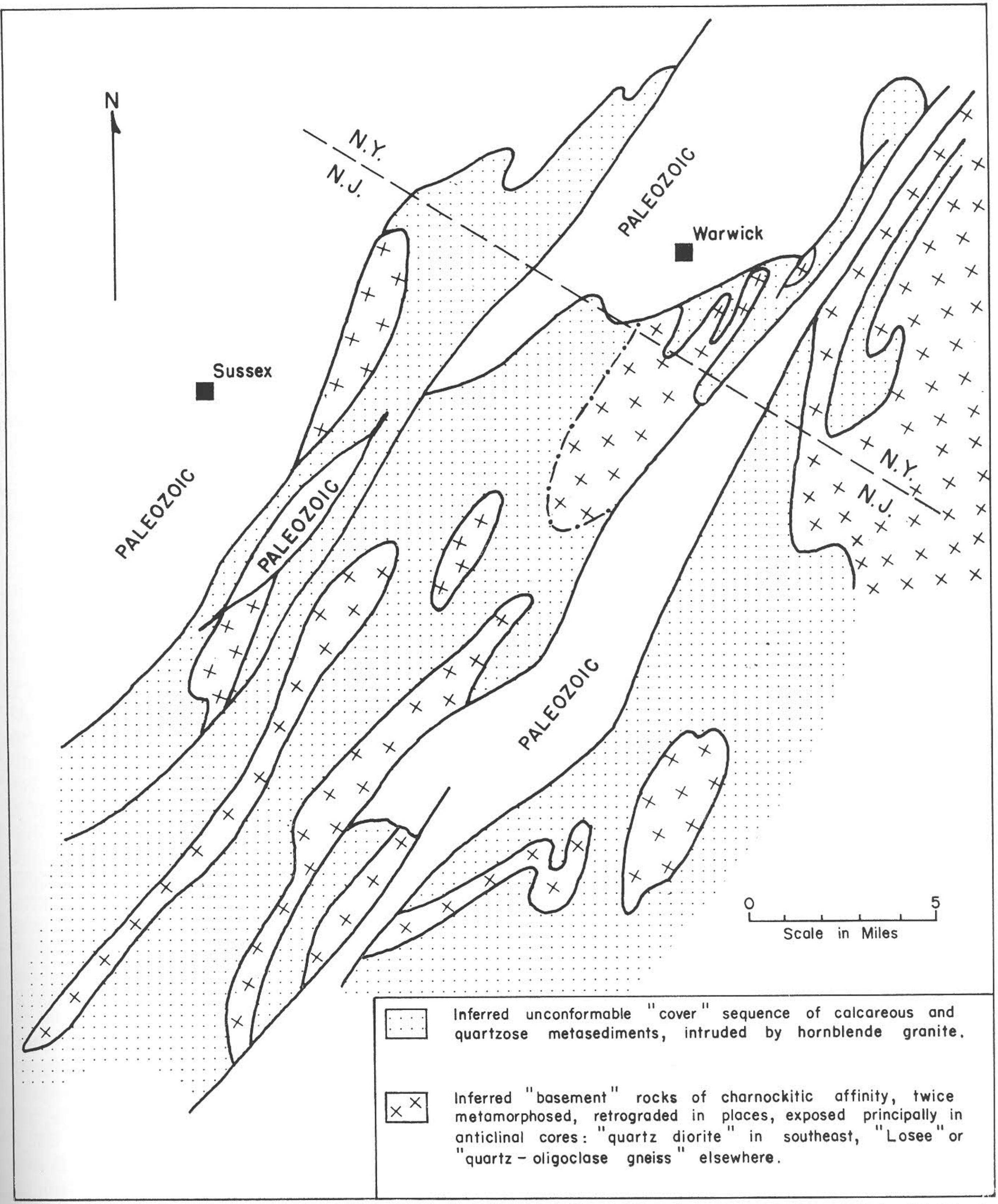


FIGURE 11. Sketch map showing inferred distribution of "basement" and "cover" rocks in the Precambrian Highlands of New York and northern New Jersey.

ton and Baker, ms.). These, and epidotic gneisses, are associated with, and apparently mantle, the charnockite-syenite gneisses. This is an anomalous association of high- and low-grade rocks easily explained only by superposed metamorphism, and indicating that the later metamorphism was not everywhere of the upper amphibolite facies.

A residual problem can now be dealt with: rocks of the east block, in the proposed scheme certainly remetamorphosed with those of the middle block, do not show retrograde effects. I suggest that block faulting along the boundary fault has resulted in juxtaposition of different metamorphic levels. Displacement need not have been enormous. The east block moved up relative to the middle block, thus exposing a deeper level where the second metamorphism may have approached granulite facies conditions, and no retrogression of the older metamorphic rocks occurred. Strictly speaking, then, it is thought that the quartz-plagioclase gneiss exposed in the portion of the east block mapped here was not directly basement for the sediments. Perhaps rocks like those presently exposed in the middle block once overlay at least the now uplifted western side of the east block as well, and were the actual floor of the later deposition. Long and Kulp (1962, p. 988) believe that block-fault juxtaposition of different levels explains considerable differences of biotite ages on opposite sides of faults farther east in the Highlands.

Because Cambrian sediments rest upon the metamorphically different rocks of the two blocks, it is clear that such faulting, if it is the real explanation for the difference, occurred after the latest metamorphism and before the Cambrian sedimentation.

The assumption of different levels is further suggested by the difference in occurrence of granitic rocks. At the deeper level, granite was developed on a large scale, with slight or no lateral contact effects and metasomatism. At the north end of the middle block, believed to be at a higher level, only minor bodies of alaskite are present, and potash metasomatism from a deeper source is suggested by the presence of considerable potash feldspar in the hornblende-feldspar gneiss and plagioclase gneisses which would otherwise match units of the east block. Occasional relict fabric in the pyroxene alaskites suggests that they are older granites of the basement, later largely remobilized. It is not known if this applies to the other granites, as they display no relict fabric. Farther south in the middle block, however, available maps and reports (e.g., Smith, 1957, plate 1; Buddington and Baker, ms.) show that hornblende granite as sheets within metasediments flanking quartz-plagioclase gneiss anticlinal cores is common. From these descriptions it is clear then that the granite is not confined to rocks of the postulated "basement" or to the east block south of the area reported on there. If the granite, in its present structural-stratigraphic positions, is related to the second metamorphism proposed here, then its wider distribution and presence in the metasedimentary "cover" is not significant, except that the granite of the middle block should have somewhat lower temperature characteristics that the granite of the east block. Available data are not very revealing on this point.

If the argument for the unconformity and polymetamorphism is not accepted, the alternative is the standard interpretation for the Highlands and the Adirondacks. All the metasediments (Grenville-type), probably then unmetamorphosed, would be the oldest sequence, interrupted and invaded by syenitic and granite rocks. The whole terrane was later metamorphosed—in Buddington's view, probably three times—with accompanying phases of magmatic invasion.

In both petrogenetic schemes, two or more major metamorphisms could be involved. The principal difference, of course, is whether the metasediments (west-block type) are very old and metamorphosed more than once, or (as proposed here) are the youngest Precambrian rocks and metamorphosed only once.

STRUCTURAL FEATURES

Foliation

Planar structure, or foliation, is nearly ubiquitous in the Precambrian rocks, although its development varies considerably. Minor exceptions are alaskite, parts of the hornblende granite, and some pyroxene rocks. Foliation may be of several types: parallel or subparallel orientation of platy minerals (biotite, phlogopite, graphite) or of elongate minerals (hornblende, sillimanite); partial orientation of tabular minerals such as feldspar; arrangement of minerals in discrete layers, either as preserved original bedding or by *lit-par-lit* injection, metamorphic differentiation, or differential replacement. In most rocks, foliation is presumed to be the result of stress-directed recrystallization during dynamothermal metamorphism, but in some rocks it probably represents alignment of minerals by flow of magma.

Foliation throughout the area is strictly parallel to lithologic layering, wrapping around the noses of folds as the rock units themselves do. According to classical theory, foliation of aligned minerals represent a cleavage, presumably developed parallel to the axial plane of a fold. It follows from the theory that cleavage (foliation) can wrap around a fold only by folding in a new deformation the axial surface of an older fold.

In this area there is no evidence of such refolding. There is no second cleavage of the "new" folds, and no lineations can be related to some older fold orientation. It is doubtful that, even with highgrade metamorphism and extreme plastic (or rheid) flowage, all traces of an earlier deformation would be erased. Departure from theory seems necessary. Perhaps the most intuitively obvious and least complex means of producing foliation parallel to folded layers in one deformation is simply by slip along lithologic layers. Differential movement rates across pre-existent discontinuities in rocks deforming as rheids are inescapable. The shear thus induced would require preferential orientation of the recrystallizing minerals. For rheid folds this would be true on the noses and crests of folds as well as on the flanks, owing to attentuation as well as shear, and it provides for the observed configuration.

The northeast strike of foliation and layering is remarkably constant in the Precambrian rocks. Dips are predominantly vertical or steep to the southeast, except on culminations of folds.

Lineation

Although lineations are not uncommon in the rocks, they are sparse on the accompanying map, primarily because of the difficulty of accurately measuring linear elements of the rock fabric where foliation surfaces are not exposed. The linear structures shown are generally mineral orientations: aligned elongated hornblende or sillimanite, or streaks of biotite or graphite in amphibolite and gneiss; pulled-out blebs of quartz in granite and alaskite; and aligned calcite rhombs in marble. At Mt. Eve, at the anticline south-southwest of Warwick, and around the Sterling Lake syncline, a few lineations represent the axial direction and plunge of minor drag folds and crenulations.

In the east and middle blocks lineations plunge uniformly northeast. Angles of plunge vary from 10 to 75 degrees, with the bulk between 15 and 30 degrees. On the flanks of folds the strike of lineations and foliation are parallel, diverging gradually around fold noses to a mutually perpendicular relation. Thus foliation outlines folds, and lineations reflect the direction and plunge of fold axes.

In the west block, lineation reveals the shallowness of structures. Mineral lineations in the marble are usually subhorizontal and plunge both southwest and northeast. Crenulations and mineral lineations in the gneisses and granite of the Mt. Eve complex are shallow and at skew angles to the general regional northeast trend.

The presence of southwest plunges, except in what is here called the west block, is virtually unknown throughout the highlands. Reconnaissance of the entire Hudson Highlands has revealed only northeast-plunging folds. Studies in New Jersey are sparse, but the maps of Sims and Buddington show only structures of northeast plunge, although rare and aberrant southeast and southwest plunges are referred to. The preponderance of northeast plunges may of course be a function of sparse mapping, but in a total area of about 850 square miles, spanning nearly 50 miles of strike length, southwest plunges are known only rarely and very locally. If the plunge is accepted at face value, then each successive layer from Ne Jersey northward is higher (younger?), and an amazingly thick section is displayed. This does not seem reasonable but an alternative explanation is not easy to propose. The solution may somehow rest upon complexities of rheid folding or re-folding, (which may be common despite the lack of evidence of it in the present area), but an answer will have to wait for more complete mapping of the entire Reading Prong.

Structures of the east block

The major structures of the east block are two large synclines.

The Sterling Lake syncline is not immediately apparent in the distribution of lithologies on the map. Faulting in the keel of the syncline at the south end of the lake has disrupted the fold. Nevertheless, foliation attitudes and mine workings in a plunging ore shoot under the lake make the overall structure clear. Minor drag folds in amphibolite on the east side of the lake have the proper shear-sense for the flank of a syncline. Figure 12 is an equal-area projection of traces of foliation planes around the syncline. The plot shows a rather poorly defined fold axis trending about N.25°E. and plunging northeast at about 10 to 15 degrees.

What becomes of the syncline north of the lake is not clear. On Hotz' map of the area to the east, no continuation of the syncline is apparent, and my reconnaissance provided no further clue. Perhaps the axis bends to the northeast similar to the axis of the syncline to the west. Or perhaps the cross-fault north of Sterling Lake has dropped the synclinal block, juxtaposing quartz-oligoclase gneiss stratigraphically above the amphibolite, with similar gneiss below it.

Just west of Sterling Lake is another syncline of similar trend. It is neatly outlined by the hook-shaped body of hornblende granite, although to the south the structure is lost, probably because the intruding granite broke through the confining rocks in the plunging keel of the fold. Faulting has not distorted the structure, and an equal-area projection of foliation traces gives a well-defined trend of N.26°E. and plunge of 25 degrees for the fold axis (figure 13). The different plunges of the similar-

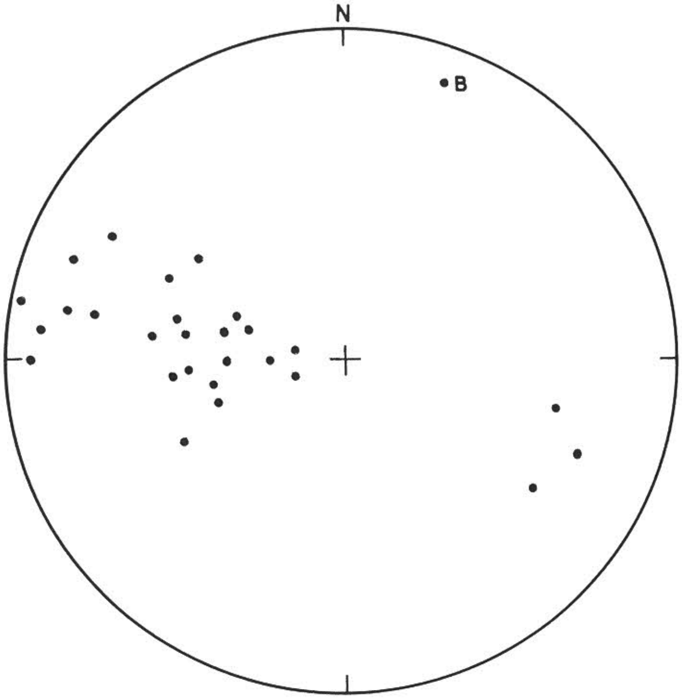


FIGURE 12. Equal-area projection of poles of foliation planes. Sterling Lake syncline; axis: N.19°, E.12°.

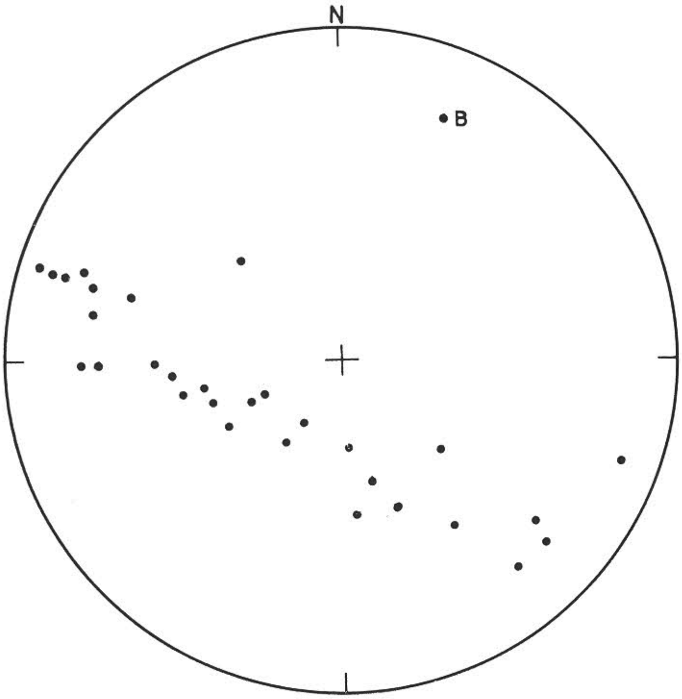


FIGURE 13. Equal-area projection of poles of foliation planes, large syncline west of Sterling Lake; axis: N.23°, E.23°.

trending, closely adjacent synclines is typical of metamorphic flow-folding.

The narrow anticline which must separate the two synclines is obscure, but quartz-oligoclase gneiss apparently occupies the core.

Eight miles along strike to south, in the Dover magnetite district of New Jersey, Sims (1958) mapped very similar broad, shallowly plunging folds, commonly filled with phacolithic granite bodies. The structural character and general lithologic types seem continuous at least that far in the east block. In some of Sims' folds, however, thin marker units follow the noses of large folds, but then hook sharply and double back on themselves. Where this occurs, lineations are aberrant with respect to the trend of the large fold. These features are typical, indeed diagnostic, of re-folded folds in metamorphic terranes. Sims commented on the puzzling aspects of the structures but did not investigate them in detail. If the Dover area structures are, in part, really refolded folds, this is the first indication of such deformation in the Highlands, unless the hook shape of the granite in the east block is construed as such. The lineations and stratigraphy involved there, however, are not consonant with refolding.

The faults shown are as Hotz (1953) mapped them, with the addition of a longitudinal fault along the west border of the hornblende granite gneiss. This fault is of unknown displacement, but it is probably small and may even be a shear zone of essentially no displacement. It is marked by a fault-line scarp, and shattering and epidote-chlorite fracture fillings in the adjacent rocks. The cross faults may likewise be more nearly shear zones. They generally produce little offset of rock units, and so any displacement must involve nearly vertical movement of steeply dipping rocks. The greatest offset of lithologies is produced by the long cross fault in the southeast corner of the area.

Discussion of the faults which separate the Precambrian blocks is reserved for a later section.

Structures of the middle block

The only conspicuous structure in the middle block is a well-defined anticline near the State line, south-southwest of Warwick. Three layers of amphibolite associated with quartz-microcline-plagioclase gneiss clearly mark the fold structure. Minor crenulations occur in both rock types at the nose of the fold.

East of the anticline is a belt of quartzose metasedimentary gneisses (includes graphitic feldspar-quartz gneiss and biotite-quartz-feldspar gneiss) which broadens markedly in the vicinity of the Warwick Reservoir. These gneisses appear to truncate the structural trends of the rocks on either side. This is evident at the north end of the prominent anticline. The metasediments also seem to truncate the charnockitic gneisses by onlap at the north end and in the medial valley of Warwick Mountain. The relations of the metasediments in the belt along Long House Creek are obscured because of alaskite intrusion and poor outcrops.

The blanket-like extent of the metasediments at the northern limit of Precambrian outcrops, and the truncation of underlying rocks suggest an unconformable or nonconformable relation (plate 1, fig. 11). The three main belts of metasediments pinch out southward and are interpreted as being complexly folded into structural depressions in an older terrane, rather in the nature of north-plunging synclinal fillings. In the same sense, the charnockitic gneiss ridges between the metasediment belts would be "anticlines," although not outlined as such by the configuration of the rock units. The presence of an unconformity provides at least a partial explanation for the lack of stratigraphic repetition in the charnockitic rock on opposite sides of the "synclines." This is only one interpretation of equivocal evidence, however. The metasediments may lie normally above the other gneiss, and the observed relations may have been produced by plastic flowage and/or unrecognized faulting.

Ten miles to the southwest, in New Jersey, the middle block consists of gneiss of charnockitic affinity in two large anticlines, with a broad intervening syncline filled with metasediments (Buddington and Baker, ms.). The synclinal series, which in part consists of epidote and clinozoisite gneisses, appears to be part of the superficial metasedimentary cover overlying anticlinal cores of charnockitic gneisses, but is somewhat different from the quartzose gneisses seen at the north end of the block. The quartzose gneisses are found by Buddington nowhere in the middle block, except in syncline-like areas at the north end of Hamburg Mountain, plunging under Paleozoic cover. It is readily apparent from figure 11 that, between the postulated unconformities at the north edge of the block and around the anticlinal cores, which are presumed to be the same surface, another area of exposed "basement" must exist, but the intervening area is not yet mapped.

Folds in the middle block plunge shallowly northward and are defined generally by steeply dipping foliation on the flanks. The structures do not differ significantly in style from those of the east block.

Faults are probably more common than shown on the map. Only two small cross-faults are really supported by the available evidence, however.

Structures of the west block

Because marker beds are lacking in the Franklin marble, folding is difficult to discern. The prevalence of steep dips of lithologic layering and foliation in the marble probably requires nearly vertical isoclinal folding throughout. Such folding is exposed in the Atlas quarry southwest of Pine Island. Most of the marble outcrops were field checked, and structural measurements consistently agreed with those recorded on the map of Hague and others (1956). With minor additions and changes, the structures shown on the present map are taken directly from Hague.

Folding in the marble is steep, but the plunge of folds is shallow, ranging from subhorizontal to 20 degrees northeast or southwest.

The nature of the structure in which the gneisses of Mounts Adam and Eve are involved is uncertain. Seemingly the trend of the gneiss belts is sharply athwart the regional trend, as if defining a major crossfold. This is the interpretation given the structure by Hague, although it is referred to as a major fold, and the minor north-and-northeast-trending folds are called cross folds. Hague suggests that the graphitic gneiss belts at the north and south ends of Mt. Eve originally connected in a synclinal nose to the east, or perhaps as two synclines separated by an intervening anticline, all striking N.70°W. The minor "cross folds" are said to indicate "secondary folding." With regard to "cross folding," Hague states (p. 462):

> Analysis of the attitude of folds in the area (25 mile strike-length, covering the width of the west block) shows that the average bearing of major fold axes is N.40°E. and the average bearings of the two sets of cross-folds are north-south and N.70°E. If the cross-folds are related to the major folding, the major compressive forces, probably directed from the southeast to the northwest, probably had minor components of force directed so as to produce cross-folds oriented at roughly 30° to the major folds. If the formation of the cross-folds postdated the major folds, the cross-folds may have resulted from compressive forces from the northeast and southwest, roughly at right angles to the major compressive forces, or from horizontal movement along northeast-southwest shears.

The term cross fold generally means a fold of some other fold structure, either syngenetic with, or later than, that structure. In that sense, none of the "cross folds" described by Hague are particularly evident from the map pattern. Instead it appears to show major structures folded in a rather unconfined tectonic style which permitted minor drag structures to diverge slightly from the axial direction of the basic structures.

The quoted discussion seems especially inappropriate for the Mt. Eve area. There, the proposed major synclinal fold would trend N.70°W., aberrant from any of the trends quoted above. The axis of "cross folding," marked by outcrop pattern and lineations would be about N.20°E., approximately parallel to the Pochuck Mountain syncline, a major structure. Using the pattern of shallow synclinal folding shown by Hague in several places just to the south, an alternative explanation of the Mt. Eve structure is obvious. The two belts of metasediments were probably not connected—their stratigraphies do not match—and their trends mark the nose of a broad, shallow syncline or anticline, the axial direction of which is marked by the minor folds and lineations.

The structure has been complicated and obscured by faulting, but especially by the intrusion of granite. Distortion of structures in a gneiss sequence surrounded by plastically flowing marble and broken through by granite magma may have been so extreme that analysis of the structure is not meaningful. Lineations in the granite, however, indicate that the granite was relatively confined by the surrounding gneisses and that the two were not wildly deformed together into some completely local configuration. Further, despite intrusion and flowage, the cited trends fit the regional pattern of major folds.

At the west edge of the quadrangle is Pochuck Mountain, consisting of a sequence of gneisses invaded by granite identical with that of Mt. Adam and thrown into a series of small folds. In the mapped area, a shallow synclinal sequence, from the lowest exposed layer up, consists of granite, quartz-microcline gneiss, amphibolite, and pyroxene gneiss. The granite is commonly transgressive on small and large scales, but has the overall character of a sill-like layer. West of the mapped area, as shown by Hague, the folding continues, becoming overturned to the west.

South along Pochuck Mountain is a very shallow doubly-plunging synclinal basin, only the northern end of which is shown on the present map. Other folds of similar style, although overturned westward occur farther southwest.

Within the area mapped for this report, the tectonic style exhibited by structures of the west block differs considerably from that of the middle and east blocks. In the west block, shallow, doubly-terminated, rather short structures, which have numerous subsidiary drag folds, suggest relatively unconfined folding. In the other blocks, long, steep, straight-sided folds, on which very few drag folds are present, suggest deformation which, even though it may have been more intense, was more confined. This difference is believed to be a function of depth of burial during metamorphism; deeper, more confined, more extreme attenuation by flow to reduce minor structures.

REGIONAL INTERPRETATION

On the basis of observed metamorphic characteristics and stratigraphic relationships of the rocks of the Precambrian terrane, the following sequence is believed to summarize the major Precambrian geologic events in this area:

1. Metamorphism of a sedimentary terrane and intrusion of hornblende granite.
2. Uplift, denudation to expose rocks of the hornblende granulite subfacies and possibly pyroxene granulite subfacies, and deposition of quartzose sediments overlain by a thick limestone sequence.
3. Metamorphism, locally of upper amphibolite facies intensity, involving partial metamorphic retrogression in rocks of the uppermost zone of the ancient basement complex.
4. Post-metamorphism block faulting which juxtaposed levels of different metamorphic grade, subsequently exposed in the rather even surface on which the Cambrian sediments were laid.

In considering the interpreted polymetamorphic history, examination of the maps of Buddington and Baker (ms.) and Hague (1956) is very interesting. These maps show that, in New Jersey, where the middle and west blocks merge in metamorphic character, the quartz-oligoclase gneiss occurs in two long, oval, anticlinal masses separated by a syncline of metasediments of west-block type. Buddington and Baker (ms.) remarked that if one wished to regard the Losee as metasedimentary, then the anticlinal areas simply exposed the lowest member of a gneiss series. The Losee, however, is different in metamorphic character from the overlying metasediments. Further, the Losee is not overlain by a single formation; rather, several metasedimentary units are truncated against the contact, with the underlying Losee gneiss in an apparent unconformable relationship. These features are excellent criteria of a mantled gneiss dome configuration produced by upbulging of remobilized portions of a basement terrane during later metamorphism. (Inconsistent synformal occurrences of Losee-type rocks in Hague's and Sims' areas were noted earlier.)

Walton and De Waard (1963) have found similar relationships in the Adirondacks, in which the rocks above and below the unconformity (particularly above) are in large part strikingly like those described in this report. A partial correlation of metamorphic events and generalized rock sequences in the Adirondacks and the Hudson Highlands is tempting (just as geologists for years have been tempted to equate the Grenville and Franklin marbles), but it can be mentioned only as a not very substantial hypothesis at the present level of knowledge.

A history involving two metamorphisms has thus far been argued on the basis of stratigraphic and structural relationships which could be interpreted in other ways, but support for the argument, in the form of radiometric mineral dates, has recently been presented (Long and Kulp, 1962). A minimum age for the later Precambrian metamorphism is given by the 840±34 million-year K-Ar age of biotite from the late orogenic Mt. Adam granite and similar biotite ages throughout the Hudson and New Jersey Highlands (Long and Kulp, 1962). Zircons from hornblende granites and quartz-plagioclase (Losee-type) gneisses of charnockitic aspect in the Highlands typically give ages of 1150 million years, and Long and Kulp (1962, p. 986) conclude that the zircon ages date a discrete metamorphic event at 1150 million years, over which was superposed a later metamorphism at about 840 million years:

"The oldest period of metamorphism recorded in the Highlands of New Jersey and nearby New York was about 1150 million years ago. The ages from micas are consistent with a definite Precambrian, if somewhat indistinct, period of recrystallization about 840 million years ago."

The presence within the "cover" sequence of abundant masses of granite which give zircon ages of 1150 million years remains to be explained. Some of the granite masses may, on closer mapping, prove to underlie the cover rocks in the same manner as do the charnockitic gneisses. Other granites, when more mineral ages are available, may prove no older than the later metamorphic episode. Where older granite is genuinely intrusive into the younger metasedimentary sequence, it is believed that remobilization and upward intrusive movement of "basement" granite occured during the later metamorphism. Degree of mobilization of granite, and its capability to intrude the "cover" sequence, would have varied with local conditions of temperature and pressure. Temperatures sufficient to permit recrystallization of zircon to reflect the age of remobilization probably were never attained.

Throughout the mapped areas of the middle and west blocks, the presumed major unconformity and the present level of erosion intersect in several places, exposing a partly retrograded charnockite-metasedimentary suite of ancient basement rocks overlain principally by heterogeneous metasediments whose metamorphic grade appears to vary from upper greenschist facies to upper amphibolite facies. This configuration suggests that post-metamorphism upwarping of the basement was uneven, exposing different metamorphic levels according to the amount of uplift. Displacement on block boundary faults appears to vary from none to several thousand feet. For example, although the boundary fault continues as a mappable line, the structural and metamorphic distinctions of the middle and west blocks appear to fade south of the area of this report. The east block—middle block boundary remains relatively distinct, however, as far south as mapping extends, although uneven displacement is suggested by variations in metamorphic character of the rocks along the line of the fault. That uneven warping and displacement of the basement blocks and subsequent planation were Precambrian events is evident from the fact that Cambrian sediments rest upon rocks of apparently different metamorphic levels.

Geology of the Paleozoic Rocks

STRATIGRAPHY

THE CAMBRIAN AND ORDOVICIAN rocks of the area provide a typical section of a stratigraphic sequence which extends from the Taconic region of eastern New York to eastern Pennsylvania. The sequence consists generally of Cambrian and Lower Ordovician carbonate rocks, largely dolomites, overlain unconformably by Middle Ordovician shales (locally including a basal limestone). Lithologic constancy both along and across strike makes correlation of widely separated sections relatively secure despite a general paucity of fossils (Table 16).

Gray and red conglomerates, sandstones, and shales of medial Devonian age and typical Catskill affinity are preserved in a downfaulted synclinal outlier. This synclinal outlier is separated by several miles from the Devonian rocks to the north and west, and is the easternmost occurrence of known Devonian rocks at this latitude.

Cambrian System

Hardyston Quartzite

General Features—The Hardyston Quartzite is the oldest Paleozoic formation in the area. It nonconformably overlies the Precambrian rocks at the north edges of the middle and west blocks and grades upward into the Cambrian Stissing Dolomite. The formation is poorly exposed, but fairly complete sections are found in the stream valleys at New Milford, and between Hoyt and Waywayanda Roads. The Hardyston is erratic in thickness, varying from 40 feet to absent, probably because it was deposited in depressions on the basement erosion surface. Eastward the unit apparently pinches out, as it is not found in the Greenwood Lake Quadrangle.

South and west of Pine Island, and at Mt. Eve, Hardyston Quartzite locally occurs at the base of Stissing Dolomite outcrops, but it is too thin to be mapped separately.

The Hardyston is a quartzitic sandstone, conglomeratic in part. It is variably bedded from shaly near the base, to massive beds six feet thick, but beds one foot thick are more characteristic. Bedding is very even, and joints very regular, causing the beds to break easily into flat-sided oblong blocks.

Basal layers are shaly, very uneven textured, and weather rusty buff. They are composed of a fine-grained sericite-clay-quartz matrix and irregular fragments of quartz and feldspar. Marble pebbles occur in a few places. Fine grains of pyrite decompose to give the weathered color. Higher layers are more massive but generally contain numerous pebbles and small clasts of glassy quartz and minor feldspar. A few layers of even-textured, rather pure quartzite are present.

The Hardyston changes from glassy and quartzose to blue-gray and dolomitic in the upper part, and is interlayered with similarly bedded dolomite which contains quartz fragments, in its lower layers. The upper contact was drawn arbitrarily where dolomite and dolomitic layers became dominant.

Fragmental material typically is angular and feldspars are fresh; presumably most or all of the fragmental material is locally derived and transported only from local highs to adjacent depressions on the old erosion surface. Widespread deposition on a nearly flat basement surface is indicated by the presence of the Hardyston and the equivalent Poughquag Quartzite southeast of the Highlands and in Paleozoic outliers within the Highlands.

Name, age, and correlation—The name Hardistonville Quartzite was proposed for this formation in New Jersey by Wolff and Brooks (1898, ref. from Wilmarth 1938) for its occurrence at the village of Hardistonville. Kümmel and Weller (1902) shortened the name to Hardyston.

Early Cambrian age for the New Jersey Hardyston is proved by the presence of olenellid trilobites. The equivalent unit in New York, the white-buff Poughquag Quartzite, also contains olenellid trilobites. The Poughquag, known as far west as Newburgh, lies between Lower Cambrian dolomite and Precambrian gneisses. Despite a lack of fossils in the present area, the identical stratigraphic position and short distance from olenellid trilobite localities to the south and east make correlation of the basal quartzite with the Hardyston secure. Vertical worm tubes (*Scolithus?*) commonly found in clastic sedimentary rocks of Early Cambrian age were seen in a few float blocks.

The name Hardyston is used here in preference to Poughquag because the outcrops in this area are at the northern end of a fairly continuous belt of Hardyston in New Jersey and because the dirty, conglomeratic character does not match the clean ortho-quartzite character of the Poughquag.

The Carbonate Sequence

Cambrian and Ordovician carbonate rocks are widespread throughout New York State, with identifiably different sequences characteristic of the Mohawk, Champlain, and Hudson Valley regions (Table 16). The Hudson Valley carbonate sequence conformably overlies Lower Cambrian Poughquag (or Hardyston) Quartzite and unconformably underlies Middle Ordovician shales or the Middle Ordovician basal limestone. Although stratigraphic sections must always be pieced together from scattered outcrops, generally an apparently continuous sequence of Lower and Upper Cambrian and Lower Ordovician dolomites and limestones is present. Middle Cambrian rocks have never been identified in New York State, perhaps owing to the scarcity of fossils throughout the carbonate section, or perhaps simply to the absence of Middle Cambrian rocks.[1]

A brief history of the nomenclature of this sequence is given by Fisher (1956, p. 343). Mather, in 1838, referred to the carbonate rocks of this stratigraphic interval as the Barnegat limestone, and two years later applied the name Newburgh to the same sequence. These names were never widely used. For the metamorphosed extension of the carbonate section into western Massachusetts and Connecticut, Emmons (1842) proposed the name Stockbridge, a term still employed. Dana (1879) introduced the name Wappinger from the Cambrian-Ordovician limestone and dolomites of southeastern New York. The Wappinger is largely unmetamorphosed and has proved divisible in a number of places. A term for the entire sequence is still useful at times, however, and Fisher (1956) commented that Stockbridge had priority in this usage. Nevertheless, the name Wappinger has been so widely used for the sequence in New York that retention of Wappinger seems more desirable than extending the usage of Stockbridge. Generally, the name Wappinger has included the "Trenton" limestone at the base of the Middle Ordovician shales the unconformity between it and the main carbonate section below has been ignored.

In the Stissing Mountain area of Dutchess County, New York, E. B. Knopf (1927, 1946, 1956) established six formations within the Lower Cambrian—Lower Ordovician sequence, plus the younger unconformable Middle Ordovician limestone. All of these units but the Copake Limestone (the youngest of the Lower Ordovician formations) have been observed in the area covered by this report, and Mrs. Knopf's terminology has been used (Table 16).

To the south, in New Jersey and Pennsylvania, the term Kittatinny is equivalent to Wappinger or Stockbridge. In those areas that have been studied, the Kittatinny has been subdivided into the Lower Cambrian Tomstown, Upper Cambrian Allentown, and Lower Ordovician Beekmantown. In Pennsylvania (Howell *et al*, 1950; Willard, 1955) the Middle Cambrian Leithsville and the lower Upper Cambrian Limeport have been defined between the Tomstown and the Allentown. The unconformably overlying Jacksonburg (Trenton) Limestone separates the Kittatinny from the Middle Ordovician shales as in New York, but has not generally been included in the term Kittatinny. The three units defined are probably further divisible, but how far the units found in Goshen Quadrangle may be carried southward is unknown.

Stissing Dolomite

General features—Overlying the Hardyston gradationally, or resting directly on Precambrian basement, is the Stissing Dolomite. It is easily recognized on the basis of distinctive rock type and proximity to Precambrian rocks. The main occurrence of the formation is at the north edge of the middle block near New Milford, and along the broken northwest margin of the west block. Two isolated areas occur in the vicinity of Bellvale. In Monroe (7½ minute) Quadrangle to the east, Stissing Dolomite has been observed to overlie granite and gneisses of the east block.

At the type area, Stissing Mountain, 60 miles to the northeast, E. B. Knopf (1962) has been able to subdivide the Stissing into seven members. She estimates the thickness as about 500 feet. In the present area, however, a thin belt of Stissing everywhere gives way to topographic lowlands with no bedrock exposed, and so only the two lowest members are found.

The bottom member is gradationally interlayered with a dolomitic upper phase of the Hardyston. At the base, very fine-grained greenish-gray (3G4/1 of N.R.C. Rock-color Chart) siliceous dolomite with numerous zones of glassy quartz fragments occurs in beds 1 to 12 inches thick. Siliceous or argillaceous partings, individually or in thin laminated zones, may separate the more massive dolomite layers. The partings weather as ribs and in places have forms suggestive of cross-stratification produced by currents from the northwest. Middle layers are finely laminated, aphanitic, greenish-gray, argillaceous dolomite containing minute layers of very fine-grained

[1] Since this paper was submitted for publication, Dr. Franco Rasetti has identified Middle Cambrian trilobites within the Taconic shale sequence in Columbia County.

glassy quartz, feldspar, pyrite, and shiny, black, minute operculae of *Hyolithellus micans*. Upper layers are almost asphanitic medium blue-gray (6B6/1) dolomite containing scattered quartz fragments, white calcite "eyes," and dark-gray chert nodules.

The overlying member is irregularly bedded and is marked especially by very thin-bedded or shaly zones. Bluish-gray, aphanitic, argillaceous dolomite and minor fragmental quartz zones make the more massive beds of figure 14. The beds are separated by rather uneven argillaceous partings and layers, usually very finely laminated. Overlying the rocks shown in figure 14 is a sequence (17 feet ±) of fissile, very smoothly laminated, argillaceous dolomite. Argillaceous rocks of all members of the Stissing weather with a conspicuous, pale, brownish-buff rind as much as an inch thick.

Total exposed thickness of the Stissing is not much more than 100 feet. How much more might be present in the covered interval is completely unknown. For the cross sections (plate 2), the thickness given by Knopf has been assumed.

FIGURE 14. Thin-bedded portion of the second member of Stissing Dolomite, two miles west-southwest of Pine Island.

Name, age, and correlation—The name Stissing was proposed by Walcott (1891, p. 360) but without clear definition or description of the rock section so named. In the present usage, the name, with careful descriptions, was introduced by Knopf for the lowest part of the carbonate section at Stissing Mountain, N.Y. (1962; abstracts 1946, 1956). The Stissing was reported to contain *Hyolithellus micans* Billings in the lower beds and *Paterina stissingensis* and *Prozacanthoides stissingensis* Dwight in the upper beds, indicative of late Early Cambrian age.

From the published description, an almost exact lithologic match of the lowest members of the present area with those at the type area is substantiated. This is further borne out by the presence of *Hyolithellus micans* in the lower beds. These beds thus furnish important evidence that matching lithologies 60 miles apart are correlative (time-equivalents), at least in this part of the section. The Stissing is the stratigraphic equivalent of the Tomstown Dolomite of New Jersey—Pennsylvania.

The nature of the contact of identified Lower and Upper Cambrian units is unknown. Neither outcrops nor fossils are available to indicate whether a complete sequence or one broken by a disconformity is present. Middle Cambrian rocks have not been found in the area studied.

Pine Plains Formation

General features—The Pine Plains Formation occurs in a prominent belt which follows the configuration of the large syncline in Warwick and Pine Island Quadrangles, and on the west side of the Wallkill peat lands. It is so diverse in character and sections across it are so incomplete that any subdivision is difficult. Nevertheless, two members may tentatively be discussed.

Dolomite ooliths in dolomite and minor occurrences of siliceous ooliths in dark-gray or black chert characterize the lower member. The ooliths, usually one to two millimeters in size, occur in scattered thin (one to four inches) layers of very fine-crystalline, lustrous, light-gray to medium-gray dolomite within more thickly bedded, light-gray, siliceous laminae weather as uneven, paper-thin ribs. Weathered color ranges from pale gray to medium gray, and an earmark of the Pine Plains is the alternation of light and dark beds, though this alternation is more prominent in the upper member. Rounded, clear or smoky quartz sand grains are scattered throughout, and are in places present in discrete layers which generally are less than an inch thick. A few outcrops weather brownish gray, with irregularly arranged, sharp, arcuate ridges which may be algal markings. No algal structure is visible on fresh surfaces, however.

The upper member is marked by the abundance of sand layers, prominent light and dark layering, and thin, ribbed zones of siliceous laminae. Aphanitic, slightly argillaceous, medium-gray dolomite weathers dark chamois or orange-buff, especially conspicuous by being less resistant than adjacent sandy or siliceous layers. Aphanitic or very fine-crystalline, medium light-gray (N7) siliceous dolomite which weathers very light gray (N8) alternates with layers of fine-crystalline, medium-gray (N6) siliceous or argillaceous, slightly lustrous dolomite which weathers mottled medium dark gray and buff. Ribbony zones of siliceous laminae are common, and greenish shaly partings may be present. Medium- to dark-gray chert occurs in small nodules and thin discontinuous layers. Rarely, there is a layer of medium dark-gray, lustrous, fine-crystalline dolomite, somewhat siliceous, and which has irregular orange markings of ankeritic dolomite and "eyes" of white calcite. The orange mottle may be the marks left by burrowing organisms. Two minor disconformities, with erosional relief as much as six inches, were noted. Thin layers of edgewise conglomerate occur in both members. Bedding thickness varies from half an inch to 6 feet (laminated) throughout.

Cryptozoon (figure 15) layers are found along the road at the southeast corner of Breeze Hill (west side of peat lands). Two tiny gastropods, *Rhachopea sp?* and *Matherella sp?* (identified by D. W. Fisher of the New York State Geological Survey) were collected on the west shoulder of the hill 3,000 feet southwest of Blooms Corners. *Rhachopea* is known from Upper Cambrian and Lower Ordovician rocks and *Matherella* from latest Upper Cambrian rocks (Fisher, personal communication, 1960). On the basis of these fossils, that outcrop might be assigned to the Briarcliff rather than uppermost Pine Plains, but the lithology suggests the latter. This is in the keel of a major syncline, however, and it is possible that a few layers of Briarcliff may overlie Pine Plains at the crest of the hill.

The thickness of the members is hard to estimate, but the total thickness of the Pine Plains must be 1,500 to 2,000 feet. This is somewhat thicker than the 1,475 feet approximated by Knopf at the type section. She lists the main identifying characteristics of the formation as: aphanitic, brown-orange chamois-weathering dolomite, ribbed or ribbony layers, sand layers, cryptozoon layers, and oolite layers.

Shallow-water shelf conditions of deposition are indicated by the presence of cryptozoon with siliceous ooliths filling crevices between the algal protuberances, edgewise conglomerates, and the abundant sand grains. All these features indicate shallow water agitated by currents. Cross-bedding in the dolomite at Township School on Price Road just south of the State line indicates currents from the west, which agrees with regional evidence of a shallow Cambrian-Lower Ordovician shelf area between land masses on the west and north, and a geosyncline forming on the east.

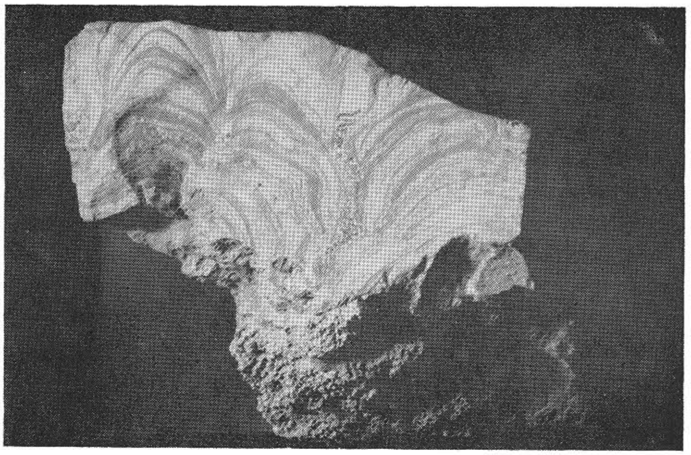
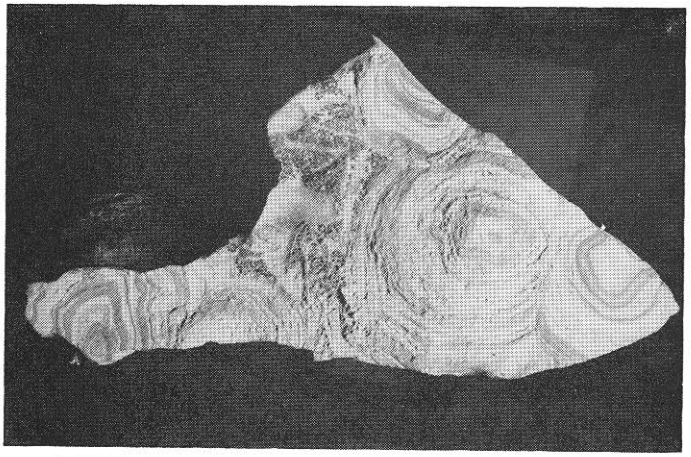


FIGURE 15. Top and side views of Cryptozoon from Pine Plains Formation at Breeze Hill. Greatest length of specimen 10 inches.



Name, age, and correlation—The name Pine Plains was proposed by Knopf (1946) for the variable dolomites occurring near Pine Plains, Dutchess County, N.Y. Latest Upper Cambrian fossils from the top of the formation (or the base of the overlying Briarcliff) date the Pine Plains as Upper Cambrian. *Cryptozoon*, ooliths, sand, and edgewise conglomerate layers are typical of Upper Cambrian dolomites of Pennsylvania and Maryland (see Sando 1957). Correlation with the type section is based on fossil evidence and lithologic match.

Briarcliff Dolomite

General features—Briarcliff Dolomite has not been positively identified in this area. The layers labeled Briarcliff may actually belong to the underlying Pine Plains or the overlying Halcyon Lake. At the type area, the unit has alternating light and dark layers similar to the Pine Plains and calc-dolomite layers similar to the Halcyon Lake, but it has distinctive druses filled with doubly-terminated quartz crystals and calcite. Knopf (1962) estimates the thickness as 700 feet. In the Goshen area, quartz-calcite druses, only in a few places containing terminated crystals, and irregular black clay partings are common in the variable dolomite called Briarcliff. These features also occur in the Halcyon Lake, but that formation is generally distinguished by the presence of calc-dolomite layers. According to Warthin and Pack (unpublished), the Middle town well (cross-section A-A' passed through 175 feet (165 feet probable true thickness) of Briarcliff, but their identification of the unit was on doubtful criteria.

The Briarcliff (?) consists of interlayered light-gray (N7), very finely crystalline, siliceous dolomite and very light brownish gray (2 YR 6/1), fine- to medium-crystalline, siliceous dolomite, and a few layers of bluish gray (5F 3/1) medium-crystalline dolomite. Medium-crystalline varieties are very even textured, rather sugary, and lustrous. Light- to medium-gray chert occurs in scattered nodules and rare layers a few inches thick. Greenish shaly partings are present in a few places. Quartz sand zones are rare. The occurrence of quartz-calcite druses and black shale partings is considered diagnostic. Thickness of beds range from 2 inches to 2 feet, and is too irregular to be distinctive.

Name, age, and correlation—Knopf (1946) named this unit from Briarcliff Manor in Dutchess County, N.Y. She reported the age as Late Cambrian (Lower Trempealeauan) on the basis of finding *Plethemetopus knopfi* Lochman and *Prosaukia briarcliffensis* Lochman. Definition of Briarcliff in the present area is uncertain, but in any case, the unit is much thinner than at the type locality.

Ordovician System

Halycon Lake Calc-dolomite

General features—Variable dolomites and calc-dolomites of the Halcyon Lake outline a major syncline between Edenville and Warwick. They are also prominent in the vicinity of Florida, and near Breeze Hill on the west edge of the Wallkill peat lands. Four small areas of Halcyon Lake occur as inliers surrounded by younger shale.

The formation is so variable lithologically and exposed in such disconnected outcrops that a reliable complete section cannot be pieced together. Much of the section consists of lustrous, fine- to medium-crystalline, mottled medium-gray (N5) and medium dark-gray (N4) dolomite. This lithology weathers distinctively white or very light-gray. It is commonly interbedded with very finely crystalline to aphanitic, medium light-gray dolomite with a pale-brown tinge. The finer dolomite is more siliceous, and commonly contains many argillaceous or siliceous laminae which give the weathered rock a ribbony character. Orange, ankeritic mottling and pale-buff mottling suggestive of burrow structures are present in some layers. Calcite-quartz druses are common in a very finely crystalline variety of the common dark dolomite. Dolomite pebble conglomerates and minute layering of different textured dolomites are present, but generally they can be seen only on the light-gray or pale buff-gray weathered surfaces. Wavy, stylolite-like black clay partings are common, and in some places mark surfaces of minor disconformity or diastems (figure 16). At the Mt. Lookout quarry, one clay parting is 2 inches thick in places and has small pockets of white fibrous gypsum. Very finely crystalline pyrite is abundant throughout the clay parting.

The rock varieties and features described are well exposed at the Mt. Lookout quarry (figure 17), which is probably in the upper part of the formation. Here, and in the same section in the large inlier east of Florida, the Halcyon Lake differs materially from parts of the Pine Plains or Briarcliff only in the presence of raised, twig-like markings, probably algal, on the topmost layers of the exposed sections. The markings are buff against light gray-weathering dolomite.

Despite the similarities of the Halcyon Lake described so far to other units of the sequence, generally some beds or nearby outcrops occur which display more diagnostic features. Distinctive of the Halcyon Lake are:

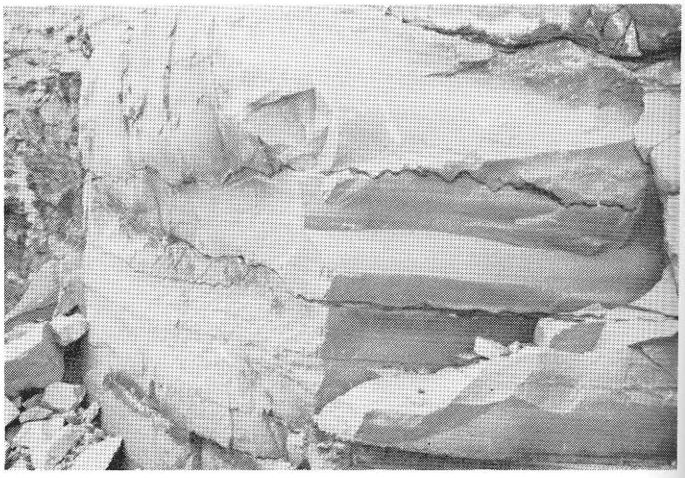


FIGURE 16. Finely laminated Halcyon Lake Calc-dolomite; note disconformable wavy clay partings. Mt. Lookout quarry.

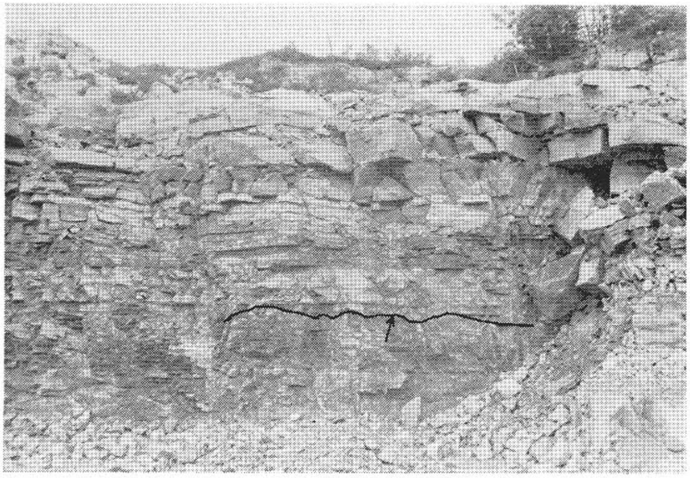


FIGURE 17. Variable bedding characteristics in Halcyon Lake Calc-dolomite. Arrow marks minor disconformity. Mt. Lookout quarry.

1) Calc-dolomite layers (calcite and dolomite in subequal amounts) so siliceous that weathered surfaces are marked by resistant masses and irregular raised networks of quartz and chalcedony (tripolite). The calc-dolomite is medium crystalline and lustrous.
2) Many of the dolomites and all the calc-dolomites weather with a definite very fine sandpaper texture, owing to the presence of disseminated quartz (silt-size, and secondary chalcedony, as distinct from the sand grains of the Pine Plains).
3) Abundant medium- to dark-gray chert, in scattered nodules, lenses, and discontinuous layers as much as 2½ feet thick, is associated with the calc-dolomites.
4) The calc-dolomites and some dolomites have an unmistakable fetid smell of H_2S when freshly broken.

The thickness of the Halcyon Lake appears to be on the order of 500 to 600 feet, although it may be less, as Warthin and Pack reported only 469 feet (440 feet probable true thickness) in the Middletown well. Knopf (1946) gave 350 feet as the probable thickness of the unit in Dutchess County. Both the Pine Plains and the Halcyon Lake in the present area are thicker than at the type sections, although the lithologic character seems constant. The thickening appears to have been at the expense of the Briarcliff. In both places the whole sequence has about the same thickness, and it is not known if the internal discrepancies result from misplacing of unit boundaries in the Goshen area or some sort of facies relationship. Misplaced top and bottom boundaries of the Briarcliff seem the most likely answer.

Name, age, and correlation—Knopf (1946) named the formation for Halcyon Lake in Dutchess County, N.Y. She reported the age as Lower Canadian, equivalent to the Gasconade, on the presence of *Ozarkispira,* and since (1962) has found *Ellesmeroceras* sp. and *Ectenoceras* sp. in the upper third of the formation. Correlation of the present area with the type area is based on matching lithologies, supported by faunal correlation of older and younger units of the carbonate sequence.

Rochdale Limestone

General features—Rochdale Limestone, the most distinctive of the carbonate units, occurs only on one hill, in the northeast corner of Pine Island Quadrangle. It is not known elsewhere west of the Hudson River in southern New York. It is sporadically present in Dutchess and Columbia Counties. At the type section, Knopf (1962) figures the thickness as about 400 feet (although possibly as much as 750 feet), with the formation truncated at the top. In the present area, a little more than 100 feet is partly exposed in the one section available. The Middletown well (cross-section A-A') penetrated 319 feet of Rochdale (300 feet probable true thickness) according to Warthin and Pack. Elsewhere in the area, the Rochdale is absent or very thin and not exposed, the erratic occurrence and thickness owing to erosion prior to deposition of the overlying shales. To the north, in Columbia County, Copake Limestone locally overlies Rochdale; if the Copake was ever present in the Goshen area, it was also removed before the shale or Balmville Limestone was deposited.

The Rochdale consists of thin-bedded limestone (figure 18) containing a few thicker layers of dolomite. The limestone is very light gray to white on weathered surfaces, and has argillaceous films and patches which weather darker and in slight relief, giving bedding surfaces irregular, fragmented appearances. Most of the formation is medium dark-gray (N4) aphanitic limestone in small, thin plates and chips cemented with minor amounts of very finely crystalline argillaceous or siliceous medium dark-gray limestone. Conchoidal fracture is characteristic of the aphanitic limestone. Some of the aphanitic limestone fragments are smoothly curved, jointed pieces of the large, nearly planispirally coiled *Ophileta* sp? which is the most common fossil in the Rochdale. Thus, the rock is essentially thin-bedded edgewise conglomerate in which lime-mud chips have been cemented by similar, but less calcareous material. The interstitial material commonly weathers brown or orangish tan.

Dolomite layers are medium light gray (N6), aphanitic to very finely crystalline, and weather brownish buff. At one place near the top of the limestone section, a wedge-like crevice in a limestone layer is filled with dolomite

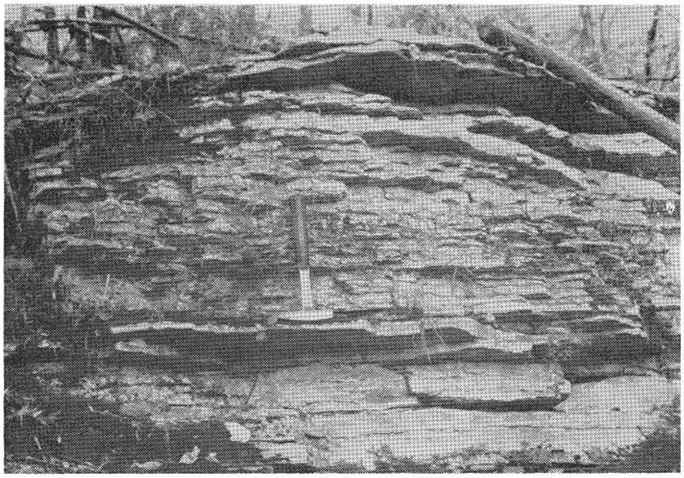


FIGURE 18. Thin-bedded Rochdale Limestone, northeast corner of Pine Island Quadrangle.

from the overlying layer. This, and the broken character of the aphanitic limestone, indicate consolidation and fragmentation (mud cracks?) of the lime mud immediately after deposition. Filling of a crevice with dolomite seems good evidence that the material deposited upon the limestone either was an original dolomitic sediment or one in which calcium carbonate sediment was replaced by dolomite as deposition occurred. Both of these modes of dolomite deposition are probably favored by a lagoonal environment such as can be inferred from the lithologic characteristics of the limestone.

Name, age, and correlation—The formation is named for its occurrence at Rochdale in Dutchess County, N.Y. (Knopf, 1946), where fossils indicate an Early Ordovician age. Correlation with the limestone of the Goshen area rests on faunal evidence and, as the lithology is identical in the two areas, is further evidence that lithologic match can be used in lieu of firmer evidence for correlation within the carbonate sequence. The value of lithologic match with respect to correlation is demonstrated for the Stissing and Rochdale, at the bottom and top of the sequence, and presumably is true for matching units in the intervening section, although the Briarcliff correlation is a problem.

In the present area, the Rochdale lithology contains *Finkelnburgia sp., Hystricurus sp., Clelandia?* (D. W. Fisher, written communication), *Ophileta* sp. (Early Canadian fauna) with preserved part of coil as much as 3 inches across, and small tightly coiled planispiral gastropods indistinguishable from *Lecanospira* (Medial Canadian fauna). It is clear that the Rochdale belongs to the Beekmantown Group of the Lower Ordovician but note that here the Rochdale lithology descends lower in the Early Ordovician. In the shaly facies of the Taconic region, the lower part of the Deepkill is considered equivalent to the Rochdale.

Balmville Limestone

General features—Balmville Limestone is the basal unit of the shale sequence which unconformably overlies the carbonate sequence. The limestone apparently is absent more than it is present, and its thickness is as erratic as its occurrence. Only 10 exposures of the Balmville are found in the area, near Gardnerville west of the peat lands, north of Campbell Hall, and 8 around the periphery of the shale in the large syncline of the Warwick-Edenville area.

The upper contact is never exposed, but the shale next above the limestone is always more calcareous than usual and a gradational contact is probable. In eastern New York, New Jersey, and Pennsylvania, however, the shale-limestone contact has been observed to be variously gradational, disconformable, and angularly unconformable (Miller, p. 210; Weaver, p. 737). The limestone rests unconformably on Halcyon Lake everywhere, with the possible exception of the Gardnerville locality, where it may overlie unexposed Rochdale. Halcyon Lake beneath Balmville 1½ miles west of Warwick is brecciated in part but elsewhere dolomite is broken and veined with calcite and quartz beneath unaffected Balmville. At Gardnerville and east of Mt. Lookout, an angular relationship is inferred from bedding attitudes of Halcyon Lake and Balmville outcrops, although actual contacts can not be seen.

Thickness of the unit, where present, does not appear to exceed 25 feet, except at Gardnerville where it is at last 60 feet thick. This may be a function of exposure, however, as Warthin and Pack identified 381 feet (350 probable true thickness) in the Middletown well. In Pennsylvania, the apparently stratigraphically equivalent Jacksonburg Limestone varies even more extremely, from absent to 600 feet thick in the space of a few miles (Miller, p. 207). Such variations in thickness, at least where no unconformity occurs at the top, and the conglomeratic nature of the limestone suggest that it was deposited on a very irregular karst surface developed on the older carbonate rocks. Such a relation is evident at the Balmville locality just north of Blooms Corners. There the floor of a small, cliff-sided cut in Halcyon Lake calc-dolomite is partly covered by a veneer of Balmville. This is apparently a fortuitous instance of the exhuming of pre-Balmville karst topography with a minimum relief of 20 feet.

Typical lithology of the Balmville is variably conglomeratic, medium dark-gray (N4), medium-crystalline limestone. The rock weathers medium- to medium-light gray (N5-N6). Abundant fossil fragments and, in places, abundant angular or rounded dolomite and chert pebbles give the limestone its conglomeratic appearance. Coarse layers may be almost coquinas of crinoid stems, bryozoa, and other fossil fragments. Bedding ranges from about one foot thick to shaly; the shaly layers are commonly somewhat argillaceous and fossils, particularly brachiopods, are better preserved than in the more massive layers. Finely crystalline layers are platy and only poorly fossiliferous.

Name, age, and correlation—The Balmville was named by Holzwasser (1926) for an excellent exposure of conglomeratic limestone on the river road near Balmville north of Newburgh. Ries (1896) had used the name Neelytown for the Balmville and underlying Halcyon Lake near Campbell Hall, but this term was abandoned. Ries erroneously identified Balmville near Stonebridge northeast of Warwick as Helderberg.

The rock type, in this stratigraphic position, is found from west central Vermont (the Whipple limestone of Fowler 1950, and others) and Washington County, New York (Platt, 1960) to Pennsylvania. In the north, it is usually called Trenton Limestone, and in the south, Jacksonburg Limestone. Fossils, however, do not permit precise correlation along strike. In most places, the age of the unit can be determined no closer than "Black River—Trenton," so it is not known if the unit is the same age everywhere, or is perhaps irregularly transgressive.

Wilderness age is indicated by fossils in Balmville of the Goshen area (Table 16). Dr. G. A. Cooper of the U.S. National Museum identified the following (written communication, 1961; parenthesis mine):

Hill due east of Mt. Lookout quarry: *Oxoplecia sp.*, *Strophomena* sp. The two brachiopods are definitely Trenton types and are similar to those that we have in the Edinburg limestone west of Washington.

One mile N.28°E. of Warwick Hospital: *Solenopora* "a small cup coral very suggestive of *Lambeophyllum*", *Dactylogonia* sp., *Eoplectodonta* sp. The latter is characteristic of our Edinburg limestone in Virginia and is a good Black River-Trenton fossil. The presence of the small coral eliminates this rock from identification as Chazyan. Our Edinburg in Virginia has this coral in abundance in the part that we would identify as low Trenton." ("Trenton" is used here in the sense of Kay, 1947, that is, as a major stage of the Middle Ordovician rather than as the restricted uppermost stage of the Middle Ordovician defined by Cooper).

Dr. Jean Berdan of the U.S. Geological Survey studied ostracodes of a collection (B1-4) from 5,500 feet northeast of Gardnerville and from a locality mapped by Larsen (1953; and noted in Bucher, 1957). She provided the following information (written communication, March 1961):

This collection (B1-4) contains the following ostracodes:

Eoleperditia sp.
Leperditella sp.
Hallatia sp. aff. *H. particylindrica* Kay
Winchellatia sp.
Oepikella sp.
Platybolbina sp.
Levisulculus? sp.

The genera *Hallatia* and *Winchellatia* were described from the Decorah formation in Iowa (Kay, 1934, 1940) and also occur in the lower part of the Trenton in Ontario and New York. On the other hand, *Oepikella, Platybolbina* and *Levisulculus,* all originally described from Scandinavia, have recently been reported in North America in beds considered to be of Black River age, (Swain, 1957, Kesling, Dec. 1960, 2 & 3). I suspect, therefore, that this collection is late Black River to early Trenton in age.

The ostracodes identified from the Balmville limestone in 1953 for L. H. Larsen, then of Columbia University, came from ledges of platy limestone above Cambro-Ordovician dolomites and below black shales about 1.8 mi. N.40°E. of Warwick, N.Y. The following genera were represented:

Eoleperditia sp., *Macronotella* sp., *Eurychilina* sp., *Krausella* sp. and *Winchellatia* sp. The *Eoleperditia* is not conspecific with the one in B1-4, and I doubt that the *Winchellatia* is, either, though in this case the preservation is too poor to be certain. These genera are sufficiently long ranging that no more precise age determination other than Middle Ordovician can be given. Subsequently I collected from Larsen's locality, but apparently not from the same horizon that he collected, as only *Krausella,* a common genus, occurs in both lots. My collection also contains *Steusloffina,* hitherto reported only from the Northwest Territories in Canada, and glacial drift in Germany.

Holzwasser (1926, p. 36), partly quoting Dwight (1880), lists these fossils and assigns the Balmville of the type locality to the Trenton on the basis of general aspect in the absence of a diagnostic fauna:

Small encrinal columns: *Orthis (Dinorthis) pectinella;* columns of *Schizocrinus nodosus; Strophomena (Rafinesquina) alternata; Chaetetes (Solenopora) compacta; Chaetetes lycoperdon* var. *ramosus; Rhynconella (Rhynchotrema) capax; Leptaena (Plectambonites) sericeus;* headplates of *Echinoencrinites (Cheirocrinus) anatiformis; Discina* n.s. *conica* probably *Petraia corniculum;* indistinct *Brachiopoda; Strophomena (Rafinesquina) deltoidea; Triplesia* n.s.; *Cleiocrinus magnificus* and *C. grandis; Dalmanella testudinaria.*

In a new correlation chart for Ordovician rocks in New York State by Fisher (1962), "Black River" and "Trenton" are used as names of rock groups of the Porterfield, Wilderness, and Barneveld stages. This usage eliminates the confusion of having two differently defined Trenton stages. Table 16 shows both old and new stage terminology for comparison. In the new usage, Balmville Limestone is entirely within the Wilderness stage.

The Shale Sequence

Nearly two-thirds of the Goshen (15 minute) Quadrangle is underlain by Middle Ordovician shales, siltstones, and graywackes. This clastic sequence extends north as far as the Fairhaven area of Vermont, and eastward into Massachusetts. East of the Hudson River, slaty cleavage is well developed and metamorphism markedly increases eastward to give high-grade schists in eastern Dutchess County, and phyllites farther north. West of the Hudson River, as discussed in detail below, the sequence is different in several respects and slaty cleavage is generally more poorly developed.

In New York, these shales and grits have commonly been known as the Hudson River slate group or by slight variants of that name. This name was introduced by Mather in 1840, and its use was subsequently and erroneously extended to shales in western New York, Canada, and even Missouri and Wisconsin. A half-century of confusion followed as to what should be included in the "Hudson River terrane," and the term was abandoned after Ruedemann (1901) demonstrated that Mather's original term had included only the bottom part of the erroneously correlated sequence. Nevertheless, the name has lingered for the unsubdivided shale sequence along the Hudson Valley north of the Highlands. Holzwasser (1926) used the term Hudson River formation for the shales and graywackes of the Newburgh Quadrangle which adjoins the Goshen Quadrangle on the northeast. In the present study, the threefold subdivision of the Hudson River sequence as recognized in the area around Albany, New York, has been used.

A thorough historical summary of the problems of Hudson River shale nomenclature is given by Holzwasser (1926), and much of the foregoing discussion has been drawn from her presentation.

From the New York-New Jersey boundary to Tennessee, the shale is known as the Martinsburg. In New Jersey and Pennsylvania, slaty cleavage is well developed, and Martinsburg slate is quarried commercially in Pennsylvania.

Normanskill Shale

Mt. Merino Shale—Mt. Merino Shale is the lower of two members of the Normanskill Shale. Its extent in the Hudson Valley and Taconic regions probably exceeds that of any other rock unit. Nearly one-half of the present area is underlain by this shale.

Considerable minor folding of the shales and very low percentage of outcrop area balk any attempt to determine a lithologic sequence within the unit. On the basis of regional relationship, however, general statements can be made concerning lithologic changes from bottom to top of the section.

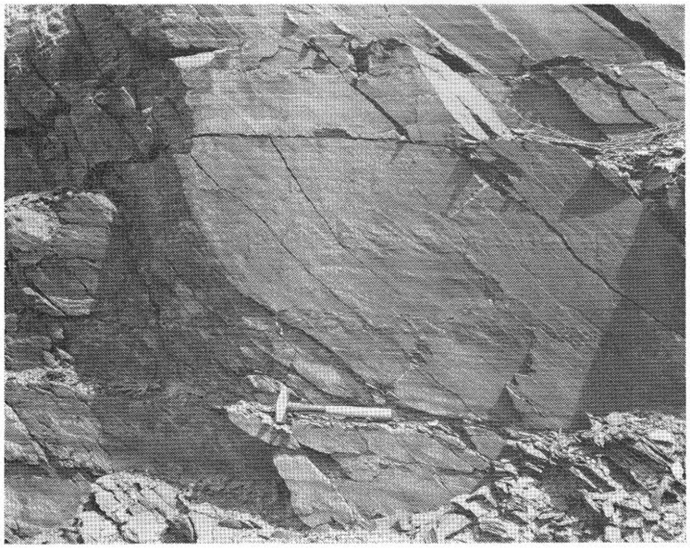


FIGURE 19. Lower part of Mt. Merino, mudrock with silty laminae; west of Chester exit, New York 17.

The lower part of the unit consists of medium dark-gray (N4) mudstone, silty in part, in non-fissile layers ¼ inch to 6 inches thick. These layers are separated by layers of silt and fine sand 1/16 inch to 4 inches thick, minutely laminated and generally very finely cross-laminated. The coarser layers are sandy buff and give outcrops conspicuous striped appearances (figure 19). Grading of beds on a minute scale is present in nearly all outcrops; the sandy laminae grade upward into the mudrock. Grading is especially apparent in rare unlaminated sandy layers. The rock seldom breaks along bedding planes, but where it does, bed surfaces are hackly and weather rusty

Higher in the unit, laminated sandy siltstone becomes more prominent, and thicker, more massive beds are typical. Buff laminae of very fine sand equal or exceed gray laminae of clayey silt. Convoluted laminae and intrastratal flowage features are common. In places, the bottoms of massive laminated beds show flute casts. Medium-grained sandstone beds as much as 5 feet thick were found at Durland Hill south of Chester and north of the West Ridge and Sleepy Valley roads intersection. These are probably isolated lenses within the Mt. Merino, but they may possibly be basal beds of the overlying member.

Clay and sericite are important components of the mud rock but very fine-grained quartz is the principal material in both lithologic types. The sandy layers generally contain enough calcite to effervesce weakly in 1:10 HCl; the calcite occurs in fairly well-crystallized euhedra of very fine sand size. Calcite is not interstitial and apparently is primary sedimentary material. The mudrock portion is never ostensibly calcareous except just above the underlying Jacksonburg-Balmville Limestone. Minute pockets of pyrite and of anthraxolite are only rarely present throughout the section.

Cleavage is ubiquitous; it is discussed in the section on deformation of the shale sequence.

Austin Glen Grit and Shale—The upper, or Austin Glen, member of the Normanskill Shale occurs in a curving belt in the northwest corner of the area. It is lithologically distinct from the Mt. Merino and the bottom contact can be chosen simply from its topographic expression, except in the vicinity of Middletown. The upper contact, with Snake Hill Shale, is lithologically and topographically less distinct and is queried where shown on the map.

The Austin Glen consists of interbedded massive, dirty sandstones or graywackes and thin-bedded fissile shales. Sandstone layers range from ½ inch to 6 feet in thickness, but are most common in the 2-inch to 1-foot range (figures 20, 21). They are unlaminated and rather homogenous up to the top few millimeters, where they may either grade subtly into mudstone or shale, or become finely laminated, passing gradually upward into more uniform shale. In a few places, bulbous elongate flute casts are present on the bottoms of sandstone beds. The intervening shale is rarely exposed between low ridges of sandstone. Where observed, it is a fissile, homogeneous clayey rock, almost a "paper shale" in its thin parting (figure 20). Commonly bedding and cleavage are so well developed and closely spaced that the shale breaks into stubby pegs.

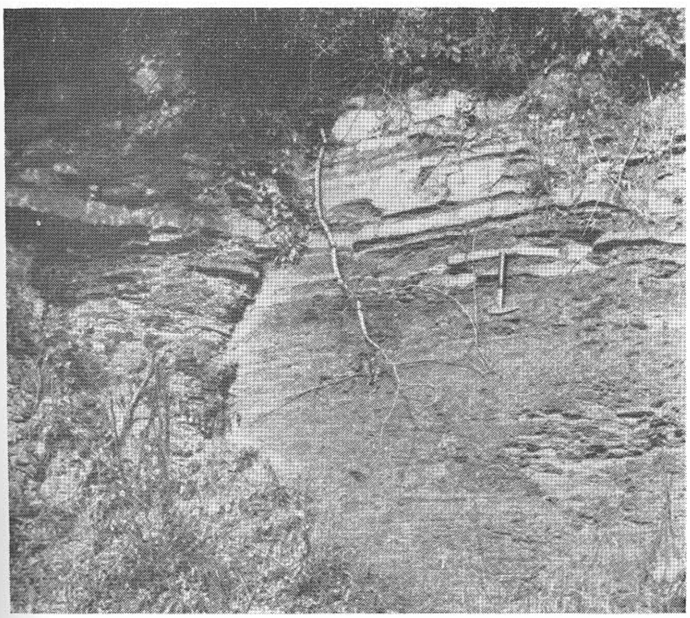


FIGURE 20. Interbedded shale and thin graywacke layers near the base of the Austin Glen; one mile west of Route 84 at Mannayunk Hill.

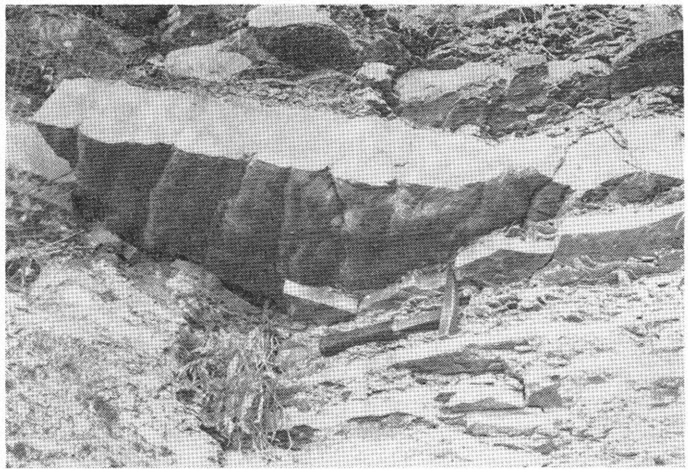


FIGURE 21. Flute casts, upper left of outcrop in figure 20, indicate current from northeast.

Austin Glen grit or sandstone typically weathers buff, with a slightly porous, rusty-brown rind ½ inch thick. The fresh rock is medium dark gray (N4) with a bluish cast. Subrounded fine- to medium-sand-size clasts of quartz and minor amounts of smaller angular grains of fresh feldspar compose 60 to 70 percent of the rock. The remainder of the rock is interstitial material, mostly calcite, with some very fine quartz, feldspar, zircon, and sericite. Sericite flakes commonly are oriented well enough to make weathered bed surfaces sparkle weakly in sunlight. Rarely, a sandstone layer contains subrounded dolomite, sharp chert, and elongate shale pebbles.

Cleavage in the Austin Glen differs from that in the Mt. Merino; it is discussed in the section on deformation of the shale.

Snake Hill Shale

Snake Hill Shale overlies the Austin Glen in the northwest corner of the area. The contact between them is doubtfully located, as both have graywacke beds. In the Snake Hill, as chosen here, graywackes rarely attain thicknesses of more than 2 feet and are less numerous than in the Austin Glen. More significant, the lithology between massive sandstones or graywackes is much like the laminated non-fissile beds of the upper Mt. Merino. Higher in the formation, northwest of the area mapped, sandy beds gradually decrease in number and the Snake Hill becomes a fairly fissile dark-gray to black shale.

Nomenclature of the Shale Sequence

The Normanskill Shale was named in 1901 by Ruedemann (p. 568) for exposures of the formation along the creek of that name at Kenwood, N.Y. Later (1942), he defined the Mt. Merino and Austin Glen members from localities in the Catskill Quadrangle. The name Snake Hill first apeared in 1911 (Ulrich, pl. 27), apparently based on work by Ruedemann, who had studied the formation in the Albany area, and at the type locality at Saratoga Lake, and later published several reports describing the unit (N.Y. State Mus. Bulls. 162, 169, 227, 285). These three units constitute the classic Hudson River shale section in the Albany area and are used as a reference section for the discussion of age relations below.

These names are used for the shale sequence of Goshen (15 minute) Quadrangle, purely in the sense of a lithologic sequence essentially continuous with that of the type localities, without regard to ages of the units. The problems involved are discussed below.

Thickness of the Shale Sequence

In the Albany area, Ruedemann (1930, p. 99) estimated the thickness of the Normanskill to be about 1,000 feet, and that of the overlying Snake Hill to be at least 3,000 feet. Probably a minimum of 1,000 feet of Normanskill is present in the Catskill Quadrangle (Ruedemann, 1942, p. 88), including about 500 feet of grit, 400 feet of the white-weathering chert member, and 100 feet of shale. Holzwasser (1926, p. 65) gave 1,500 or 2,000 feet as the probable thickness of the shale sequence (all called Snake Hill) in the Newburgh Quadrangle, but her estimate was based on conjecture about sedimentation rates, rather than geologic relationships. Ries (1896, p. 99) esti-suggested 1,800 to 2,000 feet as a minimum thickness of the shales in Orange County.

Blocks of the underlying carbonate rocks are exposed, surrounded by the Mt. Merino that remains in the eastern and central part of Goshen (15 minute) Quadrangle, as though the shale cover is fairly thin. Cross sections (N.Y. Geological Survey files) of the geologic units cut by the Delaware aqueduct north of the quadrangle show anticlinal crests of the carbonate rocks aproaching within a few hundred feet of the present land surface. These relationships would support thickness estimates for the shale perhaps similar to the one made by Ries, but they are misleading. This area is on the crest of a regional anticlinorium (Friedman, 1957; see section on structure) and near the culmination of a regional arch, and only the bottom part of the shale sequence has not been stripped away. The west limb appears to provide a complete homoclinal sequence between the carbonate contact at the west side of the peat lands and the base of the Shawangunk Conglomerate. Large new road cuts along Route 17 reveal that the west limb has been deformed in rather low, undulant folds, and that tetonic thickening or repetition of beds by folding or faulting need not be considered significant in making thickness estimates.

On that premise, and with correction for probable regional dip (cross-section A-A′, plate 2), the thickness of the Mt. Merino is available from records of the Middletown well (Warthin and Pack). The well started at the base of the Austin Glen and penetrated 4,530 feet of shale (called Snake Hill). True thickness is probably 4,000 to 4,200 feet. If the construction in cross-section A-A′ is approximately correct, even allowing for undulant folding, the Austin Glen must be on the order of 3,000 feet thick. To the base of the Shawangunk a thickness of about 5,000 feet for the Snake Hill is indicated, but it may be half that if flattening of dip is considered. This total of 10,000 to 12,000 feet is almost certainly too large, especially if broad folding flattens the regional dip between Middletown and Shawangunk Ridge; 8,000 to 9,000 feet is regarded as the best estimate.

In northeastern Pennsylvania, the Martinsburg was thought by Behre (1927) to be 11,800 feet thick. This was based on his recognition of a tripartite sequence essentially identical to the New York sequence (upper: 2,600 ft.; middle: 4,200 ft.; lower: 5,000 ft.). Willard (1941, p. 215) and others have disputed this estimate on the grounds that the upper and lower members were the same, repeated across a regional fold. Willard gives the total thickness of the presumed two units as 3,500 to 4,000 feet, and estimates the upper sandstone unit to be only 750 feet thick. Regional structure, lithologic comparison, and faunal evidence, however, support Behre's conclusion. Recent work by John C. Maxwell of Princeton University (oral communication) in the vicinity of the Delaware Watergap provides further corroboration of the tripartite sequence and the great thickness.

Age and Regional Stratigraphic Relations of the Shale Sequence

Graptolite faunas and lithologic succession in the shale sequence at the type localities and surrounding area have been restudied recently by W. B. N. Berry (1962, 1963, unpublished). He has established the graptolite zones shown in Table 16 (Berry, 1959, p. 42; 1962) and has been able to subdivide the Normanskill into four lithologic members:

4. Austin Glen sandstone and shale
3. Silty mudstone, chert, some thin graywackes
2. Silty mudstone
1. Red and green chert and mudstone

In the Goshen area, graptolite and lithologic evidence shows that Normanskill member 3 (upper Mt. Merino) rests directly on the Balmville, (Table 16, #D7-2(. Table 16 gives faunal data provided by Berry for the shale sequence.

The entire lower unit of the tripartite sequence is called Mt. Merino on the basis of lithology and position beneath Austin Glen lithology. Yet only the lower part of the unit contains graptolites distinctly belonging to zone 12 of the classic section ("Mt. Merino"). The upper part of the unit contains graptolites assignable to zone 12 or zone 13 ("Snake Hill"). Upper Mt. Merino is missing in the northern Taconic area. It is thin and of zone-12 age in the Albany area, and it clearly thickens greatly southwestward, probably crossing time lines as it does so, if the upper part actually belongs to zone 13 or is transitional between zones 12 and 13 (Table 16 and Plate 4).

TABLE 16

Shale Sequence Faunal Data

The following graptolite identifications were made by Dr. W. B. N. Berry, University of California, (personal communication):

Zone 12

#D7-2, upper Mt. Merino lithology, on road 4,000 feet north of Campbell Hall.

Corynoides calicularis Nicholson

Cryptograptus tricornis (Carruthers)

Zone 12 or 13

#D1-2, uppermost Mt. Merino lithology, on Route 17, 3,000 feet SE of Phillipsburg.

Orthograptus truncatus cf. var. *pertenuis* (Ruedemann)

Diplograptus? sp. new?

Climacograptus sp. like that in #SG-15

Climacograptus sp?

Glyptograptus cf. *G. teretiusculus* (Hisinger)

Glyptograptus euglyphus (Lapworth)?

Orthograptus? sp.

Zone 13

#A7-1, Austin Glen lithology, on Route 17, 4,500 feet north of Silver Lake.

Orthograptus truncatus var. *pertenuis* (Ruedemann)?

#A7-2, Snake Hill lithology?, on Route 17, 4,500 feet SE of Route 302 intersection.

Glyptograptus vespertinus (Ruedemann)

Collection from Fair Oaks exit on Route 17, Snake Hill lithology?

Diplograptus?

Orthograptus?

Orthograptus truncatus cf. var. *pertenuis* (Ruedemann)

#SG-138, excellent Snake Hill lithology (Canajoharie affinity), from 138 feet stratigraphically below base of Shawangunk Conglomerate, Wurtsboro exit of Route 17.

Dicranograptus nicholsoni Hopkinson

#SG-15, ditto, from 15 feet below Shawangunk

Climacograptus typicalis Hall

Climacograptus sp. new?

At various localities mentioned by Ries (1896) Darton (1885), and Prosser (1892), and a few newly discovered localities, thin sandy layers packed with fragmentary fossils occur within the Mt. Merino. The material is almost entirely brachiopod and crinoid stem pieces: it has generally been dismissed as being of "Snake Hill aspect." Reported fossils in the vicinity of Sugarloaf were: *"Orthis"* [now *Dinorthis*] *pectinella*, *"Orthis"* [now *Paucicrura*] *testudinaria*, *"Orthis" plicatella Leptaena sericea* Sow., *Camerella* [now *Parastrophina*] *hemiplicata Strophomena alternata* Cv, *Streptorynchus planimbona* or *S. felifextra? Trinucleus* [now *Cryptolithus*] *concentrica* Eaton, and fragments of *Chaetetes*, *Favosites*, and crinoid stems.

The Austin Glen member is also time-transgressive. It is thin and rests unconformably on lower Mt. Merino in the northern Taconic area (Platt, 1960, p. 44), where graptolites show it to belong to the upper part of zone 12. In the classic Albany area it is thin and probably unconformable on lower Mt. Merino (Ruedemann, 1942, p. 102), but there the lower part of the unit contains zone 12 graptolites and the upper part zone 13 graptolites. The unit thickens and changes in age progressively southwestward, changing from 500 to 3,000 feet in thickness and lying entirely in zone 13 in the Goshen area.

Similar changes mark the Snake Hill Shale as well; the base of the formation is far above the first occurrence of zone 13 graptolites in the Goshen area, though the base is only slightly above the first occurrence of zone 13 graptolites in the Albany area. Clearly the entire shale sequence crosses time lines, becoming markedly younger and thicker to the southwest. An interpretation of age relations is given in figure 22.

Behre (1927, p. 18-34) tentatively assigned the lower, middle, and upper Martinsburg members of northeastern Pennsylvania to Trenton, Eden, and lower Maysville, respectively. The faunal evidence was not unequivocal and needs re-examination, but the ages assigned are consonant with the trend observed in New York.

Time-transgression of most of the shale sequence can be demonstrated, but the age or change in age of the base of the sequence is not so clear. The Balmville-Jacksonburg Limestone has not been shown to be younger in Pennsylvania than it is in New York. If it is, there is no difficulty; if it is not, a hiatus between Jacksonburg and lower Martinsburg presumably is indicated for the southern area.

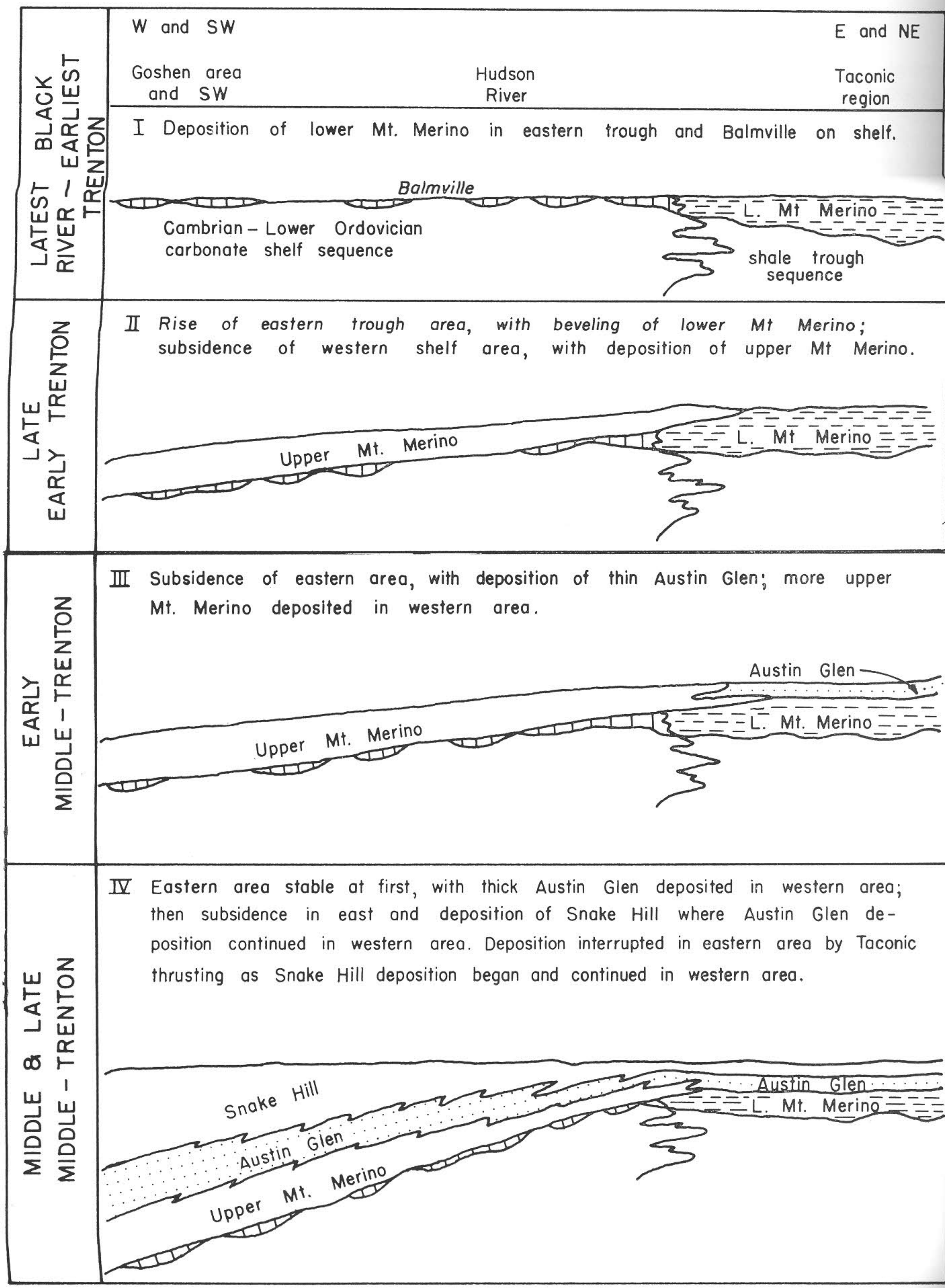


FIGURE 22. Interpretation of age and stratigraphic relationships of the shale sequence.

This would mean a different sequence of diastrophic movements of the shelf area in Pennsylvania.

Bearing on the "Taconic Problem"

The absence of the lower Mt. Merino (members 1 and 2) in the Goshen area introduces uncertainties connected with the "Taconic problem."

Berry (personal communication) reports that west of the Hudson River, only members 3 and 4 are present overlying the Balmville. East of the Hudson, however, both members 1 and 2 are present overlying Balmville or Black River—Early Trenton limestone. Here, the problem of what is autochthonous and what is allochthonous arises; that is, whether or not the "Taconic klippe," a broad, far-traveled thrust plate of Cambrian-Ordovician shales, is present, and if so, to what extent.

This "Taconic problem" has been fiercely debated for many years and the arguments are too many to be presented here. A brief summary of the debated relationships is given by Rodgers (1952, p. 10-12) and a more detailed exposé is given by Fisher (1961). General feeling in the past has been that a klippe is necessary in the northern Taconic region, but not in Dutchess County to the south (Zen, 1960). For the present discussion, the presence east of the Hudson of a major thrust plate of uncertain extent is accepted.

One problem is correlation between the shale and carbonate facies. The best faunal evidence available (see discussion of Balmville Limestone age) indicates that Balmville and Normanskill members 1 and 2 are at least in part time-equivalent, both being of Late Black River-Early Trenton age. Thus, Balmville Limestone was deposited upon the carbonate shelf sequence to the west, while lower Mt. Merino was deposited to the east upon a trough sequence of shales equivalent to the carbonate sequence. Balmville is known in eastern Dutchess County, and lower Mt. Merino occurs in western Dutchess County. How much of this overlapping is due to interfingering of the sharply dissimilar facies and how much is due to westward thrusting of the Mt. Merino is uncertain. No gradational rocks are found, however; at Newburgh the red and green shales are separated from the Balmville only by the width of the Hudson River, yet the shales never extend west of the river. This suggests that the lower Mt. Merino is allochthonous and that any depositional interfingering with the Balmville must have taken place farther east. Thus, in western Dutchess County and west of the Hudson at least, only upper Mt. Merino can be shown definitely to be autochthonous.

Framework of Sedimentation of the Shale Sequence

From the regional pattern of tectonism and sedimentation in the north-central Appalachians, it is clear that until Middle Ordovician time, New York west of the Hudson River was a stable, shallow, foreland shelf area, giving way just slightly to the east to a northeast-southwest-trending geosynclinal trough. Thus the configuration of carbonates on the west and equivalent shales on the east. In Middle Ordovician time, the picture changed. The eastern and northeastern area apparently rose and then sudsided somewhat, and the former shelf area became an area of major subsidence. This subsidence was least to the north where the Adirondacks were a stable area. Subsidence of the newly forming western trough was progressively greater, and later, to the southwest than to the northeast.

Sedimentational features of the shale-graywacke sequence indicate turbidity-current deposition (discussed, e.g., by Van Houten, 1954). Current markings were not systematically studied in the present investigation, but those noted point to currents travelling west and southwest, that is, they indicate current movement both across and along the trough. The presumed source of sediments was a tectonically active area rising to the east and northeast, a precursor of the late Ordovician Taconian orogenic belt.

The Mt. Merino appears to be a product of normal quiet, fairly deep-water mud deposition interrupted almost rhythmically by thin, sheet-flood type deposition of silt and mud. The coarser material is cross-laminated, showing current deposition, perhaps representing the farthest traveled material of turbidity currents whose loads were mostly deposited to the east.

The Austin Glen beds are typical of syn-orogenic flysch-type graywacke-shale sequences everywhere. In other areas, such graywackes have been shown to be long thin lenses whose length is measured in miles. This may be true in the Goshen area, because the Austin Glen beds seem to pinch out within a few miles to north and south. A connection between these rocks and massive Austin Glen graywackes of the Marlboro Mountain to the east along the Hudson River between Newburgh and Kingston has not been demonstrated. These two series may be different *en echelon* lenses, rather than a continuous, single "Austin Glen" unit, in which case use of a single name for all the lenses may be debated.

The remarkable continuity of graywackes, however, in disconnected lenses or not, at the same relative horizon in the shale sequence, seems to prove the usefulness of the name Austin Glen.

The different age of the Austin Glen from north to south is perhaps the best argument for the *en echelon* nature of separate graywacke lenses. It is apparent that a single great series of shales and graywackes deposited by a single series of turbidity currents would not be of different ages along its length. Lenses of graywacke deposited *en echelon* southwestward as the trough progressively deepened southwestward would explain the time-transgression. As the supply of sand to the trough appears to have been continuous, localization of graywackes along the trough appears to have been a function of bottom slope and perhaps depth of water.

By a continuation of this argument, the lower part of the Snake Hill (equivalent to Austin Glen from farther south) would be deposits representing the sandy, silty, and muddy "tails" of turbidity currents whose main loads of sand were deposited farther along the trough.

Silurian System

Silurian rocks are not exposed in the area, although they may be present beneath the faulted Devonian section. Just northwest of the area, however, a striking escarpment is formed by the Silurian Shawangunk Conglomerate overlain by other Silurian rocks. This section dips moderately westward as the west limb of what may have been a regional anticlinorium. Northeast of the area, the same Silurian section appears, somewhat fragmented by stratigraphic and structural breaks, at Schunemunk Mountain. There is no reason to suppose that Silurian and Devonian rocks did not cover most of Goshen and Greenwood Lake (15 minute) Quadrangles.

Devonian System

Devonian rocks are confined to the down-dropped syncline which separates the east block and the middle block. The resistant rocks of the syncline form a conspicuous ridge that extends nearly 40 miles from Schunemunk Mountain in the northeast, to Green Pond Mountain, New Jersey. Northeast and southwest of the present area, the syncline broadens and becomes shallower, and thin but more or less complete sections of pre-Hamilton Devonian rocks are exposed beneath the Bellvale Sandstone. Silurian rocks, not always in complete sections, are also found at both ends of the syncline. At Schunemunk Mountain, Shawangunk Conglomerate rests on Middle Ordovician shales; at Green Pond Mountain, the equivalent Green Pond Conglomerate rests directly on Precambrian gneisses. A more complete Upper Silurian and Lower Devonian Section at Highland Mills, Orange County, N.Y. has been described by Boucot (1959, p. 728-735).

In the mapped area, the syncline is narrow and bounded by faults so that no rocks older than Bellvale Sandstone are seen except for minor fault slices of Oriskany Sandstone and an isolated exposure of Pine Plains Formation. The presence or absence of older rocks would depend on whether the area of Bellvale Mountain was a local high or low on the surface of deposition. Probably it was high and the Silurian-Devonian section below the Bellvale Sandstone is thin, but there is no real evidence. The occurrence of a fault slice of Upper Cambrian Pine Plains Formation on Chapel Island at the north end of Greenwood Lake implies that, if the area was a high, at least not all the cover had been stripped from the Precambrian basement before Silurian-Devonian deposition.

Oriskany Sandstone

General features—The Oriskany Sandstone occurs in only two clusters of small slices along the faults which bound the large syncline of Devonian rocks. One locality is on the west side of Bellvale Mountain two miles north of Route 17A; the other locality is in the vicinity of the power line which crosses Trout Brook four miles north of Greenwood Lake.

In the limited exposures available, the formation varies from light-gray or buff, lustrous, hard quartzite sandstone to less well cemented, white-buff, flaggy to shaly sandstone. Conglomerate layers (Connelly Conglomerate) containing rounded quartz pebbles as large as ½ inch, and occasional lithic fragments in medium-grained matrix are typical of the quartzitic type. The flaggy variety typically weathers rusty buff; near the powerline, bedding surfaces have arcuate swashlike markings, probably the "cock's tail" markings of *Spirophyton(=Taonurus.)* From lithology and markings, it is possible that the powerline group is Esopus rather than Oriskany; without other fossil evidence, the distinction is uncertain.

Name, age, and correlation—Vanuxem (1839, N.Y. Geol. Surv. 3d Rept., p. 273) applied the name Oriskany to the thin Lower Devonian sandstone which overlies Helderberg limestones at Oriskany Falls. The Oriskany extends into Pennsylvania, western Maryland and Virginia, and eastern West Virginia where locally it is very thick. In the present area, its unfaulted thickness is probably less than 30 feet. Presumably overlying it, but exposed only north and south of the mapped area, is Cornwall Shale (Monroe Shale of older reports). Cornwall Shale has not been identified in the area, although Ries (1897) showed it extending north of the State line at Greenwood Lake.

Bellvale Sandstone

General features—Bellvale Sandstone is repeated across the syncline axis, making two prominent belts which extend the length of Bellvale Mountain. The western belt is cut unevenly by the boundary fault and is very thin in places. The unfaulted thickness of the formation has been estimated at 1,300 to 2,000 feet (Darton, 1894). In the southern part of the present area its thickness probably slightly exceeds 2,000 feet.

Generally the unit is easy to recognize, but near its base it may be confused with the underlying Cornwall Shale. Thus the shale that occurs next to Precambrian rocks by Gibson Hill Road may be Cornwall rather than Bellvale. The shale is dark greenish gray and weathers orange, and it is unlike the Ordovician shales. It was identified as Bellvale from the presence of a pebble conglomerate layer and the lack of fossils.

The Bellvale is dominantly a flaggy, gray, medium- to fine-grained rock composed of irregular quartz grains in a matrix of microgranular quartz and varying amounts of sericite or chlorite. Many of the quartz grains are somewhat rounded; commonly, however, the grains are elongate, with undulatory extinction and intricately sutured contacts with the matrix. Some of the strain features undoubtedly indicate a metamorphic source area, but the overall fabric suggests that quartz has partly recrystallized in response to deformation of the Bellvale Sandstone. Quartz veins and gash fracture fillings are common and presumably the quartz is locally derived.

Cross-stratification on a scale of several feet is common in the flaggy sandstone, and in small outcrops may easily be mistaken for bedding. It indicates southwestward or westward flow of current. Graded beds are also common. both in true beds and cross-strata. Such beds generally consist of a very thin basal layer containing pebbles and lithic fragments which grades upward through medium-grained sandstone to fine-grained sandstone. Conglomerate beds become more common near the top of the formation and the upper contact is marked where buff or gray-white conglomerate layers are succeeded by purple ones. Dark greenish-gray shales which have slick bedding surfaces occur in the lower part of the formation, and become dominant as the Bellvale grades into the Cornwall Shale.

Name, age, and correlation—The formation was named Bellvale Flags by Darton (194), but it has generally been called Bellvale Sandstone since that term was used in 1915 by Lewis and Kümmel (ref. from Wilmarth 1938). Medial Devonian plants have frequently been reported from the Bellvale (ref. from Wilmarth 1938). The formation is correlated with lower Hamilton beds of the classic Catskill Devonian section (Rickard, 1964) on faunal evidence.

Schunemunk Conglomerate

General Features—The Schunemunk Conglomerate occupies the center of the Devonian syncline. North of Route 17A the plunge carries it above the present surface and it reappears only in the center of the shallow syncline at Schunemunk Mountain, where only 300 feet remain as the cap rock of the mountain (Darton, 1894). In the present area as much as 2,000 feet is present, and farther south the thickness of the unit approaches 2,500 feet. Excellent exposures and a cross-section of the synclinal section are afforded by Route 17A, where it crosses Bellvale Mountain.

Easily the most striking rock in the area, the Schunemunk is notable for its purple and maroon colors and for the development of single graded sequences tens of feet thick (figure 23). The graded sequences ideally consist of conglomerate at the base that grades upward through successively less conglomeratic and finer-grained sandstone to silty shale. The development of individual members, however, varies markedly. Conglomerate is not always present, nor is shale; in other sequences they may be dominant. Commonly a sequence will be interrupted and succeeded by the following sequence; thus, conglomerate (or sandstone if the conglomerate is missing) may rest on conglomerate, sandstone or shale. Shale is perhaps the most erratically developed member—it varies from 21 feet thick to absent. Conglomerate varies from 10 feet thick to absent, and sandstone about the same, although it is rarely entirely absent.

A typical well-developed sequence varies upward as follows: reddish-purple (4RP 3/2) conglomerate, reddish-purple conglomeratic sandstone, grayish or slightly purplish-red (5R 3/2) silty sandstone, dusky-red (7R 3/4) silty shale. About 5 percent content of finely divided hematite suffices to give the rocks their colors.

Clasts in the conglomerate and conglomeratic sandstone vary from slightly larger than sand size to 4 inches, and are dominantly white quartz or quartzite, but include some fragments of green shale, red shale, greenish quartzite, buff sandstone, and pink sandstone. The quartzite clasts may be rounded or irregularly elongate and composed of one or several quartz grains. They clearly show derivation from a metamorphic terrane, perhaps initially deposited in the Shawangunk Conglomerate and later reworked. The red shale fragments are almost certainly derived from the previously deposited and partly indurated layers of the Schunemunk itself. Older Devonian rocks may have furnished the fragments of green shale and greenish quartzite. The lithic fragments sometimes are veined with quartz. The matrix is very fine quartz grains, interspersed flakes and sheaves of sericite, and a small percentage of very fine hematite.

Coarse layers of the sequences themselves show crude and erratically interrupted and renewed grading of beds. Cross-stratification is sometimes present, and scour-and-fill structures are common. Everywhere that it overlies shale, conglomerate contains shale fragments, which become smaller and less numerous upward from the contact

FIGURE 23. Conglomerate (on right) at base of graded sequence with red shale fragments from underlying cycle (on left), Schunemunk Conglomerate; north side of New York 17A (Mount Peter Rd.) near Kain Rd., Bellvale Mt.

(figure 23). Shale and other elongate or flat fragments are generally well orientated parallel to bedding.

The sandstones characteristically have the markedly bimodal texture of the coarser layers, but upward in each graded section difference in size between matrix and clasts diminishes in a transition to silty shale. Minor conglomeratic beds may appear throughout the sandstones. Cross-stratification and oscillation ripple marks are present in places. A poor cleavage is developed in the finer-grained sandstones, essentially parallel to the axial plane of the syncline.

The shales or very fine siltstones are even textured and poorly fissile. Bedding is not prominent and generally has been obscured by moderately well-developed axial-plane cleavage. Cross-joints in the shale at places show plumose markings.

Slickensides are common throughout the Schunemunk and are especially prominent in the finer-grained layers. Milky quartz veins are also common and are largely confined to the conglomerate layers. This may reflect control of solution movement by porosity, but as porosity of the conglomerates is little different than that of the sandstones, the distribution of veins is more suggestive of local derivation from the abundant milky quartz pebbles, or perhaps simply of more fractures in conglomerate owing to its greater competence.

Name, age, and correlation—The name Schunemunk is used here because the type locality appears in that spelling on topographic maps. Darton (1894), however, originally named the formation Skunnemunk Conglomerate and that spelling is generally used in the literature. The unit is correlated with the upper part of the Hamilton Group of the classic medial Devonian section (Rickard, 1964). Hamilton plant fossils are locally common in the unit elsewhere, but none was observed in the mapped area.

STRUCTURAL GEOLOGY

Paleozoic rocks of the Goshen area have been affected in at least three, and possibly five, epochs of regional deformation in the Appalachians. The later deformations in the area are interpreted to have been effected largely by local movement of basement blocks during regional upwarp of the basement. As is typical throughout the Appalachians, the trends of the various deformations appear to have been the same, for all features of deformation in the area are essentially parallel. Distinguishing the effects of the separate events, and dating the events, are major problems which do not have unique solutions in the Goshen area or, so far as known, in the entire region.

Pre-Trenton deformation

The unconformity at the base of the Balmville, or of the upper Mt. Merino where Balmville is absent, is quite clear. Most or all of Medial Ordovician and late Early Ordovician time is represented by the stratigraphic gap. General relationships in the Hudson Valley area commonly do not reveal whether this gap is a disconformity or an angular unconformity. Bucher (1957, p. 666-668) discussed this unconformity and could present real evidence of angularity only from the northeastern New York-Vermont area.

In the Goshen area, Balmville overlies Rochdale Limestone in the Middletown well and presumably overlay Rochdale everywhere it was present. Yet in all surface exposures, Balmville overlies the Halcyon Lake Formation. This indicates that, except for isolated places, Rochdale had been stripped from the area prior to deposition of the

Balmville. This may have been the result of gentle tilting owing to a rise of the basement, deep karst erosion, or to minor folding and faulting.

Northward tilting as a result of basement movement, and subsequent plantation, would have produced a surface of deposition such that Balmville should lie on successively younger units northward from the Highlands. This cannot explain Balmville overlying Halcyon Lake at Campbell Hall, 10 miles north of the one exposure of Rochdale Limestone. Moreover, no basement movement at this time other than very broad and shallow regional uplift, can be inferred from regional evidence.

Karst erosion was certainly a factor, probably as important as minor deformation, but the erosion cannot be evaluated. If it were the only factor, erosional relief would have had to be a minimum of 300 feet to remove Rochdale completely.

Minor folding and faulting are believed to have occurred prior to Balmville deposition. Gentle folding is inferred from localities northeast of Gardnerville and east of Mt. Lookout, where disparities of dip in closely adjacent outcrops of Balmville and Halcyon Lake are 20 and 22 degrees, respectively. This could also be the result of tilting of minor fault blocks; Platt (1960) reports faulting in the carbonates at Bald Mountain, Washington County, N.Y. during or prior to deposition of Trenton shales. Pre-Trenton (or pre-latest Black River) deformation, of whatever kind, probably is also indicated by brecciation and prominant quartz-calcite veining of the Halcyon Lake, whereas no such effects are seen in the overlying Balmville, although differences in competence might account for this.

Taconian deformation

The Taconian Orogeny was one of the major events of the Paleozoic history of the Appalachians. This deformation extended from New England at least as far south as Pennsylvania. It is dated as late Ordovician from the markedly angular contact at most places of Silurian rocks overlying tightly folded Middle and Upper Ordovician slates and shales. In southeastern New York, the Taconian event cannot be closely dated because Middle Silurian conglomerate overlies upper Middle Ordovician shale.

Folding

Northeast and southwest of Goshen (15 minute) Quadrangle, Silurian Shawangunk Conglomerate overlies Middle Ordovician shales in which well-developed slaty cleavage is present, commonly with 90-degree discordance at the contact. Along strike from these tightly deformed shales, in the Goshen area, however, the degree of deformation is markedly less. At the Shawangunk contact just outside the quadrangle (best seen at Wurtsboro exit of Route 17), essentially unfolded and uncleaved shales underlie the conglomerate with a 10-degree discordance. Southeast along Route 17 from the Wurtsboro exit the shale is progressively more deformed, with low undulant folds increasing in amplitude and becoming sharper and giving way at about the line of the Wallkill River to irregular and sometimes intense disharmonic folding figure 24).

The deformation is most clearly recorded in the Ordovician shales; the underlying carbonate section and the basal part of the shale section probably were gently folded, separated from the more disturbed rocks above the surfaces of decollément within the shales. Austin Glen and Snake Hill rocks show variable degrees of undulant folding; they occur far enough west that effects of the waning deformation were not severe, and also folding was probably damped by the massive graywacke layers.

The openness of folds even in the Mt. Merino is demonstrated by the preponderance of large angles between bedding and cleavage (figures 25, 26, 27). It is interesting to note that the three figures represent eastern and western areas of Mt. Merino, yet they are similar, in fact nearly identical, although the distribution of data is quite uneven. From these data, an average, or more precisely, a median fold has been constructed (figure 28) which turns out to resemble the fold in figure 29. Evidently this type of gently undulant folding typified Taconian deformation throughout the area, rather than folding which became more intense eastward.

If this is the general configuration of Taconian deformation, some further explanation is necessary for the progression of folding observed on Route 17 and described at the beginning of this section. The sharper folding memtioned occurs in the Goshen-Phillipsburg area and northeast to the corner of the quadrangle along that strike belt. The strata involved are about in the middle of the Mt. Merino, where the damping effects of the massive rocks above and below the Mt. Merino would have been minimal during the deformation. In this zone, decollément folding and minor thrust faulting would have been greater than above or below. It is a fact that such features were observed only in this zone, with one exception.

The exception is an area of overturned folds (and probably small thrusts although none was seen) in a belt west of the Precambrian thrust blocks of the inlier complex. It is believed that the overturning of folds toward the west was produced during the westward thrusting of the Precambrian masses, probably during the Taconian event. This is discussed in the section on the thrust blocks.

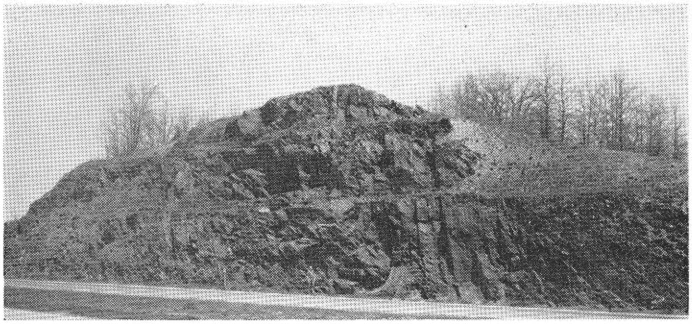


FIGURE 24. Tight fold and thrust fault in Mt. Merino mudrock, north side of New York 17, 2.8 miles west of Goshen.

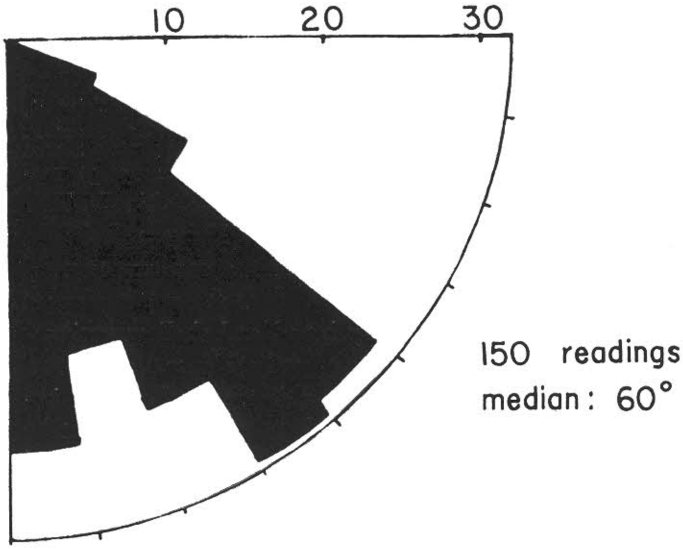


FIGURE 25. Acute angle between shale bedding and cleavage, southeast limb of shale syncline.

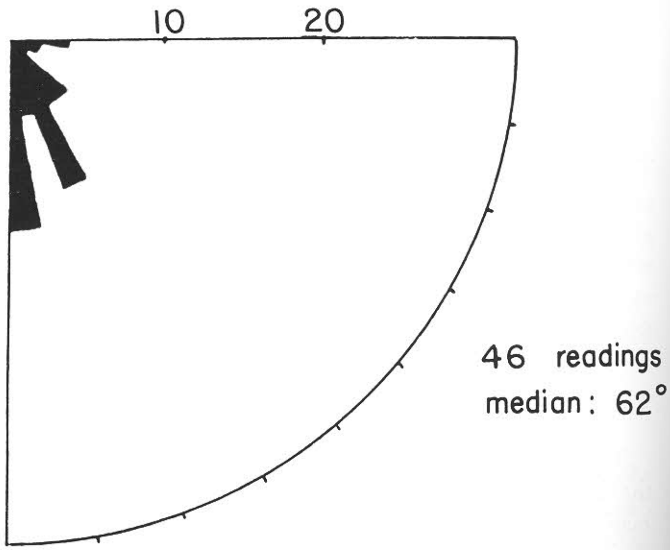


FIGURE 26. Acute angle between shale bedding and cleavage, northwest limb of shale syncline.

It would appear that sharp folds and thrusts are associated, and that they are of significant development only some distance up into the Mt. Merino. Contrast is provided by the lower part of the Mt. Merino in the large syncline of the Warwick-Edenville area, interpreted as having been formed by post-Taconian deformation. The east limb of the syncline is defined by rather low westward dips in the shale. Clearly no steep dips previously existed in the shale, because later rotation of the syncline limb would have overturned any sharp folds or at least would not have been enough to remove any steep east dips of minor fold limbs. Evidently the lower part of the Mt. Merino deformed together with carbonate sequence during the Taconian, without developing significant decollément structures.

For some reason, as yet unknown, Taconian deformation was considerably less drastic in the Goshen area than in areas only a few miles north and south. Possibly the area was shielded by a rise in the basement; this accounts for less deformation than to the north where the basement remained deep, but then the basement to the south must have remained deep, as deformation there is also stronger. Local warping of the basement may be recorded by the Precambrian inliers, but even allowing for such warping this explanation is a rather unsatisfactory one.

Shale Cleavage

Cleavage throughout the shale sequence can best be described as fracture or slip cleavage. The term fracture cleavage as used here is divorced from any connotation of origin by shear.

Cleavage which might be called slaty because of minute spacing and orientation of clays or micas is rarely present. It is best developed in shales which have been tightly folded (figures 30, 31), which accounts for its rarity. Nowhere is slaty cleavage developed to the point that rocks cleave even close to the grain level.

Fracture cleavage (plate 4) is best developed in Mt. Merino mudrock lithology, particularly in the areas of stronger disharmonic folding (figure 19). There, spacing of cleavage surfaces may be on the order of an inch, with minutely spaced incipient cleavage between actual surfaces of parting. Parting is uneven, and no single cleavage surface is very continuous. In less deformed mudrock (always laminated with silt and fine sand) cleavage is slightly more widely spaced and more uneven in parting. As the percentage of silt and sand increases in the rock. cleavage is more poorly developed; massive laminated

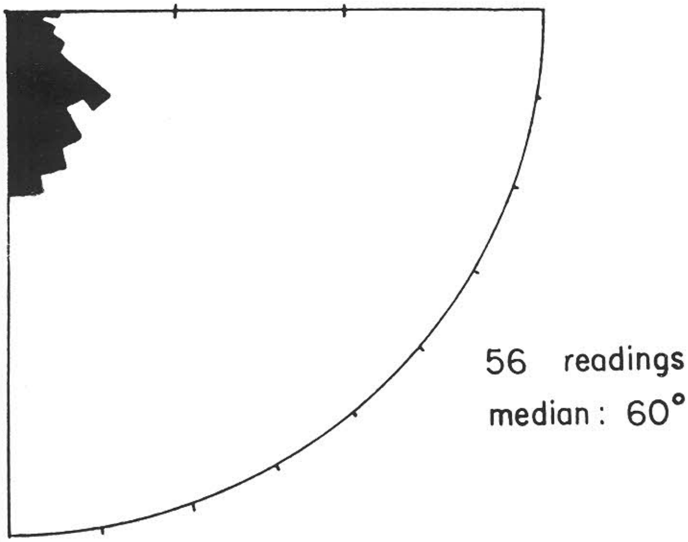


FIGURE 27. Acute angle between shale bedding and cleavage, west of a line from Campbell Hall to the northeast corner of the west block of the Precambrian.

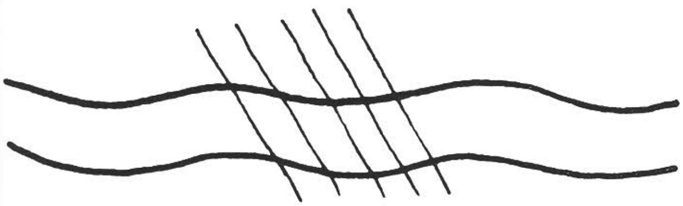


FIGURE 28. Reconstruction of a Taconian fold, based on observed bedding-cleavage relationship.

FIGURE 29. Undulant fold in Mt. Merino subgraywacke and silty shale, 2.3 miles west of Goshen interchange on north side of New York 17.

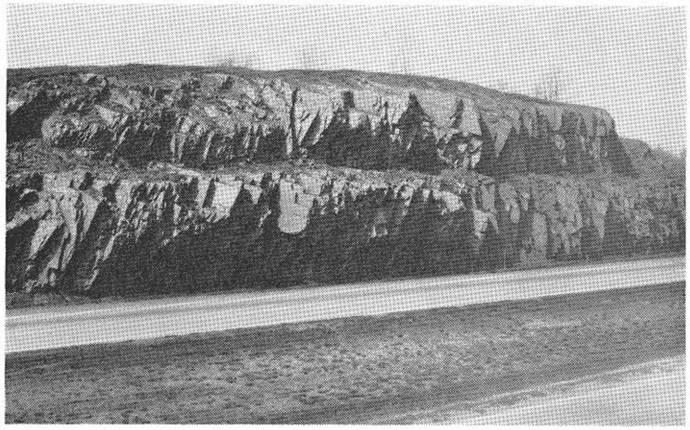


FIGURE 30. Slaty cleavage in isoclinally folded Mt. Merino; 2.8 miles west of Goshen on south side of New York 17.

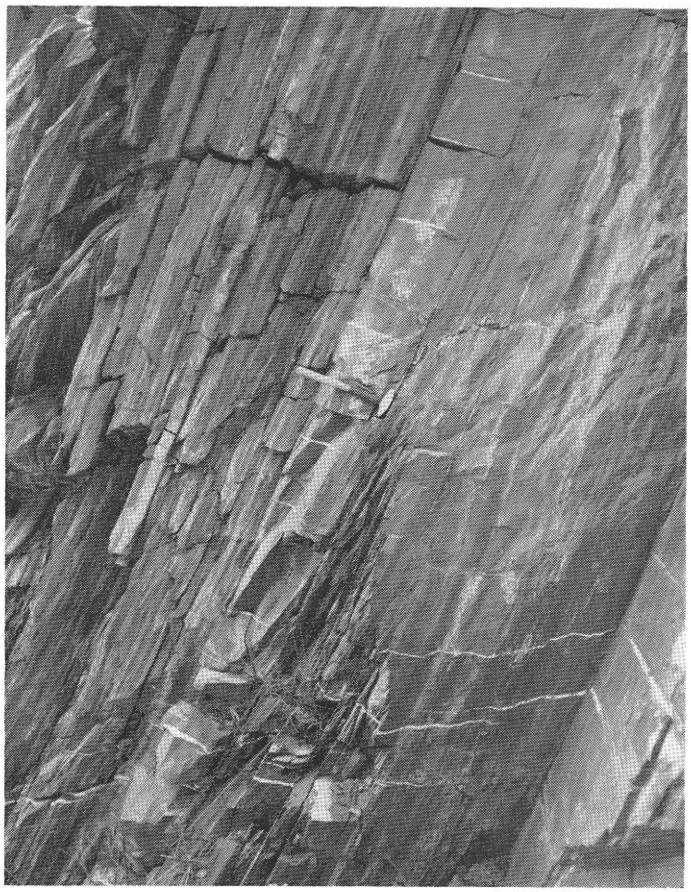


FIGURE 31. Slaty cleavage parallel to bedding in Mt. Merino. Note calcite-filled joints in subgraywacke bed; 2.8 miles west of Goshen on south side of New York 17.

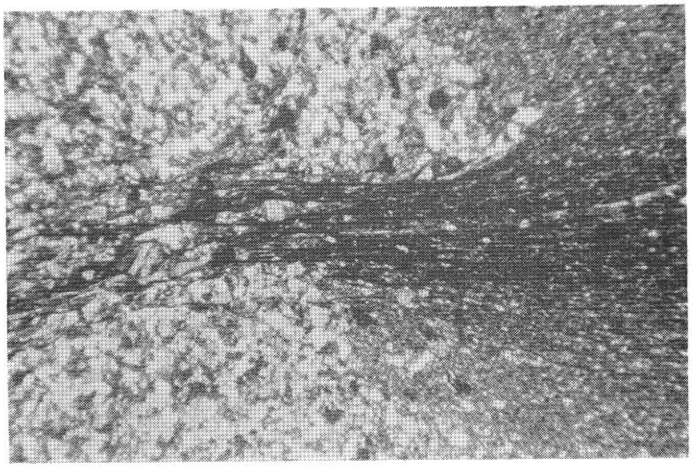


FIGURE 32. Photomicrograph of cleavage in Mt. Merino Shale showing different fracture characteristics of coarse and finer laminae.

siltstones commonly show only faint incipient cleavage. In such rocks, surfaces of parting are generally spaced from 2 inches to 2 feet (figure 29). Sandstone beds between cleaved shales or mudrocks show only joints, apparently of tensional origin, commonly filled with quartz and calcite. In folded sandstones, the joints fan around the fold, remaining perpendicular to the beds.

Even on a microscopic scale, offset of laminae by slip along cleavage planes is rare. Typically at the contact between laminae, numerous irregular microscopically spaced fractures in the muddy lamina pinch down to one or two larger and wider spaced fractures in the sandy or silty lamina (figure 32). The fracture groups themselves are much more widely spaced than are the fractures within the groups. Orientation of minerals is of course partly a function of the percentage of flaky minerals present, but even in clayey mudstone, orientation is irregular and poor. In sandy laminae, orientation of minerals is negligible.

The Snake Hill, in lithology essentially identical to the Mt. Merino, has cleavage of the same type but generally more poorly developed. Cleavage in both of these units is oriented parallel with the presumed axial surfaces of the minor folds, although there may be minor upward and downward divergence on anticlines and synclines, respectively.

Austin Glen shales are cleaved in a different manner. The shales are clayey, fissile shales which cleave better than the silty Mt. Merino and Snake Hill rocks. Cleavage is fairly smooth and closely (1/16-½ inch) spaced. The cleavage is not axial surface cleavage, but is generally at some lower angle as though, if it once was parallel to the axial surfaces, it has since been rotated by shearing movement of the massive sandstone layers above and below. Such rotation could have been induced by Allegheny deformation, to which the Austin Glen, with its thick competent beds, might reasonably have responded differently than the Mt. Merino or Snake Hill.

Post-Taconian deformation

Faulting and folding of Silurian-Devonian rocks

West of Shawangunk Mountain, the Silurian and Devonian rocks display broad, low folds of typical Appalachian Valley and Ridge character, products of either Acadian or later Paleozoic Allegheny deformation or both. The strata at Shawangunk Mountain dip west, and probably formerly extended over the Goshen area in a broad anticlinorial arch, part of the east limb of which is preserved in the Schunemunk Mountain outlier. Farther north, Silurian and Early to Medial Devonian rocks of Shawangunk Mountain are rather tightly folded in places.

Schunemunk Mountain itself consists of several fairly shallow but narrow folds unlike the broad folds to the west. At Bellvale Mountain the outlier narrows to a single syncline, isoclinally folded and overturned slightly to the west. Here, what is inferred to have been a structure much like Schunemunk Mountain has been tightly folded between rising basement blocks. Graben subsidence is estimated at 5,500 feet to accommodate the stratigraphic thickness involved. As the graben formed in the basement, Devonian sediments may have draped themselves in conformity with the new surface, initiating the fold or accentuating a syncline that already existed in the Devonian cover. Draping, as discussed below, probably can also account for overturning and the presence of slaty cleavage, although these features are generally ascribed to compression.

Profiles of aeromagnetic data across the syncline show the faults on both sides to be dipping southeast. The east fault dips vertically or very steeply, and the west fault somewhat less steeply, although the absolute angle could not be determined. The steep dip of the east fault indicates that the east block probably could not have acted as an overriding mass to the extent that much compression was exerted on the adjacent Devonian sediments. Convergence of the boundary faults at depth would require similar convergence of flow lines in material draping off the rising blocks into the graben. As subsidence of the graben became greater, this convergence would require overturning of the east limb. Slaty cleavage ("flow cleavage") is believed to have formed by attenuation of the fold limbs, perhaps supplemented by compressional crowding of material in the axial zone of the fold. Figure 33 illustrates the drape hypothesis.

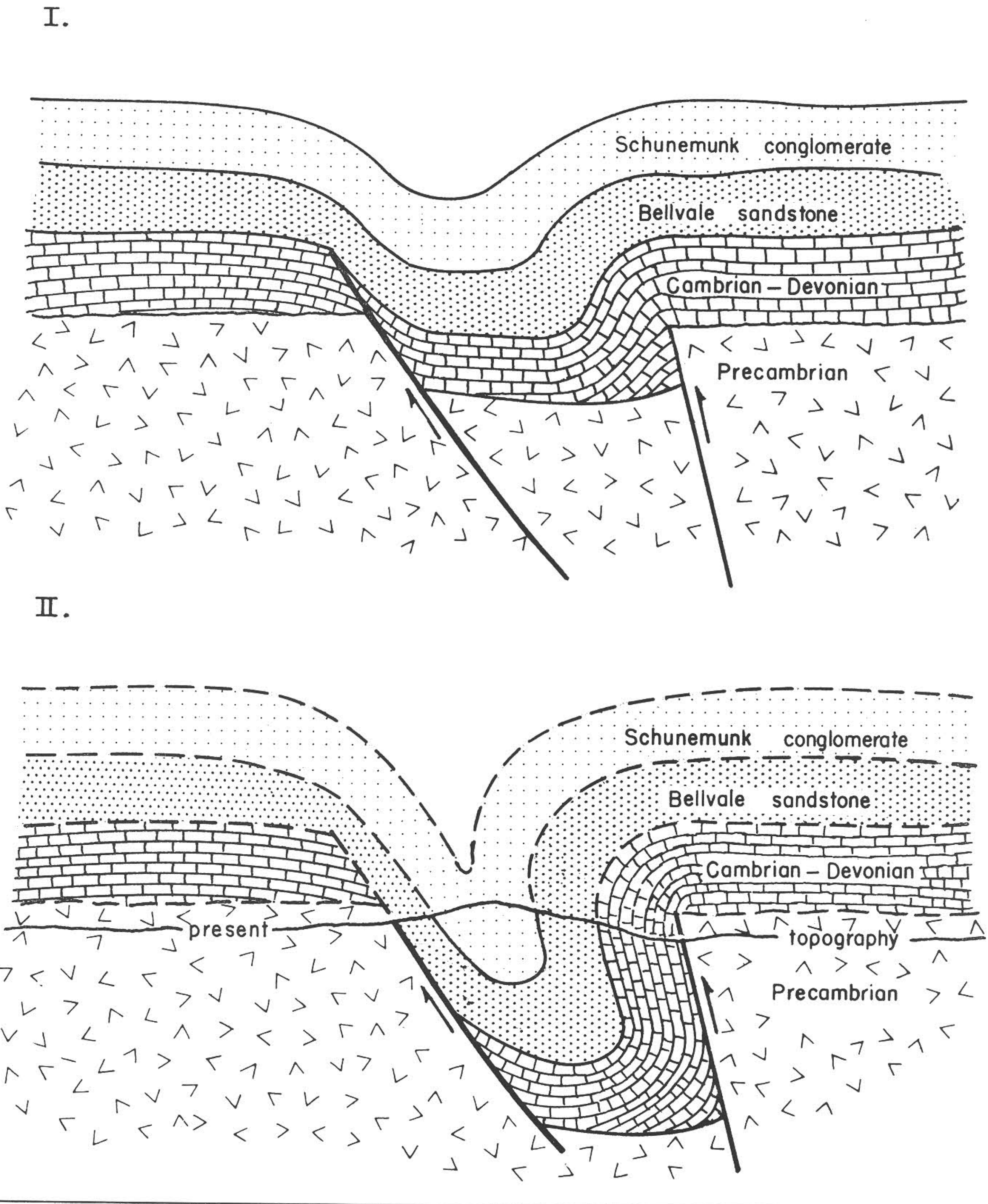


FIGURE 33. Schematic interpretation of drape hypothesis for producing an overturned fold.

Faulting and re-folding of Cambrian-Ordovician rocks

The largest and most obvious structure in the lower Paleozoic rocks is the syncline between Warwick and Edenville (plates 1 and 2). This structure is shown by dips in the Mt. Merino shale, but is especially clear in the dips of the carbonate strata. The east limb dips 15 to 20 degrees on the average, and the west limb is considerably steeper, dipping 40 to 80 degrees for the most part.

Faulted against the west limb of the syncline is an upthrown block of Precambrian. Fault displacement is about 2,500 feet in places, apparently lessening to north and south; a steep reverse fault is indicated. Projected northward, the fault seems to die north of Mt. Lookout, but farther northeast, faulting and uplift along this general line are seen at Campbell Hall. The faulting there is in the opposite sense, but regional uplift along the line is apparent. This line has been noted (Friedman; Am. Assoc. Petrol. Geol. Tectonic Map of the U.S.) as the axis of a regional anticlinorium of Allegheny deformation. The west limb of the anticlinorium dips continuously west at a low angle from the west side of the Wallkill peat lands to the Neversink Valley west of the Shawangunk escarpment. The structure involves Silurian-Devonian rocks and is clearly post-Taconian.

It is interesting to note that the asymmetry of the anticlinorium and the adjacent syncline is the reverse of the usual asymmetry of Allegheny Valley and Ridge folds. This marked asymmetry is limited to the length of the unfaulted Precambrian west block and is certainly the result of a breakout of this block at the crest of an anticlinal area during a general rise of the basement. It is believed that rise of the Precambrian middle and east blocks at this time produced the down-faulted Devonian syncline. The time of this basement upwarp is not certain; the problem is discussed in the following section.

It is believed that pre-Trenton and Taconian deformations barely warped the carbonate section, particularly toward its base. Therefore, the configuration of the large syncline is attributed to a later event, and specifically to uneven upwarp across the basement. The dips of the carbonate, assumed to have been nearly horizontal previously, provide a measure of the amount of rotation of the limbs of the syncline. By this measure, upwarp of the east side of the middle block exceeded that of the west side enough to give the effect of an actual rotation of 15 degrees. (Incidentally, the "rotation" indicated would produce 6,000 to 8,000 feet of offset on the east side—more than enough to produce the Devonian graben.) Rotation involved in forming the west limb of the syncline is more difficult to estimate because draping was probably involved, and irregular dips of the rocks suggest adjustment along unobserved faults rather than a smooth rotation. However, 35 to 50 degrees of rotation is indicated along the northern part of the fault, and 60 to 80 degrees along the southern part where the syncline appears to have been pinched rather sharply between the more stable middle block and the up-faulted west block.

Bedding and cleavage in the Mt. Merino can also be used to measure at least crudely the rotation involved in forming the syncline. Figures 34, 35, 36, and 37 show the range and distribution of cleavage and bedding dip values

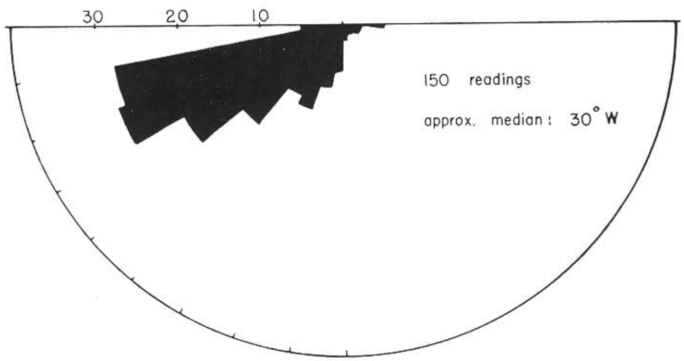


FIGURE 34. Dips of shale bedding, southeast limb of shale syncline.

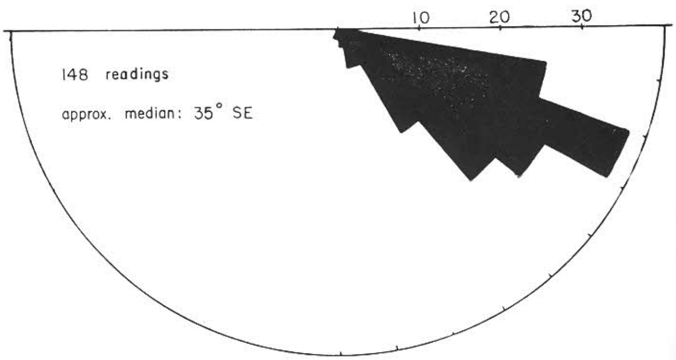


FIGURE 35. Dips of shale cleavage, southeast limb of shale syncline.

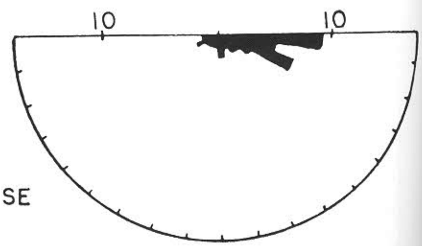


FIGURE 36. Dips of shale bedding, northwest limb of shale syncline.

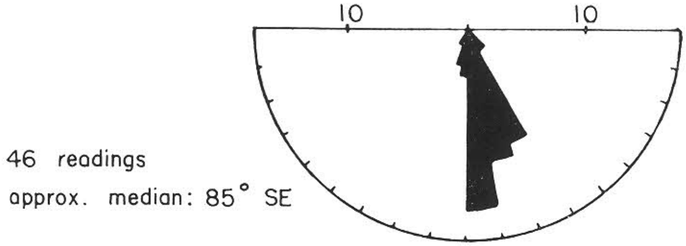


FIGURE 37. Dips of shale cleavage, northwest limb of shale syncline.

for the east and west limbs of the synclinal area marked on plate 4. Because the fold is so asymmetrical the upturned west limb is very narrow, and as the rotation broke the rocks, making them more susceptible to erosion, outcrops are scarse. The data for the two limbs are therefore only poorly comparable, but the results are nevertheless interesting. Using median values for bedding and cleavage dips, figure 38 has been constructed. The median angles between bedding and cleavage for both limbs are the same (60°), so it is clear that their Taconian-induced relation was not changed by later movement. Therefore, rotation to make bedding (statistically) horizontal or cleavage dip 60° SE. gives a measure of the later deformation. This indicates 15 to 25 degrees of rotation for the east limb and 25 to 35 degrees for the west limb. This is reasonably comparable with the figures derived from the carbonate rocks, considering that previous deformation effects in the shale were probably greater and more likely to affect the results.

The steep angle of the west-block fault suggests that the drape hypothesis of the preceding section may apply to this structure in part. Rocks of greater competence are involved but the amount of offset is less, so draping would not have to be large.

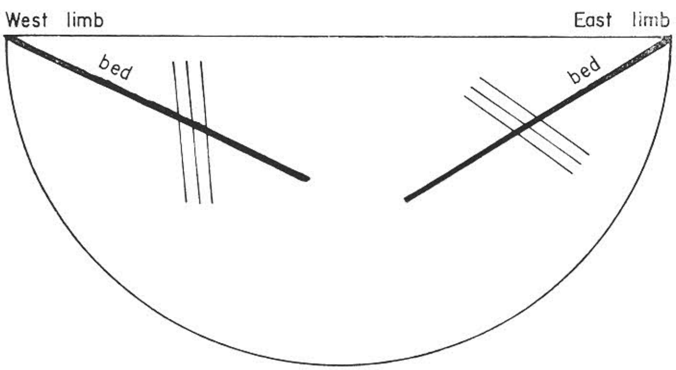


FIGURE 38. Plot of median dips of shale bedding and cleavage, for comparison of the northwest and southeast limbs of the shale syncline.

Apparently the carbonate rocks broke into blocks during the rotation. A second cleavage developed in the shale along the line of the west limb at least as far north as Campbell Hall. This cleavage is rather erratic in direction and spacing, but where well-developed, in combination with the old cleavage it results in breakage of the shale in "pencils."

The syncline is very shallow, with reversals in the plunge of its axis. Plunges of the folded strata measured along the intersections of bedding and cleavage are plotted on plate 4. Values range from 26°NE. to 13°SW.; very flat northeast plunges dominate.

Southwest of Florida, the west limb of the syncline suddenly broadens, apparently by rolling over an anticline which brings up the carbonate rocks seen in inliers south and east of Florida. This demonstrates that crumpling, as well as rotation, of rocks of the west limb was involved in the formation of the major syncline.

Precambrian thrust block inliers

Northeast of Bellvale and Schunemunk is a line of Precambrian knobs, surrounded by Paleozoic sedimentary rocks. At the southwest end of this line, in the Sugarloaf-Goose Pond Mountain complex, the knobs are connected in a more sprawling pattern than to the north, where they are confined to a narrow, straight zone (figure 39).

These hills have sometimes been described as monadnocks on the Precambrian erosion surface, now projecting through the Paleozoic rocks laid down around them. No material eroded from the gneisses has been found in the sedimentary rocks around the knobs, however. Moreover, the sedimentary rocks do not wrap around the knobs, but instead have straight contacts, in places clearly faulted.

Fault contacts may be observed on the northwest sides of Snake Mountain, Brimstone Mountain, and two knobs farther north. These show metasedimentary gneisses faulted against Ordovician shale. The exact nature of the faulting is uncertain. Narrow overhangs of Precambrian have fault soles which dip 40 to 50 degrees southeast. At Snake Hill, south of Newburgh, the Catskill Aqueduct tunnel cut through one of the knobs, revealing that it was bounded on the northwest by a fault dipping 45 degrees southeast (Holzwasser, 1926, p. 84). A thrust or moderate-angle reverse fault is inferred on the northwest side of the chain of inliers, perhaps dipping even less steeply at the south end to account for the change in pattern.

The southeast contact likewise must be a fault, although it has been seen only in the Aqueduct tunnel, where it was a normal fault dipping very steeply southeast. Projected downward, it would intersect the northwest fault, cutting the inlier off from its roots. The fault is also apparent

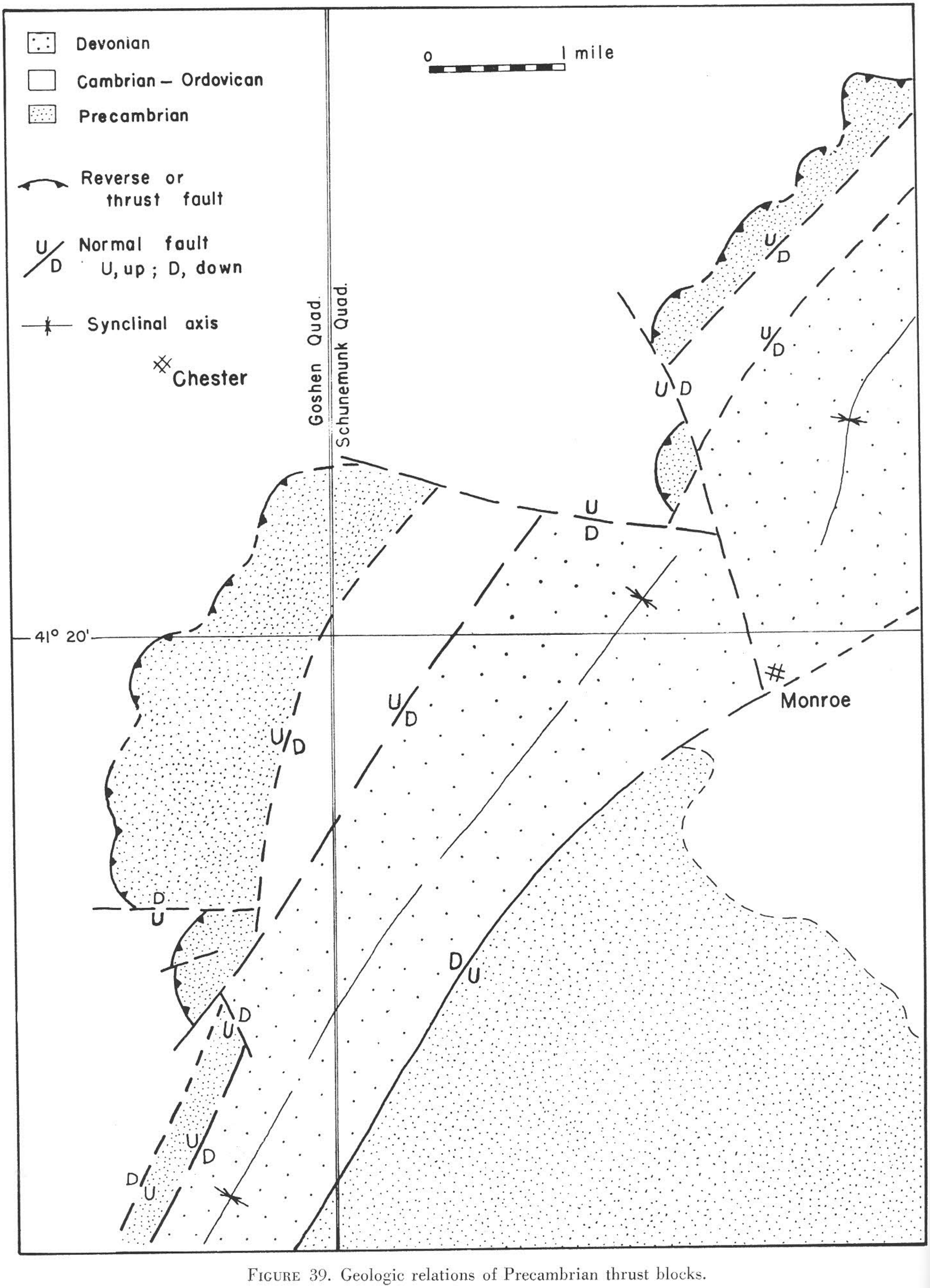


FIGURE 39. Geologic relations of Precambrian thrust blocks.

from the skew altitudes of Shawangunk Conglomerate on the southeast side of Round Hill in Schunemunk Quadrangle (Coates, 1948).

Interpreted geologic relations of the inliers are shown in figure 39. The Schunemunk Quadrangle portion is based on my reconnaissance and the work of Kothe (1960). Cross-faults have been inferred to account for offsets between inliers. These cross-faults possibly developed during thrusting, but the presence of cross-faults which cut both Devonian and Precambrian rocks suggests that most of the minor faults are lines of adjustment developed during down-faulting of the Devonian syncline.

Time of faulting cannot be determined with any certainty. The thrust nature of the northwest fault has, variously, suggested Taconian or Appalachian (Allegheny) styles of deformation to previous workers. Cleavage in the shale next to the fault is generally parallel to the fault; no secondary or later cleavage cuts the slaty cleavage. Folds overturned to the northwest are almost confined to shale west of the thrust, as though the thin skin of shale above the dolomite had been rumpled in front of the moving thrust block. These facts suggest that thrusting of basement rocks into the shale mass occurred as the shales were being folded. If this is true, as the folding was clearly Taconian, the thrust is dated. The inferences involved, however, are many.

The southeastern normal fault has been called Triassic by everyone, on the basis of style. Triassic normal faulting certainly exists 10 miles away at the Highlands margin, but as the youngest rocks involved in the present instance are medial Devonian, the time of faulting is not resolved. This question is considered in the following section.

Times of deformation

Acadian Disturbance

A major deformational event, the Acadian Disturbance, occurred throughout much of New England in late Devonian Time. The western extent of the effects of the disturbance are not well known because of probable overlapping with the late Paleozoic Allegheny event. High-grade regional metamorphism (sillimanite zone) of Acadian age (360 m.y.) fades abruptly at the Hudson River. The folded Devonian rocks of the synclinal outlier are only 16 miles to the west, and it seems reasonable to suppose that folding in the cover may have reached that far. This supposition is strengthened by the fact that the north end of the outlier is folded in three rather small, narrow folds quite out of character for the broad Allegheny folding. There is no clear evidence whether basement block faulting occurred at this time, so it is possible that the Devonian syncline was formed but was not caught between rising basement blocks until later.

Allegheny Orogeny

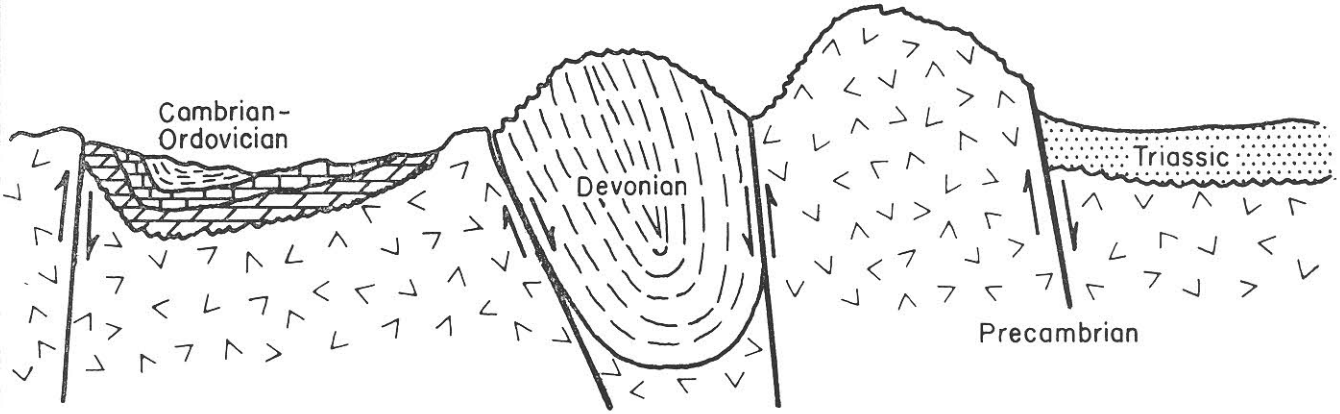
Folded Devonian and Carboniferous rocks of the Appalachian Plateau in Pennsylvania and New Jersey, and probably as far north as the Catskill region, record a late Paleozoic deformational episode, the Allegheny (or Appalachian) Orogeny. The folding is broad and of low amplitude. On the Tectonic Map of the United States (U.S. Geol. Survey and American Assoc. Petroleum Geologists, 1961) the eastern limit of this folding in southern New York is shown as an anticlinorial axis extending north from the east edge of the west block of Precambrian. Shawangunk Mountain, the eastern edge of rocks probably deformed in the Allegheny event, is 12 miles to the west, but presumably the deformation was continuous eastward to New England, where metamorphic ages (250 m.y., in Rhode Island, Connecticut, etc.) also record the event.

If the anticlinorium is truly an Allegheny fold, the rise of the west block (a break-out at the anticlinorial crest) and therefore the folding of the main shale syncline are also Allegheny products. Involvement of the west block suggests that this was the time of general upwarp of the basement and the time in which the Devonian syncline at Bellvale Mountain was squeezed and draped to isoclinal form by rising basement blocks. The whole syncline may have formed during this event but inferences of Acadian deformation cited above cannot be dismissed entirely.

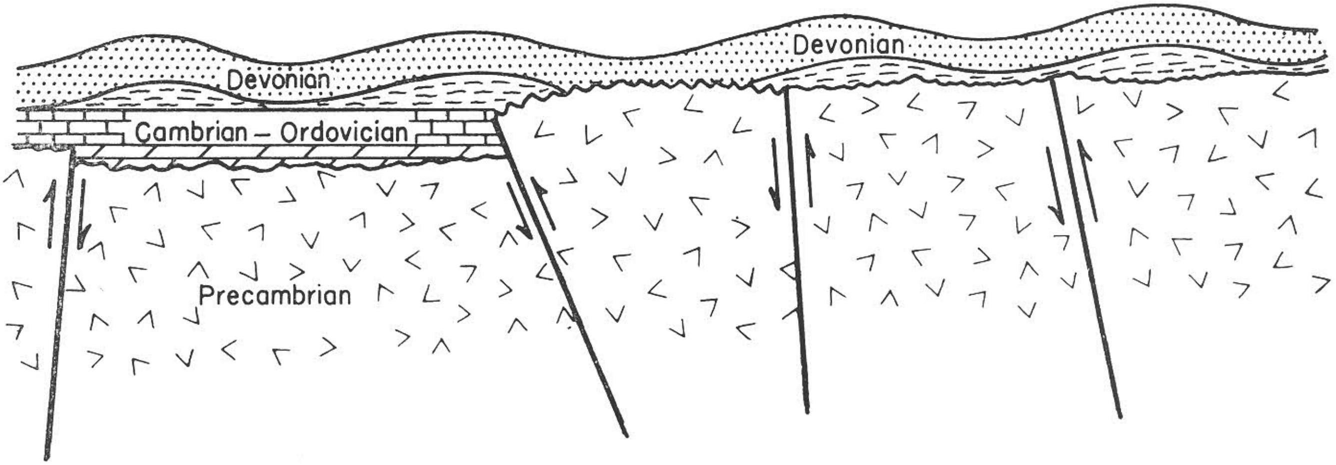
This sequence would make the normal fault on the southeast side of the inliers Allegheny rather than Triassic. The fault was almost certainly developed during down-faulting of the Devonian rocks (that is, up-faulting of basement around them). Overturning of the syncline and development of slaty cleavage seem to indicate compression during basement faulting. This compression, if real, is completely proper for Allegheny deformation (or Acadian), but is incompatible with the classical view of tensional Triassic movements.

Triassic deformation

A Triassic normal fault forms the eastern margin of the Highlands west of the Hudson. In New Jersey-Pennsylvania, the fault involves about 30,000 feet of displacement, but this lessens northward. At Stony Point, New York, where the Highlands cross the Hudson, the fault displacement is probably only a few thousand feet. There, the main fault splits into several faults of probably small displacement which cut the Highlands, and at Peekskill isolate an outlier of Cambrian-Ordovician rocks. To the west, parallel to the border fault, is a fault along the New York



B. Triassic deformation along the same lines; note reversals of movement sense owing to response to broad upwarp.



A. Pre-Triassic configuration; arrows indicate probable Allegheny, Acadian, and Taconian movement sense, which differed from inferred Precambrian movement sense.

FIGURE 40. Interpretation of basement block movement if cover deformation is assumed to be Triassic.

Thruway which brings Devonian rocks against Precambrian rocks near Highland Mills. The boundary faults of the three basement blocks of the present area are also parallel to the Triassic fault.

But the Triassic fault is probably rather small in New York, and post-Allegheny fault movement of major significance in the present area cannot be demonstrated, particularly of the tensional nature supposedly consonant with the development of a great normal-faulted Triassic trough. Repeated movement along the same fault lines from Precambrian onward is apparent, however. Moreover, the regional distribution of Triassic rocks implies broad upwarping on either side of a large trough. Thus, Triassic movements may have occurred along old lines of weakness throughout the Highlands as the basement warped upward. If the regional movement were upward, it is conceivable that where a graben was developing, a block might rise along an old reverse fault on one side, causing local compression, and the boundary on the other side would perforce be a normal fault on which an older sense of movement might be reversed (figure 40). In such an event, the isoclinal overturned Bellvale syncline and the draped structure of the shale syncline, attributed above to Allegheny deformation, may after all be Triassic structures. Similar, but not isoclinal, compressional-looking and drape structures caused by Triassic basement block movement are known in Connecticut and New Jersey (J. E. Sanders, personal communication).

It is clear that the problem of distinguishing the deformations and assigning ages to them is unresolved.

Synthesis of basement movement

The interpreted juxtaposition of rocks of different degrees of metamorphism by block-faulting of the basement was discussed in the section on metamorphism. From regional evidence it may be inferred that Lower Cambrian sediments were deposited on a relatively flat surface of little relief. As Cambrian rocks now rest on all three basement blocks, it is clear that the juxtaposition of metamorphic levels and subsequent exposure by erosions must have occurred prior to onlap of the Cambrian seas. This much of the history of basement faulting rests on the assumption that different metamorphic levels have been juxtaposed by faulting.

As the Highlands now are about 9,000 feet higher than the basement at the Middletown well, it is obvious that great uplift has occurred since the Cambrian. This uplift is believed to have occurred by block-faulting, with total displacement increasing eastward, during regional basement upwarp. The evidence indicates repeated and uneven movement of basement blocks.

Taconian basement involvement is probably represented by the thrust blocks which seem to have broken away from the front of a rising block. The Taconian event is certainly recorded at the south end of the Devonian syncline, where the basement had risen and Cambrian-Ordovician rocks were stripped away to allow deposition of Silurian rocks directly on the basement. Movement of that magnitude did not occur at the north end of the Devonian outlier.

As discussed above, basement movements of Acadian, Allegheny, and Triassic events cannot be separated. The sum of all such movements resulted in the draping and unusual asymmetry of the main shale syncline and the down-dropping, compression, and draping of the Devonian syncline. Faulting took place on lines inferred to have been faults during the Precambrian. Paleozoic and/or Triassic movement on the west block-middle block boundary fault reversed the inferred Precambrian movement sense. The middle block-east block boundary fault would have had the Precambrian movement sense of the fault on the east side of the Devonian syncline; perhaps the fault of opposite sense on the west side was not a Precambrian line.

Summary and Conclusions

THE PRECAMBRIAN TERRANE of the Goshen-Greenwood Lake area is divided naturally into three large fault blocks. Each of these blocks has distinctive metamorphic features. The east block is dominated by hypersthenic quartz-plagioclase gneiss of charnockitic aspect, pyroxene amphibolite, and hornblende granite. Petrographic characteristics of these rocks indicate hornblende granulite or, locally, pyroxene granulite subfacies conditions of regional metamorphism; retrograde features are not present. The middle block contains somewhat similar rocks but which are everywhere modified by potash metasomatism and retrograde metamorphism, and which appear to be unconformably overlain in a few places by non-retrograded amphibolite-facies metasediments. The west block is made up almost entirely of such metasediments, except for quartz-plagioclase gneisses of charnockitic aspect exposed in the cores of anticlines. Differential uplift of the blocks in Precambrian time is believed to have produced the observed juxtaposition of different metamorphic levels.

The structural-stratigraphic configuration of the non-retrograded amphibolite-facies metasediments and the apparently underlying retrograded granulite-facies rocks throughout this region suggests a cover and basement relationship as in the case of mantled gneiss domes. This interpretation calls for two metamorphic events, independent evidence of which is provided by mineral ages throughout the Highlands, which record metamorphic episodes of 1150 and 800 million years ago.

The Lower Paleozoic section consists of a basal conglomeratic quartzite and an overlying sequence of five Lower Cambrian to Lower Ordovician carbonate units, succeeded unconformably by a Middle Ordovician shale sequence which has a basal conglomeratic limestone at places. The carbonate sequence appears to be constant in lithology and age throughout eastern New York. The shale sequence consists of Normanskill Shale and Snake Hill Shale, both of which are shown by graptolite faunas to be younger in the Goshen area than they are in the Taconic region. Regional evidence suggests that this sequence becomes progressively younger and thicker southward, at least as far as Pennsylvania. In the Goshen area, only the upper part of the Mt. Merino Shale (lower Normanskill) is present; the underlying basal limestone apparently is equivalent to the lower Mt. Merino found farther east and north. This is significant because east of the Hudson River, the limestone and the lower Mt. Merino occur together which suggests overlapping sedimentary facies or, more probably, that the lower Mt. Merino is allochthonous, perhaps part of the disputed "Taconic Klippe."

Minor folding of the Cambrian-Ordovician carbonate sequence is thought to have occurred prior to deposition of the shale sequence. Both sequences were deformed in the Taconian Orogeny; this is recorded especially in the development of low folds, poor fracture cleavage, and minor thrust faults in the shales. Taconian deformation is less intense in this area than had previously been supposed.

A large syncline in Cambrian-Ordovician rocks was formed after the Taconian event, as indicated by rotation of the old cleavage in the shales and development of a new cleavage. This folding is attributed to draping in the cover over rising and tilting basement fault blocks, now exposed at the surfaces. A similar origin is proposed for an outlier of Medial Devonian rocks, a partly overturned isoclinal syncline in which shales have well-developed fracture cleavage, downfaulted at least 5,000 feet between basement blocks. Block faulting of the basement took place along inferred lines of Precambrian faulting; in places the inferred older movement sense appears to have been reversed.

Age of the deformation is uncertain. If draping over rising basement blocks produced the major synclines, the folding and faulting occurred together during either late Paleozoic or Triassic periods of deformation. If folding preceded faulting, and faulting merely accented the structures, the deformation may relate to successive late Paleozoic and Triassic movements.

Economic Geology

MAGNETITE AND ASSOCIATED URANIUM

In the past, magnetite was produced from two groups of mines and prospects in the Greenwood Lake area. The larger and more important group is located south of Sterling Lake (plate 1). These mines were worked more or less continuously from 1750 until shortly after World War I. For many years the land on which the mines are located was the property of the Sterling Iron and Railway Company, but the property is now owned and is being developed for other purposes by the Sterling Forest Corporation. The magnetite deposits are small and no longer of economic interest, but will be briefly described because of their past importance, and because speculation on their geologic origin continues today.

Detailed descriptions of the mines and prospects and histories of their development have been given by Colony (1923) and Hotz (1953), together with discussion of the geology and origin of the ore. According to Hotz (p. 194-195), "the deposits occur along two zones or mineralized belts, a stratigraphic distance of about 200 ft. apart at the south end of the Sterling Lake syncline. The underground workings of the Lake and Sterling mines, now flooded, are beneath Sterling Lake and are on the upper mineralized zone. The Tip Top mine, less than 1000 ft. south of the Lake mine shaft, is on a segment of the upper zone that has been displaced by a fault. The Summit, Upper California, Lower California, and Whitehead mines are on the lower zone." The Crawford and Steele mines are on another zone of mineralization.

In these mines, massive granular magnetite occurred generally in tabular bodies at the contact of pyroxene amphibolite and quartz-plagioclase gneiss, or within amphibolite or pyroxene amphibolite near the contact with quartz-plagioclase gneiss. White or pink granite pegmatite in sheet- or tongue-like bodies commonly is closely associated with the ore, apparently both cutting and being cut by magnetite.

Since 1900, most workers have concluded that the magnetite was deposited from iron-rich solutions genetically associated with igneous activity. Colony (1923, p. 69-73) first recognized that metasomatic replacement of host rocks by magnetite was important in the formation of the deposits. He suggested that differentation of a basic magma produced end-phase pegmatitic and magnetite-rich "aqueo-igneous" solutions. Hotz (1953, p. 214) cites as evidence of replacement origin involving hydrothermal-pneumatolytic agencies: 1) magnetite is associated with apatite, pyrite, pyrrhotite, chalcopyrite, molybdenite, chlorite, biotite, actinolite, and serpentine; 2) textural and structural relations show replacement of preexisting minerals by magnetite, and there is a lack of evidence of forceful displacive injection; 3) magnetite bodies locally transect foliation of the enclosing gneisses; 4) magnetite bodies are closely associated with pegmatite and hornblende granite believed to be of igneous origin. Source of the iron is believed by Hotz to be iron-rich vapors or solutions derived from the hornblende granite-alaskite-pegmatite magma.

Recently, an interesting argument for derivation of the iron from the surrounding host rock has been presented by Hagner and others (1963). Detailed analytical work on drill cores from Scott mine (one mile east of Sterling Lake) shows that percentage of iron in the mafic silicate and total rock decreases with proximity to the ore zone, even though the percentage of mafic silicates and magnetite in the amphibolite host shows no systematic increase or decrease. Hagner believes that, during large-scale replacement of amphibolite by salic material, iron was released from amphibolite and migrated to favorable ("low pressure") structural sites. By volumetric calculations, Hagner shows that this mechanism would provide more than enough iron to form the known deposits. The iron-percentage gradient on which the hypothesis is based is carefully documented; the proposed causative metasomatic-metamorphic replacement of amphibolite by salic material is considered more speculative.

Three small mines, located south-southeast of Warwick near the State line, make up the second group. These mines were last worked about 1880. The Warwick or Standish mine, which consisted of a few deep trenches and small shafts, partly connected by tunnels, was the only working of significant size. A belt (and adjacent isolated lenses) of amphibolite and pyroxene amphibolite, partly intermixed with quartz-microcline-plagioclase gneiss, contains zones rich in granular magnetite. The magnetite, generally associated with minor amounts of apatite, is concentrated in bands parallel to the layering of the amphibolite and has replacive relations with the silicate minerals. Pyrrhotite, pyrite, and chalcopyrite form a succession of sulfides which fill fractures and intergranular spaces. Mineralization at the Taylor mine is similar but is confined to a much smaller area. A third mine, the Ferro Hill (or Raynor?) mine, was not specifically located; it may have been a separately named part of one of the two other sets of workings.

This Warwick group of mines had not been of economic interest for many years, when the discovery by a local prospector, in 1955, of radioactivity around the old working brought the mines new prominence. After preliminary investigations, the Ramapo Uranium Corporation was formed and stock sold to finance exploration and development. Most of the effort was concentrated on the old Warwick mine, because consultant reports indicated a zone 10 feet wide and at least 850 feet long, coinciding with the line of magnetite workings, in which surface radioactivity measurements and chemical analyses suggested an average 0.20 percent U_3O_8 content. Uraninite was the chief source of the radioactivity. As development work progressed, it became apparent that uranium mineralization was uneven in the main zone and that the average grade was less than had been estimated initially. Company funds were consumed in buying equipment and in driving a fruitless tunnel. Also, a milling process expected to be able to treat very low-grade ore apparently did not prove feasible. The uranium venture failed, and by 1958 the area was quiet again.

Regardless of the economic aspect, this occurrence of uranium is interesting. A dip-needle and scintillometer grid survey at Warwick mine made in 1957 by the writer and Mr. William Mania, the original discoverer, showed only moderate correlation of magnetic and radiometric highs in the zones in the amphibolite which had been worked for iron. Numerous good radiometric values not associated with magnetic highs were found in the adjacent quartz-microcline-plagioclase gneiss, generally in areas where schlieren or lenses of amphibolite were common. A petrographic study by Abdel-Gawad (unpub.) indicates that uraninite occurrence is linked to the distribution of apatite. The apatite is closely associated with magnetite but also occurs independently. In brief, this study showed that: 1) magnetite and apatite were contemporaneous and replaced silicate minerals of the host rock; 2) uraninite partly replaced apatite or filled fractures in it; 3) pyrrhotite replaced apatite after the introduction of uraninite.

Spectrographic analysis of amphibolite from the main magnetite zone showed 70 ppm of tin, suggestive that hydrothermal solutions were available in the mineralized zone. And the sequence of mineralization certainly appears to favor hydrothermal origin rather than derivation of mineralizing elements from the surrounding rock during some major metasomatic replacement event.

CONSTRUCTION MATERIALS

Dolomitic limestones of the Halcyon Lake Calc-dolomite is quarried at Mt. Lookout south of Goshen by the Dutchess Quarry and Supply Co., Inc. The rock is crushed and sized for use as concrete aggregate and roadstone.

In various towns throughout the area, a few of the older churches or public buildings were built of the local dolomite, but as these rocks typically are bedded and jointed so that breakage is nonuniform, they have not been used as dimension stone in recent years.

At many places where Balmville limestone is exposed. the remains of old kilns are found. Apparently the limestone was burned for use in mortar, whitewash, and agricultural lime.

Glacial deposits, especially kames and kame terraces in and along the margins of the Wallkill lowlands, provide ample supply of sand and gravel everywhere in the Goshen-Greenwood Lake area. Kames form conspicuous hills (Pine Island, Pellet's Island, and others) surrounded by peatlands in Pine Island and Middletown Quadrangles. These hills consist of interstratified sand and gravel, crudely sorted and graded, and chaotically crossbedded on a large scale, which probably accumulated in large kettle holes on the surface of the Pleistocene ice sheet which covered this area and was deposited when the ice melted. The material typically contains a small amount of fines which is removed by washing, and rare cobbles and boulders. Near the surface, gravel layers commonly are moderately well cemented by calcium carbonate.

In 1959-60, when the area was mapped, the only large sand-and-gravel operation was at Pellet's Island. A few smaller operations, used intermittently for the most part by local highway departments, were located near Chester, Goshen, and Middletown. Bankrun material from numerous small pits is used locally as fill.

Granite from Mt. Adam and Mt. Eve was quarried and used as facing stone on public buildings in a few northern New Jersey towns about the turn of the century. The granite stained upon weathering, however, owing to the decomposition of trace amounts of allanite, and use of the stone soon ended.

MARBLE

For a few years prior to 1943, the Universal Atlas Cement Company extracted Franklin Marble from a quarry located one mile southwest of Pine Island. The cement company closed its operation because the marble did not meet chemical specifications, as the marble there, and throughout its extent, contains many different silicate accessory minerals unevenly distributed in variable amounts. According to information kindly furnished by the Universal Atlas Cement Company, the average composition of material quarried during the last year or two of operation was:

$CaCo_3$	89.5
$MgCO_3$	6.7
SiO_2	3.1
Al_2O_3	0.5
Fe_2O_3	0.5
	100.3%

Although the marble is not suitable for chemical use or cement manufacture, it would probably be satisfactory for several minor uses, such as those for which marble in Westchester County is quarried: filler in asphalt, hand-soap, sweeping compound, adhesives, and asbestos; roofing granules; terrazzo and cast stone; bird gravel and chicken grit; and agricultural lime.

PEAT

Black peat and rich humus derived from peat underlie thousands of acres in the "Drowned lands" of the Wallkill River, Greycourt Meadows, and several smaller swamp areas in Goshen and Greenwood Lake Quadrangles. Recent borings near Pine Island showed the thickness of the peat to vary from 4 to 14 feet, averaging about 8 feet. Parsons (1903, p. 70) reported thicknesses of more than 18 feet near Pine Island and Florida. He described the peat as being a pulpy composite type. The peat overlies varved grey or blue clay or silty sand.

Although these enormous peat deposits are near the greater New York market area, exploitation is unlikely because, except for a few, small, undrained marsh areas, the peat lands are used for agriculture. Planted primarily in onions and lettuce, the peat lands produce such rich crops that land values are too high to permit the economic extraction of peat. The only commercial production of peat in the area is from small marshes near Sterling Lake. In recent years the Sterling Forest Peat Company, Inc. has extracted modest amounts of reed-sedge peat which is dried, bagged, and sold as peat moss for gardening purposes.

SHALE

Shale which expands or bloats markedly upon firing is a valuable source of light-weight aggregate for construction purposes. As shale is the most abundant rock type in the Goshen area, it was hoped that at least some would be suitable for making light-weight aggregate. Unfortunately, however, the Normanskill and Snake Hill shales are not fairly uniform claystones but rather irregularly laminated mixtures of fine sand, silt, and clay. Organic material, important in causing bloating, is essentially absent. Firing tests done by the New York State College of Ceramics (New York State Dept. of Commerce, 1951, p. 207-210) on material from these formations in adjacent areas show that although the shales overfire at relatively moderate temperatures, the overfiring is not accompanied by bloating. Fired colors are generally not suitable for structural clay products.

Although no samples of shale from the Goshen area have been tested, the nonuniform character of the rock suggests that it will not be suitable material for light-weight aggregate. If testing is desired, however, the shales in the vicinities of Chester and Campbell Hall will probably be the most favorable, as they typically contain more clay and less silt and sand than do the shales elsewhere.

A small amount of shale is used locally as road metal on secondary roads.

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THE STATE EDUCATION DEPARTMENT

GEOLOGICAL SURVEY
JOHN G. BROUGHTON, STATE GEOLOGIST

EXPLANATION

QUATERNARY
- Peat and muck-lands

MAJOR ANGULAR UNCONFORMITY AND EROSION INTERVAL

DEVONIAN
- Dsc — Schunemunk Conglomerate
- Dbv — Bellvale Sandstone (*section broken by faulting*)
- Dor — Oriskany Sandstone

ANGULAR UNCONFORMITY

MIDDLE ORDOVICIAN
- Osh — Snake Hill Shale
- NORMANSKILL SHALE
  - Oag — Austin Glen grit and shale
  - Omm — Mount Merino Shale
- Obl — Balmville Limestone

ANGULAR(?) UNCONFORMITY

LOWER ORDOVICIAN
- Oro — Rochdale Limestone
- Ohl — Halcyon Lake calc-dolomite

UPPER CAMBRIAN
- Ꞓbr — Briarcliff Dolomite
- Ꞓpp — Pine Plains Formation

LOWER CAMBRIAN
- Ꞓst — Stissing Dolomite
- Ꞓh — Hardyston Quartzite

MAJOR NONCONFORMITY

PRECAMBRIAN (?)
- Basic dikes

PRECAMBRIAN

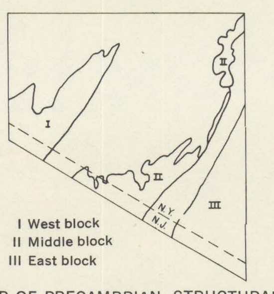
WEST BLOCK (Geology modified after Hague, et al, 1956)
- bgr — Hornblende-biotite granite (*intrusive contacts*)
- px — Pyroxene gneiss
- am — Amphibolite and hornblende gneiss
- bqf — Biotite-quartz-feldspar gneiss
- gap — Biotite-garnet-quartz-plagioclase gneiss
- gqp — Graphitic quartz-plagioclase gneiss
- qm — Quartz-microcline gneiss
- fm — Franklin Marble

MIDDLE BLOCK
- alg, al — Alaskite gneiss and alaskite (*intrusive contacts in part*) Also in EAST BLOCK
- gq — Graphitic feldspar-quartz gneiss
- bqf — Biotite-quartz-feldspar gneiss
- px — Pyroxene gneiss
- hfg — Hornblende-feldspar gneiss
- am — Amphibolite and hornblende gneiss
- qmp — Quartz-microcline-plagioclase gneiss

mu — Undifferentiated metasedimentary sequence above inferred unconformity in covered areas. (Includes intrusive alaskite in part.)

EAST BLOCK (Geology modified after Hotz, 1963)
- gh, hg — Hornblende granite (gh), medium-coarse alaskite in part; hornblende granite gneiss (hg) (*intrusive contacts*)
- hfg — Hornblende-feldspar gneiss
- am — Amphibolite
- gnq, gnc — Quartz-plagioclase gneiss (gnq); gnq interlayered with up to 50% am (gnc)

Blocks listed from top to bottom in order of inferred increasing depth during metamorphism.



INDEX MAP OF PRECAMBRIAN STRUCTURAL UNITS

Contact, solid line where exposed, short dashes where readily inferred, dot-dashed where hypothetically projected.

Outcrop

Normal fault, dashed where approximately located; dotted where inferred or projected. U, upthrown side; D, downthrown side.

Reverse fault, dashed where approximately located; dotted where inferred or projected. Teeth on upthrown block.

Strike and dip of banding and foliation in Precambrian rocks.

Strike and dip of bedding in unmetamorphosed rocks (80, overturned bedding).

Strike and plunge of mineral lineation

Trace of axial plane of anticline and plunge of axis, dashed where approximately located.

Trace of axial plane of syncline and plunge of axis, dashed where approximately located.

Trace of axial plane of overturned syncline, dashed where approximately located.

● 106 (sh)
Drilled well, depth to bedrock and rock type

Graptolite locality

Mines and quarries; prospects

Sand and gravel pit

MINES, PROSPECTS, AND QUARRIES

1. Sterling and Lake
2. Wildcat
3. Summit
4. Tip Top (Clarke)
5. Upper California
6. Whitehead
7. Lower California
8. Shaft-near-railroad
9. Brennan
10. Crawford
11. Steele
12. Taylor (Parrott)
13. Warwick (Standish)
14. Mt. Lookout quarry
15. Atlas quarry

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PLATE 1. GEOLOGY OF GOSHEN - GREENWOOD LAKE AREA, NEW YORK

By Terry W. Offield

MN 11½°

Scale $\frac{1}{48,000}$

1 ½ 0 1 2 3 4 Miles

5,000 0 5,000 10,000 15,000 Feet

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Middletown	Goshen
Pine Island	Warwick
Wawayanda	Greenwood

7½' QUADRANGLE INDEX

NEW YORK
QUADRANGLE LOCATION

Williams & Heintz Map Corporation, Wash., D.C. 20027
Geologic mapping 1957-1960