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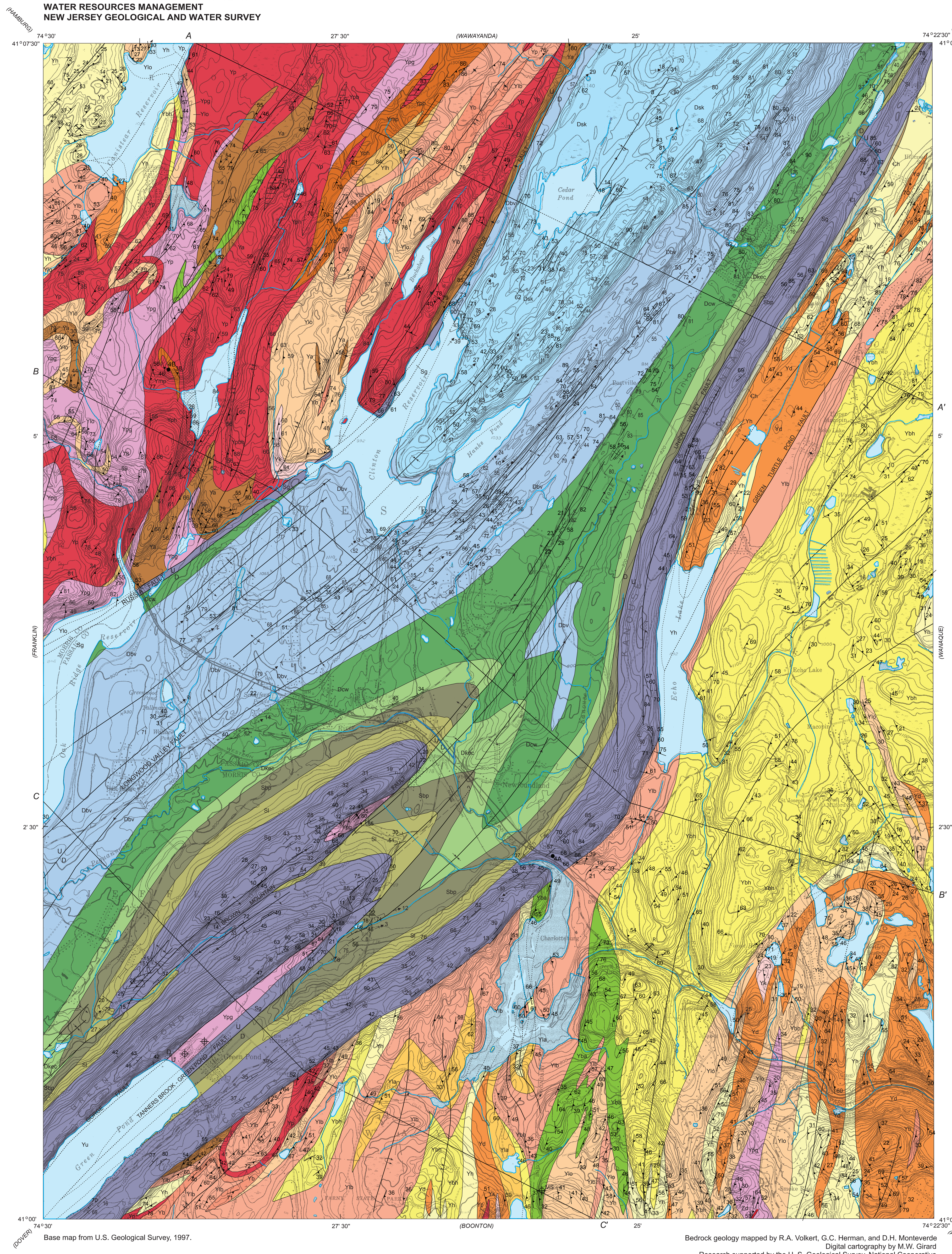

Base map from U.S. Geological Survey, 1997.

Bedrock geology mapped by R.A. Volkert, G.C. Herman, and D.H. Monteverde
Digital cartography by M.W. Girard

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SCALE 1:24 000

1 MILE — 1000 0 1000 2000 3000 4000 5000 6000 7000 FEET — 1 .5 0 1 KILOMETER

APPROXIMATE MEAN DECLINATION, 1999

BEDROCK GEOLOGIC MAP OF THE NEWFOUNDLAND QUADRANGLE PASSAIC, MORRIS, AND SUSSEX COUNTIES, NEW JERSEY

by

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INTRODUCTION

The Newfoundland quadrangle is located in northern New Jersey, in Passaic, Morris, and Sussex Counties, in the north-central part of the New Jersey Highlands province. It is situated within the Pequannock River watershed, and this stream drains the area from northwest to southeast. The quadrangle constitutes an important part of the regional groundwater and surface water supply. Damming of the Pequannock River created the Oak Ridge and Charlotteburg Reservoirs, and impoundment of smaller streams created the Canistear, Clinton, Echo Lake, and Splitrock Reservoirs.

The map area is divided into western, central, and eastern parts by the northeast-trending Green Pond Mountain Region. The western and eastern parts are underlain by rocks of Mesoproterozoic age. The topography there is characterized by ridges and stream valleys with variable orientations that reflect the structural complexity and non-linear trend of the bedrock. The central part of the map is underlain by rocks of Paleozoic age. There, the topography is dominated by a series of broad, linear, northeast-trending ridges (Green Pond, Copperas, Kanouse, and Bearfort Mountains) and intervening stream valleys that are influenced by the uniform trend of the bedrock.

All of the bedrock was modified by the effects of glaciation during the Pleistocene. The surficial geologic history, and the distribution, thickness, and composition of unconsolidated glacial deposits overlying bedrock is discussed by Stanford (1991). Bedrock continues to be modified through the processes of weathering and erosion.

STRATIGRAPHY

Paleozoic rocks

The youngest rocks in the map area are in the Green Pond Mountain Region, a block of down-faulted and folded sedimentary rocks that extends northeast-southwest and divides the Mesoproterozoic rocks into two sub-equal areas. The origin and stratigraphic relationships of Paleozoic formations of the Green Pond Mountain Region was discussed by Darton (1894), Kümmel and Weller (1902), Barnett (1970), and Herman and Mitchell (1991), and is summarized below.

Paleozoic formations record the paleoenvironmental changes spanning breakup of the Rodinian supercontinent through the end of the Acadian orogeny. The Early Cambrian Hardyston Quartzite documents an initial fluvial sedimentation across the older regolith and the subsequent drowning of the eastern North American continental margin during a marine transgression (Aaron, 1969). The overlying dolomite of the Leithsville Formation marks the stabilization of a carbonate passive margin. A long hiatus took place before deposition of the Silurian-age Green Pond Conglomerate which, in the quadrangle, unconformably overlies the Leithsville Formation as well as Mesoproterozoic gneisses. South of the map area, Green Pond Conglomerate stratigraphically rests on Middle and Upper Ordovician Martinsburg Formation (Barnett, 1976; Herman and Mitchell, 1991). The Green Pond Conglomerate has been correlated to the Shawangunk Formation along Kittatinny Mountain in the Valley and Ridge Physiographic Province to the west (Kümmel and Weller, 1902; Yeakel, 1962; Smith, 1970). Both units represent braided stream deposits (Smith, 1970) eroded from uplands to the east and southeast created during the Taconic orogeny (Yeakel, 1962; Smith, 1970, Gray and Zeitler, 1997). Silurian sedimentary rocks record a change in depositional environments from fluvial (Green Pond Conglomerate), through marginal marine (Longwood Shale), into shallow marine, and formation of a carbonate passive margin (Poxono Island and Bershire Valley Formations). An unconformity separating the Berkshire Valley Formation and overlying Connelly Conglomerate, which correlates to the widespread Wallbridge unconformity of the Appalachian Basin, marks the approaching influence of the Acadian orogeny (Ver Straeten and others, 1995; Ver Straeten and Brett, 2000; Ver Straeten, 2001).

Lower Devonian sedimentary rocks in the map area suggest several small sea level cycles (Esopus Formation and Kanouse Sandstone) before becoming a foredeep (Cornwall Shale). The Middle Devonian Bellvale Sandstone and Skunnemunk Conglomerate mark a progression back into shallower marine conditions, and then into a fluvial environment in which sediments were sourced from uplifted eastern mountains that resulted from the Acadian orogeny (Kirby, 1981).

On the east side of the Green Pond Mountain Region, Green Pond Conglomerate rests unconformably on Mesoproterozoic rocks along Copperas and Kanouse Mountains. An exception is north of Echo Lake, where Hardyston Quartzite is in unconformable contact with both the Silurian and Mesoproterozoic rocks. On the west side of the Green Pond Mountain Region, Paleozoic rocks are in fault contact with Mesoproterozoic rocks along the Reservoir fault.

Neoproterozoic rocks

Diabase dikes of Neoproterozoic age are located southeast of the Canistear and Charlotteburg Reservoirs, and also east of Hoot Owl Lake, in the southeast part of the map, where they intrude Mesoproterozoic rocks but not Cambrian or younger rocks. Dikes strike predominantly N.43ºW. to N.56ºW., and very locally N.33ºE. Those at Charlotteburg Reservoir were mapped by Parrillo (1959) during construction but they are no longer exposed. Dikes are as much as three feet wide, and they have fine-grained to aphanitic chilled margins and sharp contacts against Mesoproterozoic rocks. Elsewhere in the Highlands dikes display columnar jointing and contain xenoliths of Mesoproterozoic rocks, confirming they are younger in age than Mesoproterozoic. Dikes are interpreted as having been emplaced into a rift-related, extensional tectonic setting in the Highlands at about 600 Ma during breakup of the supercontinent Rodinia (Volkert and Puffer, 1995).

Mesoproterozoic rocks

The majority of the quadrangle is underlain by rocks of Mesoproterozoic age that include various granites and gneisses metamorphosed to granulite facies at ca.1045 to 1024 Ma (Volkert and others, 2010). Temperature estimates for this high-grade metamorphic event are ~769ºC based on a regional study using calcite-graphite thermometry (Peck and others, 2006).

Among the oldest Mesoproterozoic rocks are those of the Losee Suite (Drake, 1984; Volkert and Drake, 1999), a calc-alkaline assemblage formed in a magmatic arc (Volkert, 2004). These include quartz-rich rocks mapped as quartz-oligoclase gneiss, biotite-quartz-oligoclase gneiss, hypersthene-quartz-plagioclase gneiss, albite-oligoclase alaskite, and quartz-poor rocks mapped as amphibolite and diorite gneiss, all of which were formed from plutonic and volcanic protoliths (Volkert and Drake, 1999; Volkert, 2004). Representative rocks of the Losee Suite from elsewhere in the Highlands yield sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon ages of 1282 to 1248 Ma (Volkert and others, 2010).

Magmatic arc rocks of the Losee Suite are spatially associated with a succession of supracrustal rocks formed in a back-arc basin that was located along the continental margin west of the Losee magmatic arc (Volkert, 2004). Supracrustal rocks include a bimodal suite of volcanic rocks and metasedimentary gneisses. Volcanic rocks formed from rhyolite protoliths are mapped as potassic feldspar gneiss, and mafic volcanic rocks formed from basalt protoliths are mapped as amphibolite. Metasedimentary rocks formed mainly from clastic protoliths are mapped as biotite-quartz-feldspar gneiss, clinopyroxene-quartz-feldspar gneiss, and pyroxene gneiss. Mineralogical variants of pyroxene gneiss form distinct units that contain abundant biotite, hornblende, or both minerals, and they are mapped separately in order to define fold structures in the northwest part of the map. Supracrustal rocks west of the map area yield SHRIMP U-Pb zircon ages of 1299 to 1259 Ma (Volkert and others, 2010) that closely overlap the age of rocks of the Losee Suite.

The Newfoundland quadrangle also contains abundant granite of the Byram and Lake Hopatcong Intrusive Suites that comprise the Vernon Supersuite (Volkert and Drake, 1998). It includes monzonite, quartz monzonite, granite, and alaskite that have A-type geochemical compositions (Volkert and others, 2000). These suites are well exposed throughout the map area, where they intrude rocks of the Losee Suite and supracrustal rocks. A sample of Byram granite from along Route 23, southeast of Echo Lake yields a SHRIMP U-Pb zircon age of 1182 Ma, similar to ages of 1188 to 1184 Ma for Byram and Lake Hopatcong rocks from elsewhere in the Highlands (Volkert and others, 2010).

The youngest Mesoproterozoic rocks in the area are small, irregular bodies of granite pegmatite that have intruded other Mesoproterozoic rocks. Pegmatites are unfoliated, and they have sharp, discordant contacts, confirming their emplacement following the thermal metamorphic peak of the Ottawan orogeny at 1024 Ma. Pegmatites elsewhere in the Highlands yield U-Pb zircon ages of 1004 to 986 Ma (Volkert and others, 2005).

Other Mesoproterozoic rock in the quadrangle includes amphibolite of several different origins. Most amphibolite that is spatially associated with the Losee Suite is metavolcanic, whereas amphibolite that is interlayered with the supracrustal rocks may be metavolcanic or metasedimentary in origin. All variants of amphibolite are shown undifferentiated on the map.

STRUCTURE

Paleozoic bedding and cleavage

Bedding in the Paleozoic formations of the Green Pond Mountain Region strikes mainly northeast at an average of N.42ºE. (fig. 1). Most beds are upright and dip northwest, and less commonly southeast, and locally are overturned steeply southeast. Beds range in dip from 4º to 90º and average 54º.

Cleavage deforms some of the finer grained sedimentary rocks and also those where localized faulting is present. The average strike of cleavage is N.44ºE. (fig. 2). The dip ranges from 8º to 90º and averages 65º Generally, cleavage dips southeast, but northwest-dipping to vertical measurements were also recorded. Locally, a crenulation cleavage, or second spaced cleavage, has been observed in some units in the map.

Proterozoic foliation

Crystallization foliation in the Mesoproterozoic rocks (formed by the parallel alignment of constituent mineral grains) strikes predominantly northeast at an average of N.20ºE. (fig. 3). Foliations locally are variable, especially in the northwest part of the map, owing to the presence of folds that range in scale from outcrop to major regional extent. Foliations dip mainly southeast, and locally northwest, although in the hinge area of fold structures dips are north. The dip of all foliations ranges from 21º to 90º and averages 55º.

Folds

Folds in Paleozoic rocks of the Green Pond Mountain Region are part of a major northeast-plunging synclinorium, the axis of which passes through Bearfort Mountain. Folds on either side of the axis consist of upright synclines that plunge northeast, southwest, or are doubly plunging. Folds on Kanouse Mountain are gently inclined to recumbent.

Outcrop-scale folds are exceptionally well exposed along Route 23 near the town of Newfoundland and these folds have been a classic field trip stop for decades. The folds deform the Green Pond Conglomerate, and they include an anticline and syncline (fig. 4) that plunges 6º southwest. Beds strike about N53ºE and dip 40º northwest on the west limb and 56º southeast on the east limb. A pervasive subvertical axial planar cleavage cuts both of the folds. Folding is likely a result of westward-verging compression during the Alleghanian orogeny, because the folds deform siliciclastic and carbonate rocks of both Silurian and Devonian age.

The dominant fold geometry in Mesoproterozoic rocks consists of antiforms and synforms that have northeast-striking axial surfaces. These folds are northeast-plunging and upright or northwest overturned, and less commonly southeast overturned. Other folds have north-striking axial surfaces and are northeast-plunging and upright or northwest overturned. The overall sequence of folding is uncertain, but at least three phases of folding are preserved (fig. 4), particularly in the northwest part of the map. They may be a continuation of the same fold phase that resulted from differences in the vector of compressional stress at about 1045 Ma, or superimposed folding related to separate Mesoproterozoic tectonothermal events. Regardless, the folds deform crystallization foliation, but not postorogenic pegmatites, and thus were formed no later than the Ottawan orogeny.

The plunge of mineral lineations in Mesoproterozoic rocks is parallel to the axial surface of each of the fold phases. The plunge trend displays three populations that average 24º N.31ºE., 28º N.48ºE. and 38º N.75ºE., with 50 percent of all lineations plunging N.41ºE. to N.57ºE. No southwest plunging lineations or folds in Mesoproterozoic rocks were recognized.

Faults

Northeast-trending faults are the most common type in the quadrangle and they deform both Mesoproterozoic and Paleozoic rocks. From northwest, the major faults are the Reservoir, Russia, Longwood Valley, Brown Mountain, Gorge, Tanners Brook-Green Pond, Union Valley, and Green Turtle Pond. Faulting of Mesoproterozoic rocks is characterized mainly by brittle deformation fabric that includes breccia, gouge, retrogression of mafic mineral phases, chlorite or epidote-coated fractures or slickenslides, and (or) close-spaced fracture cleavage. Locally, Mesoproterozoic rocks along the Reservoir and Brown Mountain faults preserve a ductile deformation fabric that consists of steeply-dipping to vertical mylonite or protomylonite that is subparallel to the crystallization foliation.

The Reservoir fault extends from New York State southwest to Schooleys Mountain (Drake and others, 1996). In the map area the fault contains Paleozoic rocks on the hanging wall and Mesoproterozoic rocks on the footwall, but to the south it contains Mesoproterozoic rocks on both sides of the fault. The fault strikes about N.40ºE. and ranges in dip from steep northwest or southeast to vertical. It records a history of multiple reactivations dating from the Mesoproterozoic that display a movement sense ranging from normal to strike slip and reverse, with latest movement having been normal. The Reservoir fault is characterized by ductile deformation fabric overprinted by a pervasive brittle deformation fabric that envelops the mylonite. An unnamed splay, located east of Buckabear Pond, is cut off by, or merges with, the Reservoir fault. The splay strikes N.20ºE. to N.30ºE. and dips about 90º. It has a ductile fabric that is overprinted by brittle fabric, similar to deformation features observed along the Reservoir fault.

The timing of reactivation of the Reservoir fault using $^{40}Ar/^{39}Ar$ isotope analysis reflects a complex deformation history subsequent to cooling from Ottawan metamorphism, likely due to hydrothermal fluid movement along the fault. Amphibole age spectra yield disturbed patterns, suggesting possible resetting of amphibole at about 722 Ma and of biotite inclusions in amphibole at about 322 Ma (Price, 2005).

The Russia fault (Herman and Mitchell, 1991) strikes N.50ºE., closely paralleling the adjacent Reservoir fault, and dips southeast at about 80º. It contains Paleozoic rocks on both sides. South of the map area the fate of the fault is unknown, and to the north, in the map area, it merges with, or is cut off by the Reservoir fault. Latest movement on the fault appears to have been normal. The fault is characterized by brittle deformation fabric.

The Longwood Valley fault strikes about N.45ºE. and dips steeply northwest to vertically. It has Mesoproterozoic rocks on the footwall and Paleozoic rocks on the hanging wall in the map area. Kinematic indicators suggest the latest movement on the fault was reverse, although south of the map area dip-slip normal movement is predominant. The fault is characterized by brittle deformation fabric.

The Brown Mountain fault (Herman and Mitchell, 1991) extends along the west side of Green Pond Mountain. Along most of its length it contains Paleozoic rocks on both sides, but west of the town of Newfoundland it has a small lens of Mesoproterozoic rock on the hanging wall. The fault strikes about N.50ºE. and dips steeply northwest at about 75º. The fault is characterized by an early ductile fabric that is overprinted by brittle deformational fabric. Kinematic indicators suggest that latest movement on the fault was predominantly reverse.

The Gorge fault was named for the prominent gorge at Picatinny Arsenal to the south (Volkert, 2012), where the structure was first recognized. The fault has a strike length of about 6 miles, extending along the southeast side of Green Pond Mountain, where it merges with, or is cut off by, the Tanners Brook-Green Pond fault. The Gorge fault contains Mesoproterozoic rocks on the hanging wall and Green Pond Conglomerate on the footwall. The fault strikes N.40ºE. and dips about 60º southeast. Latest movement appears to have been reverse. The fault is characterized by ductile deformation fabric that is overprinted by brittle deformation fabric.

The Tanners Brook-Green Pond fault extends along the valley between Copperas and Green Pond Mountains, from near the town of Newfoundland south to Picatinny Lake (Kümmel and Weller, 1902; Barnett, 1976; Herman and Mitchell, 1991). The Tanners Brook fault extends from Picatinny Lake southwest to Califon where it bounds the south side of Long Valley (Volkert and others, 1990). The combined Tanners Brook-Green Pond fault has a strike length of about 30 miles. It contains mainly Paleozoic rocks on both sides in the north and Mesoproterozoic rocks on both sides from the Chester quadrangle southwest to the Califon quadrangle. The fault strikes N.40ºE. and dips northwest at about 75º. Kinematic indicators suggest that latest movement on the fault was predominantly reverse. The Tanners Brook-Green Pond fault is characterized mainly by brittle deformation fabric.

The Union Valley fault (Herman and Mitchell, 1991) extends along the northwest side of Kanouse Mountain, from Greenwood Lake south to the vicinity of Echo Lake. The fault strikes N.30ºE. and dips southeast at about 50º. It contains Paleozoic rocks on both sides along its entire length. Kinematic indicators suggest that latest movement on the fault was reverse. The fault is characterized by brittle deformation fabric.

The Green Turtle Pond fault extends through the northeast corner of the map. It was first recognized by R. A. Volkert (unpublished data) in the Greenwood Lake quadrangle to the north where it was exposed during rehabilitation of the dam at Green Turtle Pond. The fault strikes northeast and dips about 70º northwest. Kinematic indicators record a reverse sense of movement. The fault is characterized by brittle deformation fabric.

Mesoproterozoic and Paleozoic rocks throughout the map area are also deformed by small faults that strike northeast or northwest and have widths of a few feet to tens of feet. Most faults are confined to single outcrops, but some of the wider faults may be a result of the merging of smaller, parallel faults.

Joints

Joints are a common feature in both Paleozoic and Mesoproterozoic rocks in the quadrangle. They are characteristically planar, moderately well formed, and moderately to steeply dipping. Surfaces are typically unmineralized, except near faults, and are smooth and, less commonly, slightly irregular. Joints are varied in their spacing and range from 1 foot to tens of feet. Those developed in massive rocks, such as Mesoproterozoic granite or Paleozoic conglomerate and quartzite, tend to be more widely spaced, irregularly formed and discontinuous than joints in Mesoproterozoic layered gneisses and fine-grained Paleozoic rocks. Joints formed near faults are spaced 2 feet or less apart.

In the Paleozoic rocks, northwest-trending cross joints are the most common. They strike at an average of N.37ºW. (fig. 5) and dip mainly northeast at an average of 71º.

The dominant joint trend in the Mesoproterozoic rocks is nearly perpendicular to the strike of crystallization foliation (Volkert, 1996). As a result, joint trends in the Mesoproterozoic rocks are somewhat varied because of folding. The dominant set strikes northwest at an average of N.55ºW. (fig. 6) and dips southwest and, less commonly, northeast. A subordinate set strikes about N.45ºE. (fig. 6) and dips northwest, and less commonly southeast. The dip of all joints ranges from 26º to 90º and averages 73º.

ECONOMIC RESOURCES

Some Mesoproterozoic rocks in the quadrangle are host to economic deposits of magnetite mined predominantly during the 19th century. Mines are distributed throughout the quadrangle but are most abundant in the northwest and southwest parts. Detailed descriptions of these mines are given in Bayley (1910) and Sims (1958).

Mesoproterozoic rocks were quarried for crushed stone west of Canistear Reservoir and at locations north and southeast of Echo Lake. Surficial deposits of sand and gravel were mined at a few locations in the area, and peat was extracted from a single location in the valley north of Echo Lake.

DESCRIPTION OF MAP UNITS

GREEN POND MOUNTAIN REGION

Dsk **Skunnemunk Conglomerate (Middle Devonian)** (Darton, 1894) – Grayish-purple to grayish-red, thin- to very thick-bedded, locally cross-bedded, polymictic conglomerate and sandstone containing clasts of white vein quartz, red and green quartzite and sandstone, red and gray chert, and red shale; interbedded with medium-gray, thin-bedded sandstone and greenish-gray and grayish-red, mud-cracked shale. Conglomerate and sandstone matrix is primary hematite and microcrystalline quartz. Conglomerate cobbles range to 6.5 in. long, and average cobble size increases in upper part of unit. Lower contact is conformable and gradational as defined by Kümmel and Weller (1902). Unit is about 3,000 ft thick.

Dbv **Bellvale Sandstone (Middle Devonian)** (Bellvale Flags of Darton, 1894; Willard, 1937) – Upper beds are grayish-red to grayish-purple sandstone containing quartz pebbles as large as 1 in. in diameter. Lower beds are light-olive-gray- to yellowish-gray- and greenish-black-weathering, medium-gray to medium-bluish-gray, very thin- to very thick-bedded siltstone and sandstone crossbedded, graded, and interbedded with black to dark-gray shale. More sandstone in upper beds and becomes finer downward. Lower contact conformable with the Cornwall Shale and placed where beds thicken and volume of shale and siltstone are about equal. Unit is 1,750 to 2,000 ft. thick.

Dcw **Cornwall Shale (Middle Devonian)** (Hartnagel, 1907) – Black to dark-gray, very thin- to thick-bedded, fossiliferous, fissile shale, interbedded with medium-gray and light-olive-gray to yellowish-gray, laminated to very thin-bedded siltstone that increases in upper part. Lower contact with Kanouse Sandstone probably conformable. Unit is about 950 ft. thick.

Dkec **Kanouse Sandstone, Esopus Formation and Connelly Conglomerate, undivided (Lower Devonian)**

Kanouse Sandstone (Kümmel, 1908) – Medium-gray, light-brown, and grayish-red, fine- to coarse-grained, thin- to thick-bedded sandstone and pebble conglomerate. Basal conglomerate is interbedded with siltstone and contains well-sorted, subangular to subrounded, gray and white quartz pebbles less than 0.4 in. long. Lower contact with Esopus Formation gradational. Unit is about 46 ft. thick.

Esopus Formation (Vanuxem, 1842; Boucot, 1959) – Light- to dark-gray, laminated to thin-bedded siltstone interbedded with dark-gray to black mudstone, dusky-blue sandstone and siltstone, and yellowish-gray, fossiliferous siltstone and sandstone. Lower contact is probably conformable with Connelly Conglomerate. Unit is about 180 ft. thick in the map area.

Connelly Conglomerate (Chadwick, 1908) – Grayish-orange-weathering, very light-gray to yellowish-gray, thin-bedded quartz-pebble conglomerate. Quartz pebbles are subrounded to well rounded, well sorted, and as much as 0.8 in. long. Unit is about 36 ft. thick.

Sbp **Berkshire Valley and Poxono Island Formations, undivided (Upper Silurian)**

Berkshire Valley Formation (Barnett, 1970) – Yellowish-gray-weathering, medium-gray to pinkish-gray, very thin- to thin-bedded fossiliferous limestone interbedded with gray to greenish-gray calcareous siltstone and silty dolomite, medium-gray to light-gray dolomite conglomerate, and grayish-black thinly laminated shale. Lower contact is conformable with Poxono Island Formation. Unit ranges in thickness from 90 to 125 ft.

Poxono Island Formation (White, 1882; Barnett, 1970) – Very thin- to medium-bedded sequence of medium-gray, greenish-gray, or yellowish-gray, mud-cracked dolomite; light-green, pitted, medium-grained calcareous sandstone, siltstone, and edgewise conglomerate containing gray dolomite and quartz-pebble conglomerate containing angular to subrounded pebbles as much as 0.8 in. long. Interbedded grayish-green shales at lower contact are transitional into underlying Longwood Shale. Unit ranges in thickness from 160 to 275 ft.

Sl **Longwood Shale (Upper and Middle Silurian)** (Darton, 1894) – Dark reddish-brown, thin- to very thick-bedded shale interbedded with cross-bedded, very dark-red, very thin- to thin-bedded sandstone and siltstone. Lower contact is conformable with Green Pond Conglomerate. Unit is 330 ft. thick.

Sg **Green Pond Conglomerate (Middle and Lower Silurian)** (Rogers, 1836) – Medium- to coarse-grained quartz-pebble conglomerate, quartzitic arkose and orthoquartzite, and thin- to thick-bedded reddish-brown siltstone. Grades downward into less abundant gray, very dark red, or grayish-purple, medium- to coarse-grained, thin- to very thick bedded pebble to cobble-conglomerate containing clasts of red shale, siltstone, sandstone, and chert; yellowish-gray sandstone and chert; dark-gray shale and chert; and white-gray and pink milky quartz. Quartz cobbles are as much as 4 in. long. Unconformably overlies the Leithsville Formation or Mesoproterozoic rocks in the map area. Unit is about 1,000 ft. thick.

Cl **Leithsville Formation (Middle and Lower Cambrian)** (Wherry, 1909) – Light- to dark-gray and light-olive-gray, fine- to medium-grained, thin- to medium-bedded dolomite. Grades downward through medium-gray, grayish-yellow, or pinkish-gray dolomite and dolomitic sandstone, siltstone, and shale to medium-gray, medium-grained, medium-bedded dolomite containing quartz sand grains as stringers and lenses near the base. Lower contact gradational with Hardyston Quartzite. Unit ranges from 0 to 185 ft thick regionally.

Ch **Hardyston Quartzite (Lower Cambrian)** (Wolff and Brooks, 1898) – Light- to medium-gray and bluish-gray conglomeratic sandstone. Varies from pebble conglomerate, to fine-grained, well-cemented quartzite, to arkosic or dolomitic sandstone. Conglomerate contains subangular to subrounded white quartz pebbles as much as 1 in. long. Lower contact unconformable with Mesoproterozoic rocks. Unit ranges from 0 to 30 ft. thick regionally.

NEW JERSEY HIGHLANDS

Zd **Diabase dikes (Neoproterozoic)** (Volkert and Puffer, 1995) – Light-gray to brownish-gray-weathering, dark-greenish-gray, aphanitic to fine-grained dikes that intrude Mesoproterozoic rocks. Composed principally of labradorite to andesine, augite, and ilmenite and (or) magnetite. Small pyrite blebs are common. Contacts are chilled and sharp against enclosing Mesoproterozoic rocks.

Vernon Supersuite (Volkert and Drake, 1998)
Byram Intrusive Suite (Drake, 1984)

Ybh **Hornblende granite (Mesoproterozoic)** – Pinkish-gray- or buff-weathering, pinkish-white or light-pinkish-gray, medium- to coarse-grained, massive, foliated granite and sparse granite gneiss composed of mesoperthite, microcline microperthite, quartz, oligoclase, and hastingsite. Common accessory minerals include zircon, apatite and magnetite. Bodies of pegmatite too small to be shown on the map are common.

Yba **Microperthite alaskite (Mesoproterozoic)** – Pale pinkish-white- or buff-weathering, pale pinkish-white, medium- to coarse-grained, massive, foliated granite composed of microcline microperthite, quartz, oligoclase, and trace amounts of hastingsite, biotite, zircon, apatite, and magnetite.

Lake Hopatcong Intrusive Suite (Drake and Volkert, 1991)

Ypg **Pyroxene granite (Mesoproterozoic)** – Buff- or white-weathering, greenish-gray, medium- to coarse-grained, foliated granite containing mesoperthite to microantiperthite, quartz, oligoclase, and hedenbergite. Common accessory minerals include titanite, magnetite, apatite, and trace amounts of zircon and pyrite.

Back Arc Supracrustal Rocks

Yk **Potassic feldspar gneiss (Mesoproterozoic)** – Buff or pale pinkish-white-weathering, buff, pale pinkish-white or light-pinkish-gray, medium-grained, massive, foliated gneiss composed of quartz, microcline microperthite, oligoclase, biotite, and magnetite. Garnet and sillimanite occur locally.

Yb **Biotite-quartz-feldspar gneiss (Mesoproterozoic)** – Pale pinkish-white, pinkish-gray, or gray-weathering, locally rusty-weathering, pinkish-gray, tan, or greenish-gray, fine-to coarse-grained, layered and foliated gneiss containing microcline microperthite, oligoclase, quartz, biotite, and garnet. Very locally contains kornerupine. Graphite and pyrrhotite are confined to the variant that weather rusty. The rusty variant commonly contains thin quartzite layers composed of quartz, biotite, feldspar, graphite, and pyrrhotite.

Ymp **Clinopyroxene-quartz-feldspar gneiss (Mesoproterozoic)** – Pinkish-gray or pinkish-buff-weathering, white, pale-pinkish-white or light-gray, medium- to coarse-grained, foliated gneiss composed of microcline, quartz, oligoclase, diopside, and trace amounts of titanite, magnetite, biotite, and epidote.

Yp, Ypb, Yph, Ypbh **Pyroxene gneiss (Mesoproterozoic)** – Light-gray or white-weathering, greenish-gray or light-greenish-gray, medium-grained, layered and foliated gneiss containing oligoclase, diopside, varied amounts of quartz and titanite, and trace amounts of magnetite and epidote. Some variants also contain abundant biotite (Ypb), hornblende (Yph) or both (Ypbh). Unit is locally interlayered with lenses and layers of dark green, medium- to coarse-grained diopsidite composed mainly of diopside.

Magmatic Arc Rocks
Losee Metamorphic Suite (Drake, 1984; Volkert and Drake, 1999)

Ylo **Quartz-oligoclase gneiss (Mesoproterozoic)** – White-weathering, light-greenish-gray, medium- to coarse-grained, layered to massive, foliated gneiss composed of oligoclase or andesine, quartz, and varied amounts of hornblende, augite, biotite, and magnetite. Locally contains layers of amphibolite too thin to be shown on map. Unit commonly has gradational contacts with biotite-quartz-oligoclase gneiss and hypersthene-quartz-plagioclase gneiss, and occurs as thin, conformable layers within bodies of diorite.

Yla **Albite-oligoclase alaskite (Mesoproterozoic)** – Pale pink, or white-weathering, light-greenish-gray or light-pinkish-green, medium- to coarse-grained, foliated rock composed of pink albite or oligoclase, quartz, and varied amounts of hornblende, augite and magnetite. Locally contains rutile. Commonly contains conformable layers of amphibolite.

Ylb **Biotite-quartz-oligoclase gneiss (Mesoproterozoic)** – Light-gray-weathering, light-greenish-gray, medium- to coarse-grained, layered and foliated gneiss composed of oligoclase or andesine, quartz, biotite, and local hornblende. Locally contains conformable layers of biotite amphibolite.

Ylh **Hornblende-quartz-plagioclase gneiss (Mesoproterozoic)** – White or light-gray weathering, medium-gray or greenish-gray, medium- to coarse-grained, moderately foliated gneiss composed of oligoclase or andesine, quartz, hornblende, and local biotite. Locally contains thin layers of amphibolite.

Yh **Hypersthene-quartz-plagioclase gneiss (Mesoproterozoic)** – Light-gray or tan-weathering, greenish-gray or greenish-brown, medium-grained, moderately layered and foliated, greasy-lustered gneiss composed of andesine or oligoclase, quartz, augite, hornblende, hypersthene, and magnetite. Commonly contains conformable layers of amphibolite and quartz-plagioclase gneiss containing hornblende and augite.

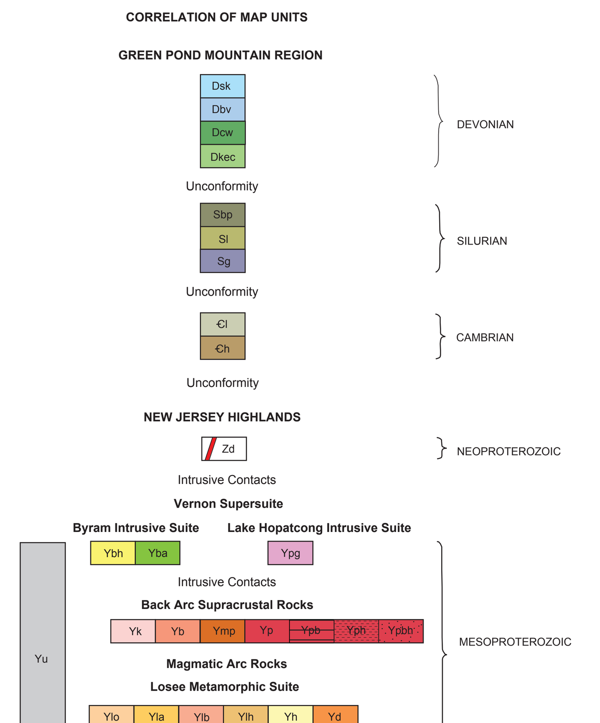
Yd **Diorite gneiss (Mesoproterozoic)** – Light-gray or tan-weathering, greenish-gray or greenish-brown, medium-grained, greasy-lustered, massive, foliated rock containing andesine or oligoclase, augite, hornblende, hypersthene, and magnetite. Thin mafic layers having the composition of amphibolite and leucocratic to mafic layers of quartz-oligoclase gneiss occur locally.

Other Rocks

Ya **Amphibolite (Mesoproterozoic)** – Grayish-black-weathering, black or grayish-black, medium-grained gneiss composed of hornblende, andesine, and magnetite. Some variants contain biotite and others contain augite and local hypersthene. Amphibolite associated with the Losee Suite is metavolcanic in origin. Amphibolite associated with supracrustal rocks may be metavolcanic or metasedimentary in origin. All types are undifferentiated on the map.

Yu **Mesoproterozoic rocks, undifferentiated** – Shown beneath Green Pond and in cross section only.

CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

Contact - Dotted where concealed.

Fault - Dotted where concealed. Queried where uncertain.

U/D Normal fault - U, upthrown side; D, downthrown side

D/U Reverse fault - U, upthrown side; D, downthrown side

FOLDS

Folds in Paleozoic rocks showing trace of axial surface, direction of dip of limbs, and direction of plunge

- Minor syncline
- Minor anticline
- Syncline
- Anticline
- Gently inclined to recumbent anticline

Folds in Proterozoic rocks showing trace of axial surface, direction of dip of limbs, and direction of plunge

- Synform
- Antiform
- Overturned synform
- Overturned antiform

PLANAR FEATURES

Strike and dip of beds

- 10 Inclined
- Vertical
- 30 Overturned

Strike and dip of cleavage

- 40 Inclined
- Vertical

Strike and dip of crystallization foliation

- 75 Inclined
- Vertical

70 Strike and dip of inclined mylontic foliation

LINEAR FEATURES

20 Bearing and plunge of intersection of bedding and cleavage in Paleozoic rocks

30 Bearing and plunge of mineral lineation in Proterozoic rocks

OTHER FEATURES

R Abandoned rock quarry

Form line showing foliation in Proterozoic rocks. Shown in cross sections.

Well or boring in Proterozoic granite

4A,B Location of photographs in figure 4 A and B

Figure 4. Examples of fold styles in rocks of the Newfoundland quadrangle.
(A, above) Upright to slightly overturned anticline and syncline pair in Green Pond. Conglomerate along Route 23, near Newfoundland.
(B, below) Superimposed folds in layered pyroxene gneiss west of Clinton Reservoir. Pens are oriented along the plunge direction of two principal fold phases.

REFERENCES CITED AND USED IN CONSTRUCTION OF MAP

Aaron, J.M., 1969, Petrology and origin of the Hardyston Quartzite (Lower Cambrian) in eastern Pennsylvania and western New Jersey, *in* Subitzky, S., ed., Geology of selected area in New Jersey and eastern Pennsylvania and guidebook of excursions, Rutgers University Press, New Brunswick, New Jersey, p. 21-34.

Barnett, S.G., III, 1970, Upper Cayugan and Helderbergian stratigraphy of southeastern New York and northern New Jersey: Geological Society of America Bulletin, v. 81, p. 2375-2402.

_______, 1976, Geology of the Paleozoic rocks of the Green Pond outlier: New Jersey Geological Survey, Geologic Report Series No. 11, 9 p.

Bayley, W.S., 1910, Iron mines and mining in New Jersey: New Jersey Geological Survey, Final Report Series, v. 7, 512 p.

Boucot, A.J., 1959, Brachiopods of the Lower Devonian rocks at Highland Mills, New York: Journal of Paleontology, v. 33, p. 727-769.

Chadwick, H.G., 1908, Revision of "the New York series": Science, new series, v. 28, p. 346-348.

Darton, N.H., 1894, Geologic relations from Green Pond, New Jersey, to Skunnemunk Mountain, New York: Geological Society of America Bulletin, v. 5, p. 367-394.

Drake, A.A., Jr., 1984, The Reading Prong of New Jersey and eastern Pennsylvania-An appraisal of rock relations and chemistry of a major Proterozoic terrane in the Appalachians, *in* Bartholomew, M.J., ed., The Grenville event in the Appalachians and related topics: Geological Society of America Special Paper 194, p. 75-109.

Drake, A.A., Jr., and Volkert, R.A., 1991, The Lake Hopatcong Intrusive Suite (Middle Proterozoic) of the New Jersey Highlands, *in* Drake, A.A., Jr., ed., Contributions to New Jersey Geology: U.S. Geological Survey Bulletin 1952, p. A1-A9.

Drake, A.A., Jr., Volkert, R.A., Monteverde, D.H., Herman, G.C., Houghton, H.F., Parker, R.A., and Dalton, R.F., 1996, Bedrock Geologic Map of Northern New Jersey: U.S. Geological Survey Miscellaneous Investigations Series Map I-2540-A, scale 1:100,000.

Gray, M.B., and Zeitler, P.K., 1997, Comparison of clastic wedge provenance in the Appalachian foreland using U/Pb ages of detrital zircons, Tectonics, v. 16, p. 151-160.

Hartnagel, C.A., 1907, Upper Siluric and Lower Devonic formations of the Skunnemunk Mountain region: New York State Museum Bulletin 107, p. 39-54.

Herman, G.C., and Mitchell, J. P., 1991, Bedrock geologic map of the Green Pond Mountain Region from Dover to Greenwood Lake, New Jersey: New Jersey Geological Survey Geologic Map Series 91-2, scale 1:24,000.

Kirby, M.W., 1981, Sedimentology of the Middle Devonian Bellvale and Skunnemunk Formation in the Green Pond Outlier in northern New Jersey and southeastern New York, unpublished MS thesis, Rutgers University, New Brunswick, New Jersey, 109 p.

Kümmel, H.B., 1908, Paleozoic sedimentary rocks of the Franklin furnace quadrangle, New Jersey, *in* Spencer, A.C., Kümmel, H.B., Salisbury, R.D., Wolff, J.E., and Palache, Charles, Description of the Franklin furnace quadrangle, New Jersey: U.S. Geological Survey Atlas Folio 161, p. 10-12.

Kümmel, H.B., and Weller, Stuart, 1902, The rocks of the Green Pond Mountain region: New Jersey Geological Survey Annual Report 1901, p. 1-51.

Parrillo, D.G., 1959, Bedrock geology of the Charlotteburg dam site: New Jersey Geological Survey, unpublished report on file in the office of the New Jersey Geological Survey, Trenton, New Jersey, unpaginated.

Peck, W.H., Volkert, R.A., Meredith, M.T., and Rader, E.L., 2006, Calcite-graphite thermometry of the Franklin Marble, New Jersey Highlands: Journal of Geology, v. 114, p. 485-499.

Price, R.E., 2005, $^{40}Ar/^{39}Ar$ evidence for early (700 Ma) Iapetan oblique divergence in the Highlands region, NJ-NY-PA, unpublished MS thesis, Rutgers University, Newark, New Jersey, 36 p.

Rogers, H.D., 1836, Report on the geological survey of the State of New Jersey: Philadelphia, Desilver, Thomas, & Co., 174 p.

Sims, P.K., 1958, Geology and magnetite deposits of Dover District, Morris County, New Jersey: U.S. Geological Survey Professional Paper 287, 162 p.

Smith, N.D., 1970, The braided stream depositional environment: Comparison of the Platte River with some Silurian clastic rocks, North-Central Appalachians, Geological Society of America Bulletin, v. 81, p. 2993-3014.

Stanford, S.D., 1991, Surficial geologic map of the Newfoundland quadrangle, Passaic, Morris and Sussex Counties, New Jersey: New Jersey Geological Survey Map 91-3, scale 1:24,000.

Vanuxem, Lardner, 1842, Geology of New York, part III, comprising the survey of the third geological district: Albany, New York, 306 p.

Ver Straeten, C.A., 2001, Event and sequence stratigraphy and a new synthesis of the Lower to Middle Devonian, eastern Pennsylvania and adjacent areas: *in*, Inners, J.D., and Fleeger, G.M., eds., 2001 a Delaware River odyssey, Guidebook, 66th Annual field conference of Pennsylvania Geologists, Shawnee-on-Delaware, Pennsylvania, p. 35-53.

Ver Straeten, C.A., and Brett, C.E., 2000, Bulge migration and pinnacle reef development, Devonian Appalachian Foreland Basin: Journal of Geology, v.108, p. 339-352.

Ver Straeten, C.A., Brett, C.E., and Albright, S.S., 1995, Stratigraphic and paleontologic overview of the upper Lower and Middle Devonian, New Jersey and adjacent areas, *in* Baker, John, ed., Contributions to the paleontology of New Jersey, Geological Association of New Jersey XII Annual Meeting, Wayne, New Jersey, p. 229-239.

Volkert, R.A., 1996, Geologic and engineering characteristics of Middle Proterozoic rocks of the Highlands, northern New Jersey, *in* Engineering geology in the metropolitan environment: Field Guide and Proceedings of the 39th annual meeting of the Association of Engineering Geologists, p. A1-A33.

_______, 2004, Mesoproterozoic rocks of the New Jersey Highlands, north-central Appalachians: petrogenesis and tectonic history, *in* Tollo, R.P., Corriveau, L., McLelland, J., and Bartholomew, J., eds., Proterozoic tectonic evolution of the Grenville orogen in North America: Geological Society of America Memoir 197, p. 697-728.

_______, 2012, Bedrock geologic map of the Dover quadrangle Morris and Sussex Counties, New Jersey: New Jersey Geological and Water Survey Open-File Map OFM 91, scale 1:24,000.

Volkert, R.A., Aleinikoff, J.N., and Fanning, C.M., 2010, Tectonic, magmatic, and metamorphic history of the New Jersey Highlands: New insights from SHRIMP U-Pb geochronology, *in* Tollo, R.P., Bartholomew, M.J., Hibbard, J.P., and Karabinos, P.M., eds., From Rodinia to Pangea: The Lithotectonic Record of the Appalachian Region, Geological Society of America Memoir 206, p. 307-346.

Volkert, R.A., and Drake, A.A., Jr., 1998, The Vernon Supersuite: Mesoproterozoic A-type granitoid rocks in the New Jersey Highlands: Northeastern Geology and Environmental Sciences, v. 20, p. 39-43.

________, 1999, Geochemistry and stratigraphic relations of Middle Proterozoic rocks of the New Jersey Highlands, *in* Drake, A.A., Jr., ed., Geologic Studies in New Jersey and eastern Pennsylvania: U.S. Geological Survey Professional Paper 1565-C, 77 p.

Volkert, R.A., Feigenson, M.D., Patino, L.C., Delaney, J. S., and Drake, A.A., Jr., 2000, Sr and Nd isotopic compositions, age and petrogenesis of A-type granitoids of the Vernon Supersuite, New Jersey Highlands, USA: Lithos, v. 50, p. 325-347.

Volkert, R.A., Markewicz, F.J., and Drake, A.A., Jr., 1990, Bedrock geologic map of the Chester quadrangle, Morris County, New Jersey: New Jersey Geological Survey, Geologic Map Series 90-1, scale 1:24,000.

Volkert, R.A., and Puffer, J.H., 1995, Late Proterozoic diabase dikes of the New Jersey Highlands- A remnant of Iapetan rifting in the north-central Appalachians, *in* Drake, A.A., Jr., ed., Geologic studies in New Jersey and eastern Pennsylvania: U.S. Geological Survey Professional Paper 1565-A. 22 p.

Volkert, R.A., Zartman, R.E., and Moore, P.B., 2005, U-Pb zircon geochronology of Mesoproterozoic postorogenic rocks and implications for post-Ottawan magmatism and metallogenesis, northern New Jersey Highlands and contiguous areas, USA: Precambrian Research, v. 139, p. 1-19

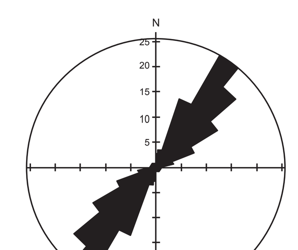
Wherry, E.T., 1909, The early Paleozoic of the Lehigh Valley district, Pennsylvania: Science, new series, v. 30, 416 p.

White, I.C., 1882, The geology of Pike and Monroe Counties: Pennsylvania Geological Survey, 2nd series, Report G-6, 407 p.

Willard, Bradford, 1937, Hamilton correlations: American Journal of Science, 5th series, v. 33, p. 264-278.

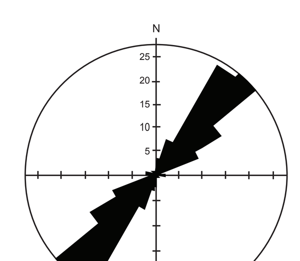
Wolff, J.E., and Brooks, A.H., 1898, The age of the Franklin white limestone of Sussex County, New Jersey: U.S. Geological Survey 18th Annual Report, pt. 2, p. 425-457.

Yeakel, L.S., 1962, Tuscarora, Juniata, and Bald Eagle paleocurrents and paleogeography in the Central Appalachians, Geological Society of America Bulletin, v. 73, p. 1515-1540.



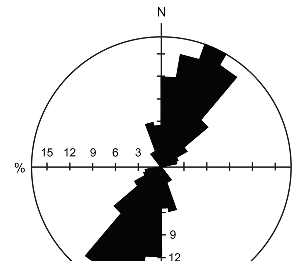
Average trend = N42°E
Sector angle = 10°
n = 442

Figure 1. Rose diagram of bedding strikes in Paleozoic rocks.



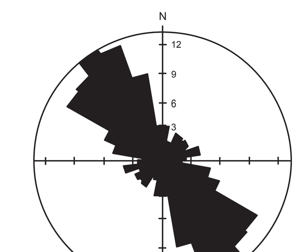
Average trend = N44°E
Sector angle = 10°
n = 237

Figure 2. Rose diagram of cleavage strikes in Paleozoic rocks.



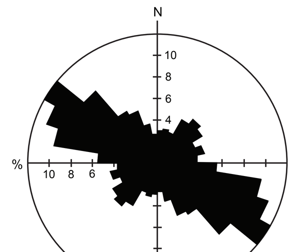
Average trend = N20°E
Sector angle = 10°
n = 1,095

Figure 3. Rose diagram of foliation strikes in Mesoproterozoic rocks.



Average trend = N38°W
Sector angle = 10°
n = 590

Figure 5. Rose diagram of joint strikes in Paleozoic rocks.



Average trend = N62°W
Sector angle = 10°
n = 1,719

Figure 6. Rose diagram of joint strikes in Mesoproterozoic rocks.