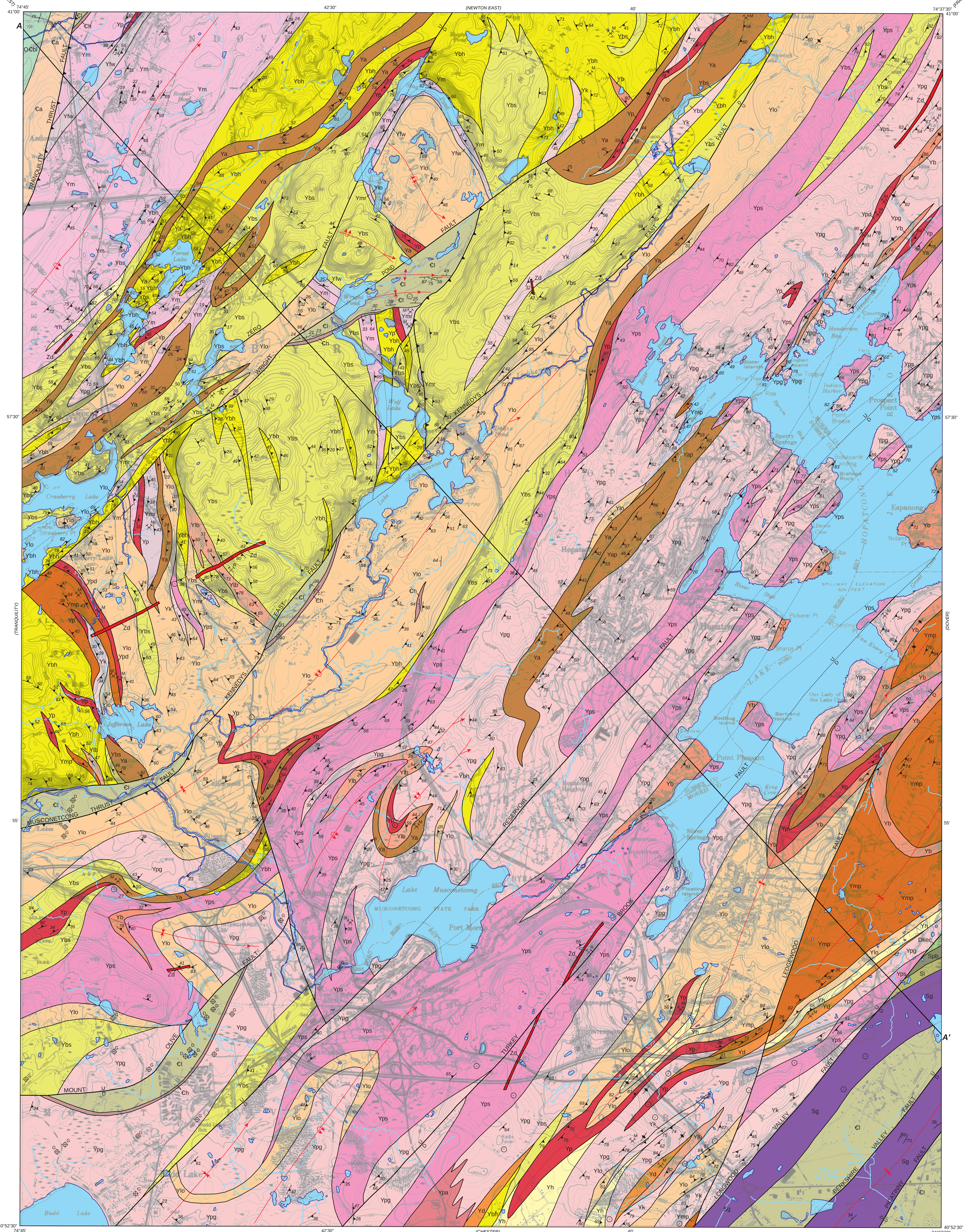
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WATER RESOURCES MANAGEMENT
NEW JERSEY GEOLOGICAL AND WATER SURVEY

Prepared in cooperation with the
U.S. GEOLOGICAL SURVEY
NATIONAL GEOLOGIC MAPPING PROGRAM

BEDROCK GEOLOGIC MAP OF THE STANHOPE QUADRANGLE
MORRIS AND SUSSEX COUNTIES, NEW JERSEY
OPEN FILE MAP OFM 124



Base map by the Army Map Service and United States Geological Survey. Edited and published by the United States Geological Survey.

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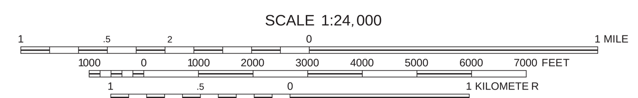
Topography from aerial photographs by photogrammetric methods. Aerial photographs taken 1942. Field check 1943. Culture revised by the United States Geological Survey 1954.

Hydrography Dataset Streams and Waterbodies, 2002.

Polyconic projection. 1927 North American datum 10,000-foot grid based on New Jersey coordinate system, 1000-meter Universal Transverse Mercator grid ticks, zone 18.

SCALE 1:24,000

CONTOUR INTERVAL 20 FEET



Geology mapped by R.A. Volkert in 2009

Digital cartography by R.S. Pristas

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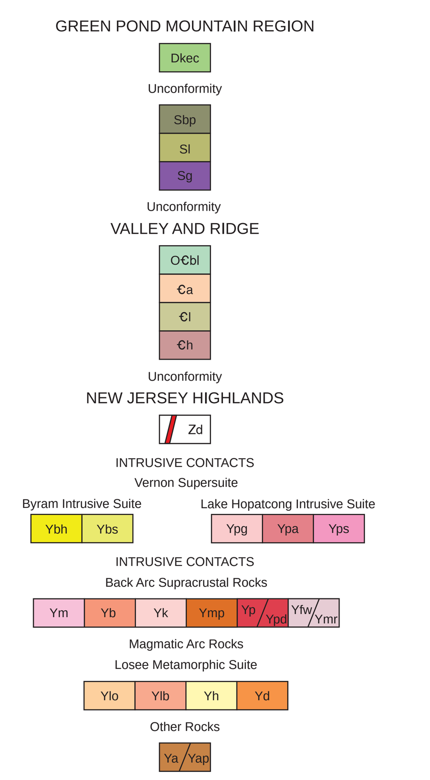
Bedrock Geologic Map of the Stanhope Quadrangle
Morris and Sussex Counties, New Jersey

by
Richard A. Volkert[1]
2018

CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

Contact - Dotted where concealed beneath water.

Fault - Dotted where concealed. Queried where uncertain.

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

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

Inclined thrust fault - teeth on upper plate

FOLDS

Folds in Proterozoic rocks showing trace of axial surface, direction and dip of limbs, and direction of plunge. Dotted where concealed beneath water.

Upright synform

Overturned antiform

Overturned synform

Folds in Paleozoic rocks showing trace of axial surface, direction and dip of limbs, and direction of plunge. Folds in bedding and/or cleavage. Dotted where concealed beneath water.

Anticline

Syncline

PLANAR FEATURES

Strike and dip of beds

Inclined

Overturned

Strike and dip of crystallization foliation

Inclined

Vertical

LINEAR FEATURES

Bearing and plunge of mineral lineation in Proterozoic rocks

OTHER FEATURES

Abandoned magnetite mine

Active rock quarry in granite or gneiss

Abandoned rock quarry in granite or gneiss, R; marble, Mr

Bedrock float used to draw lithologic contact

Bore hole or water well in granite or gneiss, R; marble, Mr; dolomite, D

Form line showing foliation in Proterozoic rocks. Shown in cross section only.

INTRODUCTION

The Stanhope 7.5-minute quadrangle, located in the New Jersey Highlands Physiographic Province, is characterized by parallel, northeast-trending ridges with elevations that locally exceed 1,100 ft. above sea level. Tiny topographic expression is disrupted in the southern part of the map area by the generally east-west-trending Wisconsinan-age terminal moraine that includes more than 200 ft. of glacial sediment deposited on the bedrock surface (Stanford and others, 1996). The Stanhope quadrangle is situated in the Musconetcong River watershed, and along with Lubbers Run these two streams constitute the dominant regional drainages.

The bedrock geology of the Stanhope quadrangle has been the subject of study for more than a century (Bayley and others, 1914; Hague and others, 1956; Chapman, 1966; Young, 1969; Volkert and others, 1989). However, most previous bedrock studies lack continuity with the more recent detailed geologic mapping of adjacent quadrangles and conformity with the present geologic framework proposed for Mesoproterozoic rocks in the Highlands. Moreover, new interpretations of bedrock geologic relationships, based in part on detailed major and trace element geochemistry, stable isotope analyses, and uranium-lead (U-Pb) geochronology, has considerably improved much of the previous work in the quadrangle. Therefore, interpretations presented here supersede those shown on the more recent bedrock geologic maps of Volkert and others (1989), and Drake and others (1996). This report provides updated, detailed geologic information on the stratigraphy, structure, ages and descriptions of geologic units in the map area. Cross section A-A' shows a vertical profile of the geologic units and their structure, and rose diagrams in figures 1-3 provide a directional analysis of selected structural features.

STRATIGRAPHY
Paleozoic rocks

Lower Paleozoic formations of Cambrian and Ordovician age of the Kittatinny Valley Sequence crop out throughout the quadrangle where they unconformably overlie, or are in fault contact with Mesoproterozoic rocks in tectonic lenses on some of the major faults. Lower Paleozoic rocks that do not crop out were also recently discovered under part of the Wisconsinan terminal moraine north of Budd Lake (F.J. Markewicz, unpublished data on file in the office of the New Jersey Geological and Water Survey) and are shown on this new iteration of the bedrock map. The Kittatinny Valley Sequence was previously considered to be part of the Lehigh Valley Sequence of MacLachlan (1979) but was reassigned by Drake and others (1996). In the map area it includes the Kittatinny Supergroup (Hardyston Quartzite, Leithsville Formation, Allentown Dolomite, and lower part of the Beekmantown Group). East of the Longwood Valley fault, in the southeastern part of the quadrangle, lower and Middle Paleozoic rocks of Cambrian through Devonian age of the Green Pond Mountain Region unconformably overlie, or are in fault contact with, Mesoproterozoic gneisses.

Neoproterozoic rocks

Northeast-striking (~N54°E, n = 8), dark greenish-gray, medium- to coarse-grained diabase dikes of Late Neoproterozoic age intrude Mesoproterozoic rocks throughout the quadrangle but not Cambrian or younger rocks. The dikes are as much as 15 ft. thick and have coarse-grained interiors and fine-grained to aphanitic chilled margins against Mesoproterozoic rocks. Very locally they display columnar cooling joints and contain xenoliths of the enclosing Mesoproterozoic rocks. The dikes were emplaced into a rift-related extensional tectonic setting in the Highlands at about 600 Ma (million years ago) during breakup of the supercontinent Rodinia (Volkert and Puffer, 1995).

Mesoproterozoic rocks

The Stanhope quadrangle is predominantly underlain by Mesoproterozoic rocks that include a heterogeneous assemblage of granite, gneisses of sedimentary and volcanic origin, and marble. Mesoproterozoic rocks were metamorphosed to granulite-facies conditions during the Grenvillian Orogeny between 1045 and 1030 Ma (Volkert and others, 2010). The peak temperature calculated for this high-grade metamorphism is 769°C from regional calcite-graphite thermometry (Peck and others, 2006).

Among the oldest map units in the quadrangle are magmatic arc rocks of the Losee Suite that include plutonic variants mapped as quartz-oligoclase gneiss and diorite gneiss, and volcanic rocks mapped as biotite-quartz-oligoclase gneiss and hypersthene-quartz-plagioclase gneiss. Rocks of the Losee Suite yielded sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon ages of 1282 to 1248 Ma (Volkert and others, 2010). The Losee Suite is spatially and temporally associated with a succession of supracrustal rocks formed in a back-arc basin adjacent to the Losee magmatic arc. These include felsic volcanic rocks of rhyolitic composition mapped as microcline gneiss and mafic volcanic rocks mapped as amphibolite, as well as metamorphosed sedimentary rocks mapped as potassic feldspar gneiss, biotite-quartz-feldspar gneiss, pyroxene-quartz-feldspar gneiss, pyroxene gneiss, and marble. Felsic volcanic rocks from varied stratigraphic positions within the succession of supracrustal rocks yielded U-Pb zircon ages of 1299 to 1240 Ma (Volkert and others, 2010) that closely overlap the age of the Losee Suite.

Granite and related rocks of the Byram and Lake Hopatcong Intrusive Suites are widespread and abundant in the map area where they intrude rocks of the Losee Suite and supracrustal rocks. The Stanhope quadrangle is designated as the type section (location in the Highlands where the rocks are best exposed) for both suites that together comprise the Vernon Supersuite (Volkert and Drake, 1998). Byram and Lake Hopatcong rocks form a complete differentiation series that includes monzonite and syenite, quartz monzonite and quartz syenite, granite, and alaskite. Granite of both suites yielded similar U-Pb zircon ages of 1188 to 1182 Ma (Volkert and others, 2010).

The youngest high-grade crystalline rocks in the quadrangle are granite pegmatites that are undeformed and have discordantly intruded most other Mesoproterozoic rocks as small, irregular bodies. None of the pegmatites are large enough to be shown on the map. Elsewhere in the Highlands, undeformed coarse-grained felsic intrusions and pegmatites yielded U-Pb thermal ionization mass spectroscopy (TIMS) zircon ages of 1004 to 987 Ma (Volkert and others, 2005), indicating they are latest Mesoproterozoic to earliest Neoproterozoic in age.

STRUCTURE
Paleozoic bedding

Bedding in the Paleozoic rocks has a mean strike of N53°E ± 29°(fig. 1). Beds dip northwest and, less commonly, southeast, although in the tectonic lens along Kennedys-East fault they are overturned and dip moderately to steeply southeast. The dip of all beds ranges from 21° to 87° and averages 48°.

Proterozoic foliation

Crystallization foliation (the parallel alignment of mineral grains) is a penetrative metamorphic fabric formed as a result of directed compressional stresses during high-grade metamorphism that deformed Mesoproterozoic rocks during the Grenvillian Orogeny. The strike of crystallization foliation is fairly uniform throughout most of the map area, but varies somewhat locally because of folding of the rocks. The mean strike of foliation is N32°E ± 4° (fig. 2). Foliation dips southeast and, less commonly, northwest between 9° to 90° and averages 56°. Locally, in the hinge areas of major folds, foliations strike northwest and dip gently to moderately northeast.

Folds

Folds in the Paleozoic rocks postdate the development of bedding and they were formed during the Taconian and (or) Alleghanian orogenies at about 450 Ma and 250 Ma, respectively. Paleozoic folds include an east-northeast-striking, east plunging, open and upright anticline and syncline pair in the Wright Pond area, and a northeast-striking and plunging, upright to locally overturned, and gently inclined to recumbent syncline in the Green Pond Mountain Region.

Folds that deform Mesoproterozoic rocks deform earlier formed planar metamorphic fabrics and therefore postdate the development of crystallization foliation. They formed during the Grenvillian Orogeny at ca.1045 to 1030 Ma. The characteristic fold pattern in the map area consists of broad, open, northwest-overturned to locally upright, northeast-plunging antiforms and synforms. The dominant plunge of mineral lineations is parallel to the axes of these folds; it ranges from 4° to 60° and averages 22° toward N50°E (n = 78), although locally the trend plunges an average of 13° to S53°W (n = 7). In the northern and western part of the map, between the Zero and Kennedys-East faults, folds are characterized by northwest overturned limbs and southeast-plunging axes defined by lineations that plunge an average of 23° to S61°E (n = 14). These folds were interpreted by Volkert and others (1989) to be refolded folds that were subsequently truncated by the bounding faults. However, it is here considered more likely that they formed as a result of rotational movement along the bounding faults.

Faults

The structural geology of the quadrangle is dominated by northeast-trending faults that deform both Mesoproterozoic and Paleozoic rocks and partition the bedrock formations into a series of structural blocks. These structural blocks and associated sub-blocks were assigned names by Volkert and others (1989) based on what they perceived to be lithological and geochronological differences between the blocks. More recent studies by the author in the New Jersey Highlands show that no differences are present between the structural blocks and that the use of names for them is unnecessary. From the northwest, the major faults in the map area are the Tranquility thrust fault, Zero fault, Wright Pond fault, Kennedys-East fault, Reservoir fault, Turkey Brook fault, Ledgewood fault, Longwood Valley fault, Berkshire Valley fault, and Picatinny fault. Most faults display complex movement histories and multiple reactivations from the Proterozoic through the Mesozoic. Earliest deformation recorded by the faults formed under higher-temperature ductile conditions and consists mainly of mylonitic fabric. This fault fabric typically is overprinted by deformation formed under lower temperature brittle conditions that consists of brecciation, recrystallization, alteration of mafic mineral phases, chlorite- or epidote-coated fractures or slickensides, and (or) close-spaced fracture cleavage.

The Tranquility thrust fault strikes about N20°E and dips gently to moderately southeast. The fault is poorly exposed in the map area, but to the north, in the Newton East quadrangle, the fault contains Mesoproterozoic marble and gneiss on the hanging wall thrust westward over Paleozoic dolomite and Mesoproterozoic rocks on the footwall (Drake and Volkert, 1993). There the fault was penetrated at a depth of -3,422 ft. in drill hole DH2 and -1,593 ft. in drill hole DR1 at the Limecrest quarry during drilling in 2009 (Volkert, 2010). West of the map area, the Tranquility thrust fault was encountered by New Jersey Zinc Company geologists in drill core in the Tranquility quadrangle (Baum, 1967). In the Hamburg quadrangle, the Tranquility thrust fault appears to merge with the Pochuck fault (Dalton and others, 2014). The Tranquility thrust fault is characterized by an older ductile deformation fabric strongly overprinted by younger brittle deformation.

The Zero fault strikes about N35°E and dips steeply southeast an average of 80°. Latest movement appears to have been normal. Here, the fault contains Mesoproterozoic rocks on both sides, but northeast in the Franklin quadrangle the fault borders the west side of the Wallkill River Valley where it places Mesoproterozoic rocks on the footwall against Paleozoic rocks on the hanging wall (Hague and others, 1956). In the map area, the fault merges with, or is cut off by the Wright Pond fault, and at its northern end in the Franklin quadrangle, the Zero fault loses displacement and terminates in a series of horsetails that are cut off by the Kennedys-East fault (Volkert and Monteverde, 2013). The Zero fault is characterized by an older ductile deformation fabric that is overprinted by younger brittle deformation fabric of probable Paleozoic age (Metsger, 2001).

The Wright Pond fault strikes about N50°E and dips steeply southeast an average of 75°. Latest movement was normal, but the fault also preserves a component of left-lateral strike slip movement. In the map area, the Wright Pond fault contains a lens of Hardyston Quartzite and Leithsville Formation on the hanging wall, but otherwise throughout its length the fault has Mesoproterozoic rocks on both the hanging wall and footwall. The fault is characterized by brittle deformation fabric.

The Kennedys-East fault strikes about N45°E and dips steeply southeast an average of 75°. The fault borders the west side of Lubbers Run Valley in the map area and the east side of the Wallkill River Valley to the north. It has been mapped as Kennedys fault in the southwest Highlands and the East fault in the northern Highlands (Drake and others, 1996), but recent detailed quadrangle-scale mapping shows that it is the same fault. In the Hamburg quadrangle, the fault is cut off by the Hamburg fault (Dalton and others, 2014). Latest movement appears to have been reverse. The Kennedys-East fault contains Mesoproterozoic rocks on both sides along most of its length, but north of the map area it contains Paleozoic rocks on the footwall and Mesoproterozoic rocks on the hanging wall. The fault is characterized by brittle deformation fabric.

The Musconetcong thrust fault is a major regional structure that extends from the Delaware River north to the map area (Drake and others, 1996) where it is cut off by the Kennedys-East fault. The Musconetcong thrust fault borders the western side of Schooleys Mountain and the east side of Musconetcong Valley. The fault strikes generally northeast and dips moderately southeast an average of 30°. It contains Mesoproterozoic rocks on the hanging wall that have been thrust onto Paleozoic and Mesoproterozoic rocks on the footwall. The fault does not crop out in the map area but is known from a series of borings drilled in the Musconetcong Valley to the southwest (Dames and Moore, 1981).

The newly recognized and named Mount Olive fault extends from the southeastern part of the Tranquility quadrangle, through Mount Olive, to the town of Stanhope where it is cut off by an unnamed, northwest-striking fault. The Mount Olive fault does not crop out and is known from a series of water wells and borings that penetrated Paleozoic Hardyston Quartzite and Leithsville Dolomite (F.J. Markewicz, unpublished data). The fault strikes east-northeast and probably dips southeast at an undetermined angle. It contains Mesoproterozoic rocks on the hanging wall and Paleozoic and Mesoproterozoic rocks on the footwall based on this same structural relationship of fault-bounded Paleozoic lenses throughout the quadrangle. Latest movement is here interpreted to have been normal.

The Reservoir fault here strikes about N45°E and dips steeply southeast an average of 85°. Elsewhere it dips vertically or steeply northwest. In the map area it contains Mesoproterozoic rocks on both sides of the fault, whereas northeast of the quadrangle the fault places Paleozoic rocks on the hanging wall against Mesoproterozoic rocks on the footwall. The fault records a history of movement involving reverse, dextral strike slip, and normal, with latest movement having been normal. The Reservoir fault is characterized by ductile deformation fabric in the center of the fault, overprinted by a pervasive brittle deformation fabric that envelops the mylonite on both sides of the fault over a total width of as much as 1,000 ft.

The Turkey Brook fault strikes about N40°E and dips steeply southeast an average of 75°. The fault contains Mesoproterozoic rocks on both sides along its entire length. The latest movement is inferred to have been normal. The fault is characterized by brittle deformation fabric as much as a few hundred feet wide.

The Ledgewood fault strikes about N20°E and dips steeply toward the southeast at about 70°. The fault contains Mesoproterozoic rocks on both sides along its entire length. Latest movement on the fault appears to have been normal. The Ledgewood fault is characterized by brittle deformation fabric.

The Longwood Valley fault strikes about N40°E and dips steeply southeast an average of 80°. In the map area and to the northeast, the fault contains Mesoproterozoic rocks on the footwall and Paleozoic rocks of the Green Pond Mountain Region on the hanging wall (Herman and Mitchell, 1991; Drake and others, 1996). The latest movement on the Longwood Valley fault was normal. The fault is characterized by brittle deformation fabric along its entire length.

The Berkshire Valley fault is not exposed in the map area, or to the northeast in the Dover quadrangle. Its occurrence was inferred by Herman and Mitchell (1991) based on missing stratigraphic units between the Green Pond Conglomerate and Cornwall Shale in the Berkshire Valley. The fault strikes about N40°E and dips southeast an average of 45°. It contains Paleozoic rocks on both sides along its entire length. The latest movement appears to have been reverse. The fault is characterized by a zone of brittle fabric of unknown width.

The Picatinny fault strikes N30°E and dips southeast an average of 50°. The fault contains Paleozoic rocks on both sides along most of its length, except for a short segment in the Dover quadrangle, near Picatinny Lake, where Mesoproterozoic rocks are present on the hanging wall (Volkert, 2012). Latest movement appears to have been reverse. The fault is characterized by brittle deformation fabric.

Mesoproterozoic rocks throughout the map area are also deformed by smaller, less regionally pervasive, northeast- or northwest-striking faults, some of which appear to be confined to outcrop scale. Fault widths are typically a few inches to a few feet. These faults are characterized mainly by brittle deformation features.

Joints

Joints are a common feature in Mesoproterozoic and Paleozoic formations in the map area. Those developed in Paleozoic rocks are common in limestone, dolomite, and sandstone. The dominant joint set in Paleozoic rocks strikes northwest. Joints are typically planar, moderately well formed, and moderately to steeply dipping. Surfaces of joints are typically unmineralized, except where proximal to faults, and are smooth and less commonly slightly irregular. Joints are variably spaced from a foot to tens of feet. Those developed in massive rocks such as granite tend to be more widely spaced, irregularly fractured and discontinuous than joints developed in the layered gneisses and finer-grained crystalline rocks. Joints proximal to faults are typically closely spaced 2 ft. or less.

Joints developed in Mesoproterozoic rocks are characteristically planar, moderately well formed, moderately to widely spaced, and moderately to steeply dipping. Surfaces of joints are typically unmineralized, except where proximal to faults, and are smooth and less commonly slightly irregular. Joints are variably spaced from a foot to tens of feet. Those developed in massive rocks such as granite tend to be more widely spaced, irregularly fractured and discontinuous than joints developed in the layered gneisses and finer-grained crystalline rocks. Joints proximal to faults are typically closely spaced 2 ft. or less.

The dominant strike of joints within the Mesoproterozoic rocks is nearly at a right angle to the trend of the crystallization foliation, a relationship that has been observed in Mesoproterozoic rocks throughout the Highlands (Volkert, 1996). Consequently, the strike of joints in the map area displays some variability because of folding of the rocks. The mean strike of the dominant joint set is N56°W ± 8° (fig. 3) and dips mainly southwest and, less commonly, northeast. A subordinate joint set strikes northeast about N45°E and dips with near equal abundance northwest and southeast. The dip of all joints ranges from 36° to 90° and averages 73°.

ECONOMIC RESOURCES

Mesoproterozoic rocks in the Stanhope quadrangle are host to numerous economic deposits of iron ore (low-Ti magnetite) mined mainly during the 18th and 19th centuries. Detailed descriptions of these mines are given in Bayley (1910). In addition, several unnamed magnetite mines previously unreported were discovered during the course of this mapping. The locations of all known mines in the map area are provided in a database available online through the New Jersey Geological and Water Survey. Mesoproterozoic granite and marble were quarried at locations throughout the quadrangle, and granite is currently quarried for crushed stone in the southern and northeastern parts of the map area.

DESCRIPTION OF MAP UNITS
Green Pond Mountain Region

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 subangular 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-to-gray and pink milky quartz. Quartz cobbles are as much as 4 in. long. Unconformably overlies the Leithsville Formation, Allentown Dolomite or Mesoproterozoic rocks in the map area. Unit is about 1,000 ft. thick.

Valley and Ridge
Kittatinny Valley Sequence

Beekmantown Group (Clarke and Schuchert, 1899)

O€bl — **Beekmantown Group, lower part** (Lower Ordovician to Upper Cambrian) – Consists of an upper, middle, and lower sequence, but only the lower sequence is exposed in the quadrangle. Lower sequence consists of medium- to medium-dark-gray, aphanitic to coarse-grained, thinly-laminated to thick-bedded, slightly fetid dolomite having quartz-sand laminae and sparse, very thin to thin, black chert beds. Individual bed thickness decreases and floating quartz sand content increases toward lower gradational contact. Contains conodonts of North American Midcontinent province *Cordylodus proavus* to *Rossodus manitouensis* zones (Karklins and Repetski, 1989) as used by Sweet and Bergstrom (1986). Entire unit is Stonehenge Limestone of Drake and others (1985) and Stonehenge Formation of Volkert and others (1989). Markewicz and Dalton (1977) correlate lower sequence to the Rickenbach Formation. Unit is about 600 ft. thick.

€a — **Allentown Dolomite** (Upper Cambrian) (Wherry, 1909) – Upper sequence is light-gray- to medium-gray-weathering, medium-light- to medium-dark-gray, fine- to medium-grained, locally coarse-grained, medium- to very thick-bedded dolomite; local shaly dolomite near the bottom. Floating quartz sand and two series of medium-light- to very light-gray, medium-grained, thin-bedded quartzite and discontinuous dark-gray chert lenses occur directly below upper contact. Lower sequence is medium- to very-light-gray-weathering, light- to medium-dark-gray, fine- to medium-grained, thin- to medium-bedded dolomite and shaly dolomite. Weathered exposures characterized by alternating light- and dark-gray beds. Ripple marks, oolites, algal stromatolites, cross-beds, edgewise conglomerate, mud cracks, and paleosol zones occur throughout but are more abundant in lower sequence. Lower contact gradational into Leithsville Formation. Unit contains a trilobite fauna of Dresbachian (early Late Cambrian) age (Weller, 1903; Howell, 1945). Approximately 1,800 ft. thick regionally.

€l — **Leithsville Formation** (Middle to Lower Cambrian) (Wherry, 1909) – Upper sequence, rarely exposed, is mottled, medium-light- to medium-dark-gray-weathering, medium- to medium-dark-gray, fine- to medium-grained, medium- to thick-bedded, locally pitted and friable dolomite. Middle sequence is grayish-orange or light- to dark-gray, grayish-red, light-greenish-gray- or dark-greenish-gray-weathering, aphanitic to fine-grained, thin- to medium-bedded dolomite, argillaceous dolomite, dolomitic shale, quartz sandstone, siltstone, and shale. Lower sequence is medium-light- to medium-gray-weathering, medium-gray, fine- to medium-grained, thin- to medium-bedded dolomite. Quartz-sand lenses occur near lower gradational contact with Hardyston Quartzite. Archaeocyathids of Early Cambrian age are present in formation at Franklin, New Jersey, suggesting an intraformational disconformity between Middle and Early Cambrian time (Palmer and Rozanov, 1967). Unit also contains *Hyolithellus micans* (Offield, 1967; Markewicz, 1968). Approximately 800 ft. thick regionally.

€h — **Hardyston Quartzite** (Lower Cambrian) (Wolff and Brooks, 1898) – Medium- to light-gray, fine- to coarse-grained, medium- to thick-bedded quartzite, arkosic sandstone and dolomitic sandstone. Contains *Scolithus linearis* (?) and fragments of the trilobite *Olenellus thompsoni* of Early Cambrian age (Nason, 1891; Weller, 1903). Thickness regionally is less than 20 ft.

New Jersey Highlands

Zd — **Diabase dikes** (Late Neoproterozoic) (Volkert and Puffer, 1995) – Light gray- or brownish-gray-weathering, dark-greenish-gray, aphanitic to fine-grained dikes. Composed principally of plagioclase (labradorite to andesine), augite, and ilmenite and (or) magnetite. Locally occurring pyrite blebs are common. Contacts are typically chilled and sharp against enclosing Mesoproterozoic country rock. Dikes are tholeiitic to alkalic in composition and hypersthene normative.

Vernon Supersuite (Volkert and Drake, 1998)
Byram Intrusive Suite (Drake and others, 1991)

Ybh — **Hornblende granite** (Mesoproterozoic) – Pinkish-gray- to buff-weathering, pinkish-white or light-pinkish-gray, medium- to coarse-grained, foliated granite composed principally of microcline microperthite, quartz, oligoclase, and hornblende. Some variants are quartz monzonite or quartz syenite. Includes bodies of pegmatite too small to be shown on the map.

Ybs — **Hornblende monzonite** (Mesoproterozoic) – Pinkish-gray- to buff-weathering, pinkish-gray or greenish-gray, medium- to coarse-grained, foliated monzonite or syenite, and less abundant quartz monzonite or quartz syenite, composed of microcline microperthite, oligoclase, hornblende, and quartz. Contains sparse amounts of pyroxene where in contact with rocks of the Lake Hopatcong Intrusive Suite in the southeastern part of the map.

Lake Hopatcong Intrusive Suite (Drake and Volkert, 1991)

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

Ypa — **Pyroxene alaskite** (Mesoproterozoic) – Buff- or white-weathering, greenish-buff to light pinkish-gray, medium- to coarse-grained, massive, moderately foliated granite composed of mesoperthite to microantiperthite, quartz, oligoclase, and sparse amounts of clinopyroxene. Common accessory minerals include titanite, magnetite, apatite, and trace amounts of zircon.

Yps — **Pyroxene monzonite** (Mesoproterozoic) – Gray-to buff- or tan-weathering, greenish-gray, medium- to coarse-grained, massive, moderately foliated monzonite or syenite and less abundant quartz monzonite or quartz syenite. Composed of mesoperthite, microantiperthite to microcline microperthite, oligoclase, clinopyroxene, titanite, magnetite, and sparse apatite and local quartz. Locally contains sparse amounts of hornblende.

Back-arc basin supracrustal rocks (Volkert, 2004)

Ym — **Microcline gneiss** (Mesoproterozoic) – Pale pinkish-white weathering, tan to pinkish-white, fine- to medium-grained, layered and foliated rock composed of quartz, microcline microperthite, and oligoclase. Common accessory minerals include biotite, garnet, magnetite, and sillimanite. Locally interlayered with quartz-rich metasedimentary rock. Contains conformable clots and lenses of partial melt.

Yb — **Biotite-quartz-feldspar gneiss** (Mesoproterozoic) – Gray-weathering, locally rusty, gray, tan, or greenish-gray, medium- to coarse-grained, moderately layered and foliated gneiss containing microcline microperthite, oligoclase, quartz, and biotite. Locally contains garnet, tourmaline, sillimanite, and magnetite; graphite and pyrrhotite occur in rusty gneiss.

Yk — **Potassic feldspar gneiss** (Mesoproterozoic) – Light-gray- or pinkish-buff-weathering, pinkish-white or light-pinkish-gray, fine- to medium-grained and locally coarse-grained, moderately foliated gneiss composed of quartz, microcline microperthite, oligoclase, and variable amounts of biotite, garnet, tourmaline, sillimanite, and magnetite.

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

Yp / Ypd — **Pyroxene gneiss** (Mesoproterozoic) – White- or tan-weathering, greenish-gray, fine- to medium-grained, well layered and foliated gneiss containing oligoclase, clinopyroxene, variable amounts of quartz, and sparse amounts of epidote, titanite, scapolite, or calcite (Yp). Unit is spatially associated with thin, generally conformable layers of medium-grained, green, nearly monomineralic diopsidite (Ypd) composed of diopside.

Yfw / Ymr — **Marble** (Mesoproterozoic) – White- to light-gray-weathering, white or grayish-white, fine- to coarse-crystalline, calcitic to locally dolomitic marble with accessory graphite, phlogopite, chondrodite, and clinopyroxene. Contains pods and lenses of clinopyroxene-hornblende rock, clinopyroxene-garnet rock, scapolite-phlogopite rock, and clinopyroxene-rich rock. Marble was separated by New Jersey Zinc Company geologists (Hague and others, 1956) into a structurally lower Franklin Marble layer (not exposed in map area) and an upper Wildcat Marble layer (Yfw). Marble outcrops exposed near Cranberry Lake, Stag Pond, and Wright Pond cannot be definitively correlated to the Wildcat Marble and are mapped as undifferentiated marble (Ymr).

Magmatic arc rocks (Volkert, 2004)
Losee Suite (Drake, 1984; Volkert and Drake, 1999)

Ylo — **Quartz-oligoclase gneiss** (Mesoproterozoic) – White-weathering, light-greenish-gray, medium- to coarse-grained, moderately layered and foliated gneiss to indistinctly foliated gneiss and less abundant granofels composed of oligoclase or andesine, quartz, and variable amounts of hornblende, biotite, and clinopyroxene. Locally contains thin layers of amphibolite (Ya).

Ylb — **Biotite-quartz-oligoclase gneiss** (Mesoproterozoic) – White- or light-gray-weathering, medium-gray or greenish-gray, medium- to coarse-grained, moderately well layered and foliated gneiss composed of oligoclase or andesine, quartz, biotite, and trace amounts of garnet. Some outcrops contain hornblende. Locally interlayered with amphibolite (Ya).

Yh — **Hypersthene-quartz-plagioclase gneiss** (Mesoproterozoic) – Gray- or tan-weathering, greenish-gray or greenish-brown, medium-grained, moderately well layered and foliated, greasy lustered gneiss composed of andesine or oligoclase, quartz, clinopyroxene, hornblende, and hypersthene. Commonly contains thin, conformable layers of amphibolite and mafic-rich quartz-plagioclase gneiss.

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

Other rocks

Ya / Yap — **Amphibolite** (Mesoproterozoic) – Grayish-black, fine- to medium-grained, moderately layered and foliated rock composed of hornblende and andesine (Ya). Most of the unit is associated with the supracrustal succession and the Losee Suite and interpreted to be metavolcanic, although some amphibolite that is intimately layered with pyroxene gneiss contains abundant clinopyroxene and titanite (Yap) and may be metasedimentary in origin. Metavolcanic amphibolites are undifferentiated on the map.

Yu — **Mesoproterozoic rocks, undifferentiated** – Shown in cross section only.

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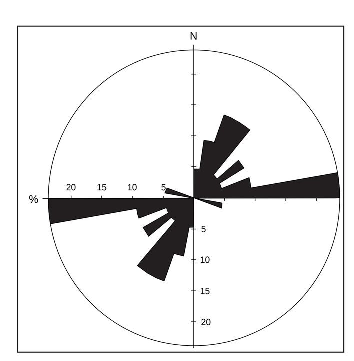
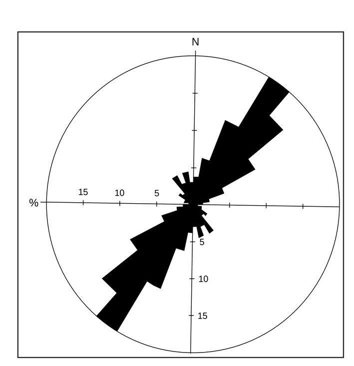


Sector angle = 10°
n = 21

Figure 1. Rose diagram showing the orientation of bedding in Paleozoic rocks.



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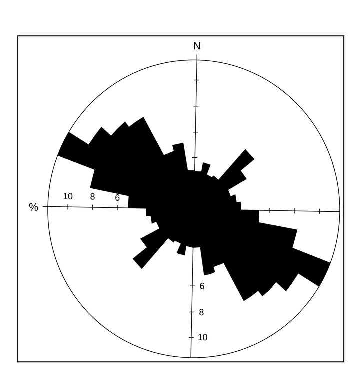
n = 993

Figure 2. Rose diagram showing the orientation of crystallization foliation in Mesoproterozoic rocks.



Sector angle = 10°
n = 1356

Figure 3. Rose diagram showing the orientation of joints in Mesoproterozoic rocks.