DEPARTMENT OF ENVIRONMENTAL PROTECTION
WATER RESOURCE MANAGEMENT
NEW JERSEY GEOLOGICAL SURVEY

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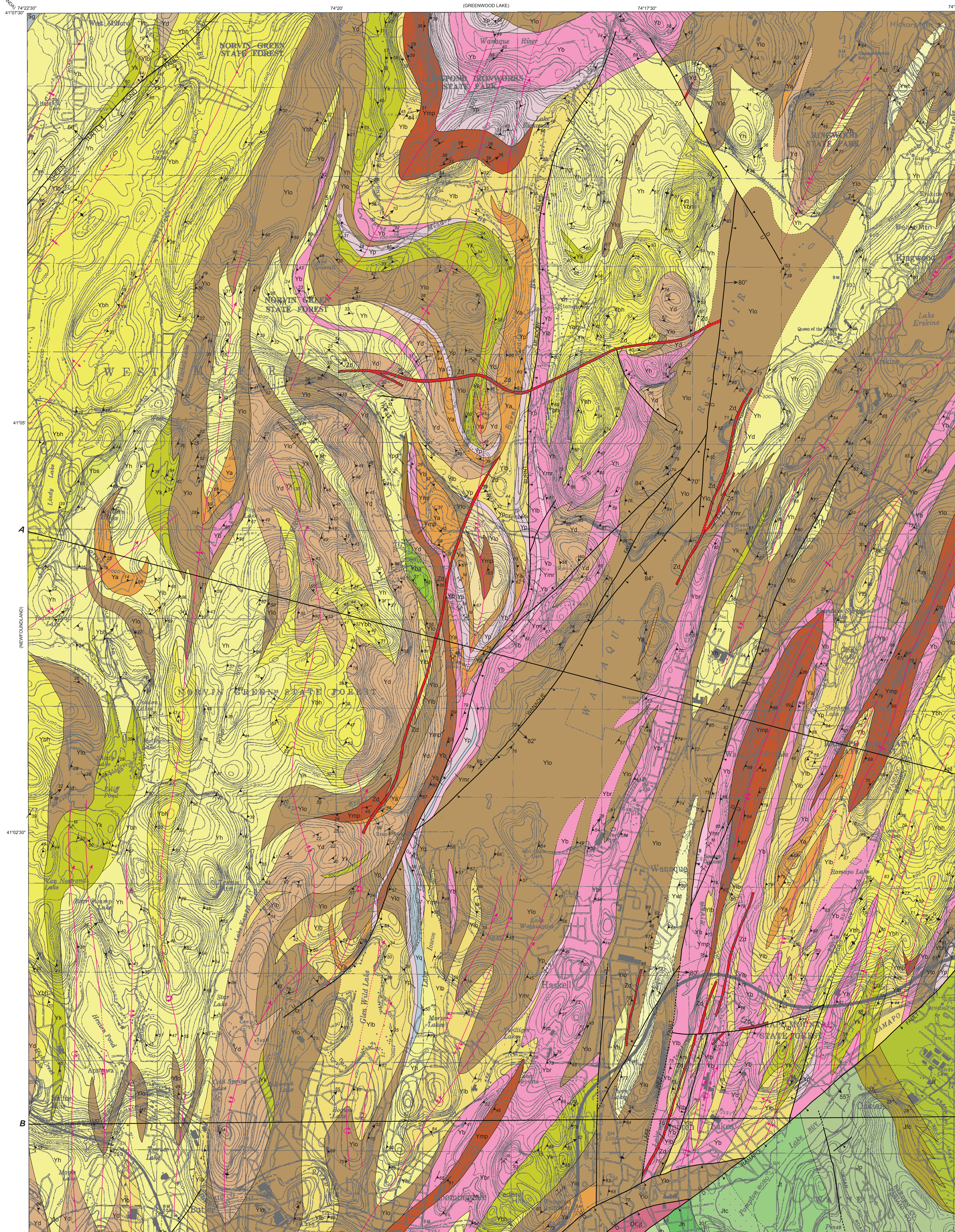


Produced by the United States Geological Survey
Topography compiled 1942. Planimetry derived from imagery taken 1995 and other sources. Survey control current as of 1954

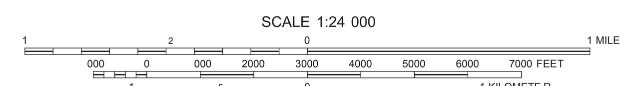
North American Datum of 1983 (NAD 83). Projection and 1,000-meter grid: Universal Transverse Mercator, zone 18
2,500-meter ticks: New Jersey Coordinate System of 1983

North American Datum of 1927 (NAD 27) is shown by dashed corner ticks. The values of the shift between NAD 83 and NAD 27 for 7.5-minute intersections are obtainable from National Geodetic Survey NADCON software

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Landmark buildings verified 1954

SCALE 1:24 000



Bedrock geology mapped by R.A. Volkert in 1988 and 2000.
Digital cartography by R.S. Pristas.

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Bedrock Geologic Map of the Wanaque Quadrangle, Bergen, Morris and Passaic Counties, New Jersey

by
Richard A. Volkert
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INTRODUCTION

The Wanaque quadrangle is located in northern New Jersey in Passaic, Morris, and Bergen Counties within a mixed commercial, industrial and residential setting. However, large tracts in the central and western parts of the area remain undeveloped. The Wanaque, Pequannock, and Ramapo Rivers are the dominant streams in the map area. The south-flowing Wanaque River is predominant and drains the eastern part of the quadrangle; the east-flowing Pequannock River drains the southwestern part of the quadrangle and the southwest-flowing Ramapo River drains the southeastern part. The upland areas west of Wanaque Reservoir are primarily drained by Burnt Meadow Brook, West Brook, and Blue Mine Brook, but ridges in this area are also highly dissected by numerous streams of smaller order.

The Wanaque quadrangle constitutes an important part of the regional groundwater and surface-water supply. Impoundment of the Wanaque River in Ringwood Borough, and also in Wanaque Borough, has created the Monksville and Wanaque Reservoir systems, respectively, which are a major water source for northeastern New Jersey.

The map area straddles the boundary between the Highlands and Piedmont Physiographic Provinces, but is predominantly in the former. The Ramapo fault traverses the quadrangle northeastward from the vicinity of Pompton Junction (Bloomingdale Borough) to Oakland Borough where it trends parallel to the Ramapo River. The fault provides a structural and physiographic boundary between the Highlands and Piedmont provinces.

Dominant elevations are within the Highlands part of the map with a maximum elevation of about 1180 ft. above sea level in the area of Norvin Green State Forest. The Preakness Basalt forms the dominant relief within the Piedmont part of the quadrangle, with an elevation of about 600 ft. above sea level on Preakness Mountain near Oakland Borough.

STRATIGRAPHY

Bedrock in the Wanaque quadrangle ranges in age from Mesoproterozoic to Silurian. The southeastern part of the area is underlain by Mesozoic igneous and sedimentary rocks of the Piedmont. Bedrock of Paleozoic age extends through the extreme northwestern corner of the map area and also crops out as small tectonic lenses along the Ramapo fault. Rocks of Mesoproterozoic age of the New Jersey Highlands underlie the remainder of the map area.

Mesozoic Rocks

The youngest bedrock in the quadrangle is Mesozoic in age and occurs in the Newark basin, a northeast-trending half-graben in northern and central New Jersey that contains a total of approximately 24,600 ft. of interbedded Upper Triassic to Lower Jurassic sedimentary and igneous rocks. These consist of conglomerate, sandstone, siltstone, and shale of fluvial and lacustrine origin, and three interbedded tholeiitic basalt flows. However, only the upper part of this stratigraphic succession crops out in the quadrangle.

The general stratigraphic order of the Mesozoic bedrock is one of progressive younging from north to south. Sedimentary units from oldest to youngest include the Feltville, Towaco and Boonton Formations, all of Lower Jurassic age. These form a muted topographic surface that is now largely covered by glacial sediments (Stanford, 1993). Conglomeratic lithofacies of the Towaco and Feltville Formations supports the moderate relief south of Pompton Lake and at Oakland, respectively. Finer-grained lithofacies of the Towaco Formation are sparsely exposed north of Pines Lake, whereas finer-grained variants of the Boonton and Feltville Formations are not exposed in the map area but crop out along strike to the south, in the Pompton Plains quadrangle (Volkert, 2010).

Mesozoic igneous rocks in the map area consist of the Hook Mountain Basalt, Preakness Basalt and Orange Mountain Basalt of Lower Jurassic age. The Hook Mountain Basalt is sparsely exposed along the nose of Packanack Mountain south of Pompton Lake, whereas the Preakness Basalt is well exposed on Preakness Mountain south of Oakland. The Orange Mountain Basalt is not exposed but crops out to the immediate east in the Ramsey quadrangle. The Hook Mountain Basalt and Preakness Basalt both contain coarse-grained layers and local basaltic pegmatite at several stratigraphic intervals that are mapped as gabbroid. Gabbroid and pegmatite layers within the Preakness Basalt are interpreted by Puffer and Volkert (2001) to have formed through fractionation from finer-grained basalt. Gabbroid layers within the Hook Mountain Basalt likely formed through a similar process. Gabbroid is absent within these basalt formations in the map area because of stratigraphic thinning, but it is well exposed along strike to the south in the Pompton Plains and Paterson quadrangles.

Paleozoic Rocks

The Green Pond Conglomerate of Silurian-age is not exposed in the northwestern corner of the map area but is inferred from outcrops that are present along strike to the north and south (Herman and Mitchell, 1991) where it unconformably overlies Mesoproterozoic rocks. Sedimentary rocks of probable Ordovician age are locally preserved as a tectonic lens on the footwall of the Ramapo fault, where highly deformed dark gray phyllonitic shale containing thin, discontinuous siltstone beds crops out along the Pequannock River at Riverdale and projects into the Wanaque quadrangle. These rocks appear to have an affinity to rocks of the Jutland Klippe sequence in the High Bridge quadrangle and Peapack Klippe sequence in the Chester and Gladstone quadrangles (Drake et al., 1996). Similar highly deformed phyllonitic shale is also preserved on the footwall of the Ramapo fault west of the Ramapo River a few miles to the northeast in the Ramsey quadrangle (Volkert, 2011).

Neoproterozoic Rocks

Mesoproterozoic rocks in the quadrangle are intruded by numerous diabase dikes of Neoproterozoic age (Volkert and Puffer, 1995) that trend toward the east or north-northeast. The dikes have sharp contacts and chilled margins against enclosing Mesoproterozoic country rock. Dikes are interpreted as having been emplaced at ca. 600 Ma during incipient rifting of the eastern Laurentian continental margin in response to breakup of the supercontinent Rodinia (Volkert, 2004). Diabase dikes are best exposed along the ridge crest east of Lake Inez, along the eastern side of Wanaque Reservoir by Furnace Road Dam, west of Wanaque Reservoir near Stonetown, near Blue Mine Brook, and also along the ridge north of West Brook.

Mesoproterozoic rocks

Mesoproterozoic rocks in the map area include a heterogeneous assemblage of granites, gneisses of sedimentary and volcanic origin and marble. These rocks were metamorphosed to granulite facies during the Grenville orogeny at ca.1050 Ma (Volkert, 2004). Temperature estimates for this high-grade metamorphism are constrained from regional calcite-graphite thermometry to ~769°C (Peck et al., 2006) and from biotite thermometry to ~754°C (Volkert, 2006).

The oldest Mesoproterozoic rocks in the map area are calc-alkaline, plagioclase-rich gneiss mapped as quartz-oligoclase gneiss or hypersthene-quartz-plagioclase gneiss, formed in a continental-margin magmatic arc, and which constitute the newly named Wanaque tonalite gneiss. This gneiss crops out in a belt in the eastern part of the quadrangle that extends northward from the Ramapo fault at least to Ringwood. Wanaque tonalite gneiss has not been recognized outside of the Wanaque quadrangle. Geochemical analyses of samples from the map area are given in table 1. Three samples of this gneiss from the map area yielded sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon ages of 1366 to 1345 Ma (Volkert et al., 2010).

Calc-alkaline, plagioclase-rich gneisses of the Losee Metamorphic Suite (Drake, 1984; Volkert and Drake, 1999) are widely distributed throughout the quadrangle. They include rocks mapped as quartz-oligoclase gneiss, biotite-quartz-oligoclase gneiss, hypersthene-quartz-plagioclase gneiss, and diorite gneiss that were formed in a continental-margin magmatic arc from volcanic and plutonic protoliths (Volkert and Drake, 1999; Volkert, 2004). Geochemical analyses of selected samples from the map area are given in table 1. Quartz-oligoclase gneiss and hypersthene-quartz-plagioclase gneiss from elsewhere in the Highlands have yielded SHRIMP U-Pb zircon ages of 1282 to 1254 Ma (Volkert et al., 2010). A sample of diorite gneiss from the map area yielded a SHRIMP U-Pb zircon age of 1248 Ma (Volkert et al., 2010).

Magmatic arc rocks of the Losee Suite are spatially and temporally associated with a succession of supracrustal rocks that were formed in a back-arc basin (Volkert, 2004). Supracrustal rocks include a bimodal suite of rhyolitic gneiss mapped as potassic feldspar gneiss and mafic volcanic rocks mapped as amphibolite, as well as metasedimentary rocks mapped as biotite-quartz-feldspar gneiss, pyroxene gneiss, clinopyroxene-quartz-feldspar gneiss, quartzite, and marble. Metasedimentary rocks are best exposed in the vicinity of Harrison Mountain Lake, Ramapo Mountain, and north of Lake Ioscoe. Supracrustal rocks from elsewhere in the Highlands have yielded SHRIMP U-Pb zircon ages of 1299 to 1251 Ma (Volkert et al., 2010).

Mesoproterozoic rocks are intruded by hornblende-bearing granite, alaskite and monzonite of the Byram Intrusive Suite (Drake et al., 1991; Volkert and Drake, 1999) that constitutes part the Vernon Supersuite (Volkert and Drake, 1998). Radiometric dating of granite of the Byram Intrusive Suite yielded SHRIMP U-Pb zircon ages of 1184 to 1182 Ma (Volkert et al., 2010). Hornblende granite crops out in large bodies east of Ramapo Lake, west of Kitchell Lake, and on ridge tops in Norvin Green State Forest.

The youngest Mesoproterozoic rocks in the quadrangle are small, irregular bodies of unfoliated granite pegmatite and weakly foliated granite dikes and veins that crosscut other Mesoproterozoic rocks in the map area. Pegmatites are mainly discordant to metamorphic foliation. None of the pegmatites are large enough to be shown on the map. Similar rocks from elsewhere in the Highlands yield U-Pb zircon ages of 1004 to 986 Ma (Volkert et al., 2005).

STRUCTURE

Proterozoic foliation

Crystallization foliation (the parallel alignment of mineral grains) in the Mesoproterozoic rocks is an inherited feature resulting from compressional stresses during high-grade metamorphism that deformed Mesoproterozoic rocks during the Ottawan phase of the Grenville orogeny. The strike of crystallization foliation is fairly uniform throughout most of the map area, but locally it is somewhat varied, especially in the central and northern parts of the quadrangle because of deformation of the rocks due to folding. The strike of foliation is mainly toward the northeast and averages N.19°E. (Fig. 1). Locally, in the hinge areas of major folds, foliations strike west or northwest. Northeast-trending foliations dip predominantly southeast and less commonly northwest. However, within the hinge area of fold structures foliations dip gently to moderately north. The dip of all foliations in the map area ranges from 12° to 90° and averages 58°.

Mesozoic bedding

Bedding in the Mesozoic rocks is fairly uniform and strikes generally northwest at an average of N.27°W. Most beds dip southwest at 16° to 33° and average 23°.

Folds

Folds that deform Mesoproterozoic rocks in the map area were formed during the Grenville orogeny at about 1050 Ma. The folds deform earlier-formed planar metamorphic fabrics so they postdate the development of crystallization foliation. Fold geometries are complex and display evidence for at least two phases of folding based on outcrop data and map pattern, resulting in three characteristic fold styles. They include antiforms and synforms that are north-plunging west-overturned, northeast-plunging, northwest-overturned to upright, and east-northeast-plunging, northwest-overturned. The folds are defined by a continuous range of mineral lineations ranging in plunge azimuth from N.07°E. to N.85°E. and arbitrarily separated into three populations. Lineations plunge at an average of 24° N.20°E. (n=21), 27° N.43°E. (n=52), and 41° N.71°E. (n=11). The dominant population is consistent with the plunge and plunge azimuth of most folds in Mesoproterozoic rocks throughout the Highlands. The strike of bedding in Mesozoic sedimentary rocks is affected by their location in the map area on the east limb of a broad, regional syncline and west limb of an anticline, both of which plunge northwest.

Faults

The structural geology of the quadrangle is dominated by northeast-trending faults that deform both Mesoproterozoic and Paleozoic rocks. These faults were active during the Ottawan (Grenville), Taconian and Alleghanian compressional orogenies, and also during Neoproterozoic and Mesozoic extensional rifting events. Widths of fault zones are on the order of tens of feet but they may be as much as several hundred feet. Some of the wider fault zones are possibly due to the interaction of several smaller parallel or anastomozing faults. Most of the faults are characterized by brittle deformation fabrics that consist of the retrogression of mafic mineral phases, chlorite or epidote-coated fractures or slickensides, and (or) close-spaced fracture cleavage. From the northwest, the major faults include the Green Turtle Pond fault, Wanaque fault, Burnt Meadow fault, Lake Inez fault, and Ramapo fault.

The Green Turtle Pond fault extends through the northwest corner of the map area and has also been mapped in the Greenwood Lake quadrangle to the north (Volkert, 2008) where it was exposed during rehabilitation of the dam at Green Turtle Pond. This fault strikes northeast and dips about 65° to 70° northwest. Kinematic indicators preserved along the fault record a reverse sense of movement.

The generally north-striking Wanaque fault extends along the western edge of, and then through, the Wanaque Reservoir. It consists of a network of fault splays that dip steeply northwest or southeast at 70° to 85°. The Wanaque fault appears to be cut off by the Burnt Meadow fault. The latter is a north-striking structure that extends from Glen Wild Lake north to Monksville Reservoir. The Burnt Meadow fault dips east at about 65°. The fault is cross cut by a Late Proterozoic diabase dike without apparent displacement of the dike, suggesting that the fault has probably remained inactive since the Mesoproterozoic.

The Lake Inez fault strikes generally northward from Pompton Lakes to Skyline Lakes. It is not exposed in outcrop but is inferred from lineaments identified on aerial photographs and from the map pattern of contacts along the fault. This fault is interpreted to dip steeply east at 75° to 85°.

The Ramapo fault is a dominant structural feature in the region and it preserves a complex history of movement that extended from the Proterozoic through the Mesozoic. Multiple episodes of reactivation during this time have left overprinting brittle and ductile fabrics that record kinematic indicators consistent with normal, reverse, and strike-slip movement. In the Wanaque quadrangle the Ramapo fault strikes about N.40°E. The dip of the fault is about 50° to 55° southeast and is well constrained by borings drilled to the southwest at Bernardsville (Ratcliffe and others, 1990), and by a series of borings drilled for Route 287 between Montville and Riverdale (Woodward Clyde Consultants, 1983). However, outcrops of ductily deformed Mesoproterozoic rocks on the footwall block of the fault, especially to the south in the Pompton Plains quadrangle, consistently record an older mylonitic foliation of probable Paleozoic age that dips steeply southeast at 60° to 85°.

Mesoproterozoic rocks throughout the map area are also deformed by smaller, less regionally pervasive, northeast or northwest-trending faults, some of which appear to be confined to outcrop scale. These faults are characterized mainly by brittle deformational fabrics similar to those seen on some of the major faults in the quadrangle. Widths of these smaller faults typically are on the order of a few inches to a few feet, although some of the wider faults are as much as tens of feet wide and may result from the intersection of several smaller parallel faults.

Small brittle faults of Mesozoic age and of apparent limited displacement cut the Preakness Basalt in the southeastern part of the map area. These faults are characterized by breccia and eroded gaps in basalt outcrops.

Joints

Joints are a ubiquitous feature in Mesoproterozoic rocks of the map area. They are characteristically planar, moderately well formed, moderately to widely spaced, and moderately to steeply dipping. Surfaces of joints are typically unmineralized, except near faults, and are smooth and less commonly slightly irregular. Joints are variably spaced from a ft. to tens of ft. Those developed in massive rocks such as granite tend to be more widely spaced, irregularly formed and more discontinuous than joints developed in the layered gneisses. Joints formed near faults are spaced 2 ft. or less, a part.

The dominant joint trend within the Mesoproterozoic rocks is nearly perpendicular to the trend of the crystallization foliation, and this relationship of the principal joint set to foliation is a consistent feature observed in Mesoproterozoic rocks throughout the Highlands (Volkert, 1996). Consequently, joint trends in the map area display some variability owing to the varied orientation of crystallization foliation in rocks that are folded. The dominant joint set strikes northwest at an average of N.63°W. (Fig. 2). Joints of this set dip mainly southwest and less abundantly northeast. A minor joint set strikes toward the northeast and dips with near equal abundance northwest and southeast (Fig. 2). The average dip of all joints is 70°.

ECONOMIC RESOURCES

Some Mesoproterozoic rocks in the central part of the Wanaque quadrangle that formed in a magmatic arc and back-arc basin tectonic environment contain small economic deposits of iron ore (magnetite). A few of the magnetite deposits were initially mined before the Civil War, and then subsequently mined intermittently until the late 1800's (Bayley, 1910). Graphite ore was mined at a single, small, previously unreported occurrence north of Lake Ioscoe in the middle to late 1800's (Volkert, 1997). A very small, previously unreported mica prospect occurs a short distance south of Wanaque Reservoir and another small mica mine is located at Federal Hill in Bloomingdale. Details surrounding the history of these prospects are unknown. Mesoproterozoic gneiss and granite are currently quarried at two locations in the quadrangle for use as aggregate and dimension stone. Two small quarries, now abandoned were also developed in gneiss and granite in the southern part of the map area, and marble was locally extracted from another small subsequently abandoned quarry near Haskell, likely for use as a flux during the roasting of magnetite from local mines. Deposits of glacial sand and gravel were worked at several locations throughout the quadrangle, mainly in the lowland valleys.

NATURALLY OCCURRING RADIATION

Background levels of naturally occurring radioactivity were measured in Mesozoic bedrock outcrops using a hand-held Micro R meter and the results are given under the individual rock unit descriptions. In general, basalt yields consistently low readings that average 6 Micro R/Hr regardless of stratigraphic position, texture, or composition. Sedimentary units yield higher and somewhat more varied readings that appear to be related mainly to grain size. Values recorded from conglomerate and pebbly sandstone are lower (9 to 13 Micro R/Hr.) than from sandstone and finer-grained siltstone and shale (11 to 21 Micro R/Hr.), suggesting that clay minerals may be the principal hosts of the radiogenic mineral phases. This relationship applies on a regional basis as well, based on measurements of various lithofacies of the Mesozoic sedimentary formations from quadrangles in the Newark basin from New Brunswick north to Pompton Plains (R.A. Volkert, unpublished data).

DESCRIPTION OF MAP UNITS

NEWARK BASIN

Jb **Boonton Formation** (Lower Jurassic) (Olsen, 1980) – Reddish-brown to brownish-purple, fine-grained, commonly micaceous sandstone, siltstone, and mudstone, in fining-upward sequences mostly 5 to 13 ft. thick. Red, gray, and brownish-purple siltstone and black, blocky, partly dolomitic siltstone and shale are common in the lower part of unit. Irregular mud cracks, symmetrical ripple marks, hummocky and trough cross-laminated beds, burrows, and evaporite minerals are abundant in red siltstone and mudstone. Gray, fine-grained sandstone may have carbonized plant remains and reptile footprints occur in middle and upper parts of unit. Conglomerate and conglomeratic sandstone containing subangular to subrounded pebble-to-boulder clasts of Mesoproterozoic rocks and less abundant Paleozoic quartzite, shale, and dolomite, and Jurassic basalt within a matrix of coarse brown sand interfinger with upper part of unit along the Ramapo fault. Maximum thickness of the Boonton Fm. regionally is about 1,640 ft. Levels of natural radioactivity range from 13 to 15 (mean=14) Micro R/Hr. in reddish-brown lithologies, 15 to 17 (mean=16) Micro R/Hr. in gray lithologies, and 11 to 13 (mean=12) Micro R/Hr. in conglomerate.

Jh **Hook Mountain Basalt** (Lower Jurassic) (Olsen, 1980) – Dark-greenish-gray to black, generally fine-grained, amygdaloidal basalt composed of plagioclase, clinopyroxene, and iron-titanium oxides. Contains small spherical to tubular gas-escape vesicles, some filled by zeolite minerals or calcite, typically above flow contacts. Elsewhere unit contains dark-gray, coarse-grained gabbroid composed of clinopyroxene and plagioclase grains as much as 0.5 in. long that occurs at several stratigraphic intervals in the unit but is most abundant in the lowest flow. Gabbroid has sharp upper contacts and gradational lower contacts with finer-grained basalt. Unit consists of at least two, and possibly as many as three major flows. Base of lowest flow is intensely vesicular. Tops of flows are weathered and vesicular. Maximum thickness regionally is 361 ft. Levels of natural radioactivity range from 4 to 10 (mean=6) Micro R/Hr.

Jt, Jtc **Towaco Formation** (Lower Jurassic) (Olsen, 1980) – Reddish-brown to brownish-purple, buff, olive-tan, or light-olive-gray, fine- to medium-grained, micaceous sandstone, siltstone, and silty mudstone in fining-upward sequences 3 to 10 ft. thick. Unit consists of at least eight sequences of gray, greenish-gray, or brownish-gray, fine-grained sandstone, siltstone, and calcareous siltstone, and black microlaminated calcareous siltstone and mudstone with diagnostic pollen, fish, and dinosaur tracks. Gray fine-grained sandstone has carbonized plant remains. Irregular mud cracks and symmetrical ripple marks may be present. Sandstone is often hummocky and trough cross-laminated, and siltstone commonly planar laminated or bioturbated and indistinctly laminated to massive. Several feet of unit have been thermally metamorphosed along contact with Hook Mountain Basalt. Conglomerate and conglomeratic sandstone with subangular to subrounded clasts of Mesoproterozoic rocks, Paleozoic quartzite and quartz, dolomite, and shale in matrix of coarse brown sand to silt (Jtc) interfinger with unit. Maximum thickness of the Towaco Fm. regionally is about 1,250 ft. Levels of natural radioactivity range from 12 to 21 (mean=15) Micro R/Hr. in reddish-brown lithologies, 13 to 20 (mean=16) Micro R/Hr. in gray lithologies, and 9 to 13 (mean=11) Micro R/Hr in conglomerate.

Jp **Preakness Basalt** (Lower Jurassic) (Olsen, 1980) – Dark-greenish-gray to black, fine-grained, dense, hard basalt composed of calcic plagioclase and clinopyroxene. Contains small spherical tubular gas-escape vesicles, some filled by zeolite minerals or calcite, just above scoriaceous flow contacts. Elsewhere unit contains dark-gray, coarse- to very-coarse-grained gabbroid composed of clinopyroxene grains as much as 0.5 in. long and plagioclase grains as much as 1.0 in. long that occurs at several stratigraphic intervals in the unit but is most abundant in the lowest flow. Gabbroid has sharp upper contacts and gradational lower contacts with finer-grained basalt. Unit consists of at least three major flows, the tops of which are marked by prominent vesicular zones up as much as 8 ft. thick. Radiating slender columns 2 to 24 in. wide, due to shrinkage during cooling, are abundant near the base of the lowest flow. Maximum thickness regionally is about 1,040 ft. Levels of natural radioactivity range from 3 to 8 (mean=6) Micro R/Hr.

Jf, Jfc **Feltville Formation** (Lower Jurassic) (Olsen, 1980) – Reddish-brown or light-grayish-red, fine- to coarse-grained sandstone, siltstone, shaly siltstone, and silty mudstone, and light- to dark-gray or black, locally calcareous siltstone, silty mudstone, and carbonaceous limestone. Upper part of unit is predominantly thin- to medium-bedded, reddish-brown siltstone and locally cross-bedded sandstone. Reddish-brown sandstone and siltstone are moderately well sorted, commonly cross-laminated, and interbedded with reddish-brown, planar-laminated silty mudstone and mudstone. As much as 2 ft. of Feltville has been thermally metamorphosed along the contact with the Preakness Basalt. Conglomerate and conglomeratic sandstone with subangular to subrounded clasts of Mesoproterozoic rocks, Paleozoic quartzite and quartz, dolomite, and shale in matrix of coarse brown sand to silt (Jfc) interfinger with unit near Oakland. Maximum thickness of the Feltville Fm. regionally is about 510 ft. Levels of natural radioactivity range from 11 to 14 (mean=12) Micro R/Hr in reddish-brown sandstone and siltstone and 9 to 13 (mean=11) Micro R/Hr in conglomerate.

Jo **Orange Mountain Basalt** (Lower Jurassic) (Olsen, 1980) – Dark-greenish-gray to black, fine-grained, dense, hard basalt composed of calcic plagioclase and clinopyroxene. Locally contains small spherical to tubular gas-escape vesicles, some filled by zeolite minerals or calcite, typically above base of flow contact. Unit consists of three major flows that are separated in places by a weathered zone, a bed of thin reddish-brown siltstone, or by volcaniclastic rock. Lower part of upper flow is locally pillowed; upper part has pahoehoe flow structures. Middle flow is massive to columnar jointed. Lower flow is generally massive with widely spaced curvilinear joints and is pillowed near the top. Individual flow contacts are characterized by vesicular zones as much as 8 ft. thick. Thickness of unit is about 590 ft. Levels of natural radioactivity range from 5 to 9 (mean=6) Micro R/Hr. Unit is not exposed in the map area and is shown in cross section only.

JTrp **Passaic Formation** (Lower Jurassic and Upper Triassic) (Olsen, 1980) – Interbedded sequence of reddish-brown, and less commonly maroon or purple, fine- to coarse-grained sandstone, siltstone, shaly siltstone, and silty mudstone. Reddish-brown sandstone and siltstone are thin- to medium-bedded, planar to cross-bedded, micaceous, and locally mud cracked and ripple cross-laminated. Root casts and load casts are common. Shaly siltstone and silty mudstone are fine-grained, very-thin- to thin-bedded, planar to ripple cross-laminated, locally fissile, bioturbated, and contain evaporite minerals. Elsewhere they form rhythmically fining-upward sequences as much as 15 ft. thick. As much as 2 ft. of unit has been thermally metamorphosed along the contact with the Orange Mountain Basalt. Unit is not exposed in the map area and is shown in cross section only.

GREEN POND MOUNTAIN REGION

Sg **Green Pond Conglomerate** (Middle and Lower Silurian) (Rogers, 1836) – Medium- to coarse-grained, red 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 shale, siltstone, sandstone, chert, and (or) white-gray and pink milky quartz. Unit is not exposed in the map area. Thickness regionally is about 1,000 ft.

JUTLAND KLIPPE SEQUENCE

O€jt **Jutland klippe sequence undivided** (Middle Ordovician to Upper Cambrian?) (Perissoratis et al., 1979) – Gray-weathering, dark-gray phyllonitic shale containing thin, discontinuous siltstone lenses. Not exposed in the map area, but crops out to the immediate south along the Pequannock River at Riverdale and also along the Ramapo River near Oakland, and is known from water-well records and drill-hole data. Unit is in fault contact with Mesoproterozoic rocks on the west and Mesozoic rocks on the east. Thickness of unit is unknown. Levels of natural radioactivity range from 11 to 15 (mean=14) Micro R/Hr.

NEW JERSEY HIGHLANDS

Zd **Diabase dikes** (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, ilmenite and (or) magnetite. Pyrite blebs are common. Contacts are typically chilled and sharp against enclosing Mesoproterozoic rock. Dikes are as much as 40 ft. wide and a mile or more long.

Vernon Supersuite (Volkert and Drake, 1998)

Byram Intrusive Suite (Drake et al., 1991)

Ybh **Hornblende granite** (Mesoproterozoic) – Pinkish-gray or buff weathering, pinkish-white or light-pinkish-gray, medium- to coarse-grained, foliated granite composed of mesoperthite, microcline microperthite, quartz, oligoclase, and hornblende. Unit includes small bodies of pegmatite too small to be shown on map.

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

Ybs **Hornblende monzonite** (Mesoproterozoic) – Tan- to buff-weathering, pinkish-gray or greenish-gray, medium- to coarse-grained, gneissoid rock of syenitic to monzonitic composition. Composed of mesoperthite, microcline microperthite, oligoclase, hornblende, and magnetite.

Back-Arc Basin Metasedimentary Rocks

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

Yb **Biotite-quartz-feldspar gneiss** (Mesoproterozoic) – Pale pinkish-white weathering, pinkish-gray and gray weathering (Yb), locally rusty (Ybr), gray, tan, or greenish-gray medium-to coarse-grained, moderately layered and foliated gneiss containing microcline microperthite, oligoclase, quartz, biotite, garnet, and sillimanite. Graphite and pyrrhotite are confined to the variant that weathers rusty. This variant is commonly spatially associated with thin, moderately foliated to well-layered quartzite that contains biotite, feldspar, and graphite. Ybr locally mined for graphite.

Ymp **Clinopyroxene-quartz-feldspar gneiss** (Mesoproterozoic) – Pinkish-gray or pinkish-buff-weathering, white to pale-pinkish-white, medium-grained, massive, foliated gneiss composed of microcline, quartz, oligoclase, clinopyroxene, and trace amounts of titanite and opaque minerals. Commonly contains thin, conformable layers of amphibolite too thin to be shown on map.

Ypd **Diopsidite** (Mesoproterozoic) – Dark grayish-green-weathering, light- to medium-green, medium-grained, nearly monomineralic rock composed of clinopyroxene (diopside). Unit is typically thin and discontinuous over distances of a few hundred feet. Most often spatially associated with clinopyroxene-quartz-feldspar gneiss and pyroxene gneiss, although locally unit is layered with quartzite along Blue Mine Brook.

Yp **Pyroxene gneiss** (Mesoproterozoic) – White-weathering, greenish-gray, medium-grained, well-layered gneiss containing oligoclase, clinopyroxene, variable amounts of quartz, and trace amounts of opaque minerals and titanite. Some phases contain scapolite and calcite. Commonly spatially associated with diopsidite, amphibolite and marble.

Yq **Quartzite** (Mesoproterozoic) – Light gray-weathering, light-gray, vitreous, medium-grained,massive to well-layered rock composed predominantly of quartz and variable amounts of clinopyroxene. Contains locally abundant graphite and pyrrhotite north of Lake Ioscoe where it is host to a small graphite deposit. Unit is spatially associated with pyroxene gneiss, biotite-quartz-feldspar gneiss, and less commonly, with diopsidite and potassic feldspar gneiss.

Ymr **Marble** (Mesoproterozoic) – White-weathering, white, light-gray, or pale-pink, medium-grained, calcitic to locally dolomitic marble containing calcite, antigorite and (or) lizardite, phlogopite, and trace amounts of graphite and pyrrhotite. Unit is spatially associated with pyroxene gneiss, with which it commonly has a gradational contact, and quartzite.

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, moderately layered to foliated gneiss composed of oligoclase or andesine, quartz, and variable amounts of hornblende and (or) biotite. Locally contains layers of amphibolite too thin to be shown on map. Unit occurs as conformable layers as much as 8 ft. thick within bodies of diorite in the western part of quadrangle.

Ylb **Biotite-quartz-oligoclase gneiss** (Mesoproterozoic) – White or light-gray-weathering, medium-gray or light greenish-gray, medium- to coarse-grained, layered and foliated gneiss composed of oligoclase or andesine, quartz, biotite, and local garnet. Some outcrops contain hornblende. Locally contains thin layers of biotite-bearing amphibolite not shown on map.

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

Yd **Diorite** (Mesoproterozoic) – Light-gray or tan-weathering, greenish-gray or greenish-brown, medium- to coarse-grained, greasy lustered, massive, foliated rock containing andesine or oligoclase, clinopyroxene, hornblende, and hypersthene. Thin mafic layers having the composition of amphibolite are common.

Wanaque Suite (Volkert et al., 2010)

Ywt **Wanaque tonalite gneiss** (Mesoproterozoic) – White or light-gray-weathering, light-greenish-gray or greenish-gray, medium-grained, massive, foliated gneiss composed of oligoclase or andesine, quartz, clinopyroxene, hornblende, and hypersthene. Confined to a belt east of Wanaque Reservior

Other Rocks

Ya **Amphibolite** (Mesoproterozoic) – Gray to grayish-black, medium-grained gneiss composed of hornblende and andesine. Some phases contain biotite and (or) clinopyroxene. Amphibolite associated with the Losee Metamorphic Suite is metavolcanic in origin. Amphibolite associated with metasedimentary rocks may be metavolcanic or metasedimentary in origin. Both types are shown undifferentiated on the map.

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EXPANATION OF MAP SYMBOLS

Contact - Dotted where concealed. Dashed and queried where uncertain.

Fault - Dotted where concealed. Queried where uncertain.

D/U **Normal fault** - Bar and ball show dip of fault plane and arrow shows attitude of fault plane where known.

U/D **Reverse fault** - Bar and ball show dip of fault plane and arrow shows attitude of fault plane where known

Faults of indeterminate dip direction and attitude.

FOLDS

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 crystallization foliation

62 **Inclined**

Vertical

40 **Strike and dip of inclined beds**

LINEAR FEATURES

18 **Bearing and plunge of mineral lineation in Proterozoic rocks**

OTHER FEATURES

G **Active rock quarry**

R **Abandoned rock quarry**

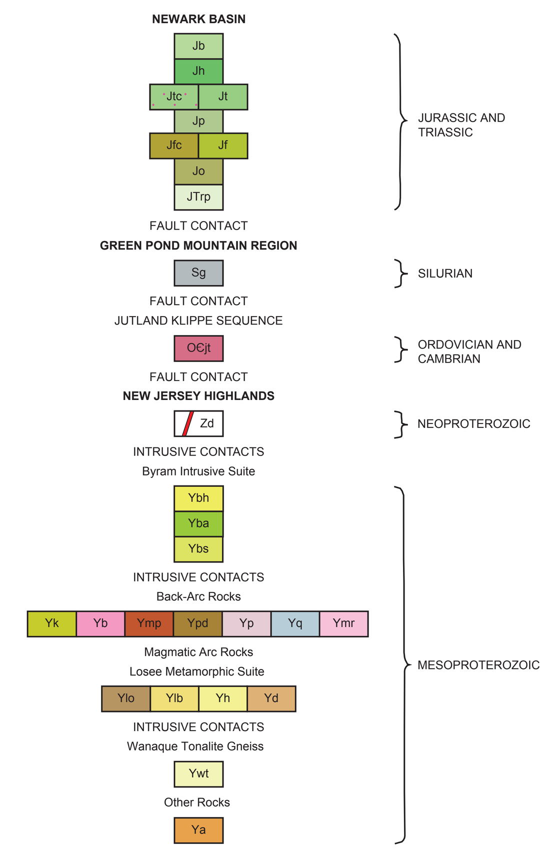
G **Abandoned graphite mine**

M **Abandoned magnetite mine**

Mi **Abandoned mica mine**

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

CORRELATION OF MAP UNITS



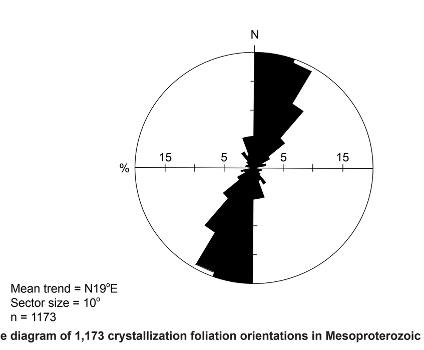


Figure 1. Rose diagram of 1,173 crystallization foliation orientations in Mesoproterozoic rocks.

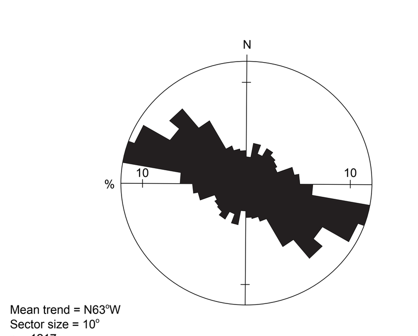


Figure 2. Rose diagram of 1,217 joint orientations in Mesoproterozoic rocks.

Table 1. Geochemical analyses of selected Mesoproterozoic and Neoproterozoic rocks from the Wanaque quadrangle

Sample	Ywt	Ywt	Ywt	Ywt	Ywt	Ylo	Ylo	Yh	Yd	Zd
(wt. %)										
SiO_2	64.79	64.41	63.60	65.30	64.90	68.03	64.92	67.03	60.40	49.34
TiO_2	0.50	0.50	0.61	0.44	0.45	0.38	0.49	0.48	0.74	3.45
Al_2O_3	16.42	16.87	15.30	16.10	16.30	14.99	16.02	15.76	16.80	12.56
Fe_2O_3*	4.53	4.64	7.25	4.54	4.17	3.46	4.58	4.01	6.80	14.94
MgO	1.90	1.87	1.69	1.95	1.76	1.31	1.81	1.92	2.88	4.44
MnO	0.06	0.06	0.09	0.07	0.07	0.04	0.06	0.05	0.10	0.22
CaO	4.69	4.82	4.77	4.75	4.72	3.53	4.45	4.51	5.96	7.87
Na_2O	4.30	4.16	4.21	4.44	4.51	3.73	3.96	4.22	4.28	2.86
K_2O	1.39	1.26	0.83	1.51	1.46	2.17	1.76	1.68	1.08	1.22
P_2O_5	0.19	0.18	0.19	0.18	0.18	0.13	0.19	0.18	0.40	0.56
LOI	0.39	0.26	0.42	0.15	0.35	0.69	0.30	0.42	0.06	1.67
Total	99.16	99.03	98.96	99.43	98.87	98.46	98.54	100.26	99.50	99.33
(ppm)										
Rb	31	35	32	--	--	59	39	32	20	18
Ba	397	302	218	--	--	553	345	277	480	438
Sr	616	640	474	--	--	381	545	608	770	300
Th	0.29	0.55	0.45	--	--	0.32	2.69	1.41	0.2	2.10
Ta	0.25	0.17	0.23	--	--	0.09	0.25	0.24	--	1.80
Hf	2.60	3.20	3.90	--	--	3.10	4.00	2.70	--	6.40
Nb	4.90	3.40	4.60	--	--	4.60	4.30	4.60	30	26
Y	11	9.20	23	--	--	13	11	10	20	42
Zr	115	137	176	110	110	119	173	116	180	304
Co	12	13	14	--	--	9.00	15	10	3.80	40
Cr	50	20	50	--	--	20	20	20	40	20
Sc	9.00	9.00	16	--	--	11	9.00	10	1.10	31
V	73	74	106	--	--	49	74	75	19	393
La	21.40	13.90	16.80	--	--	22.20	17.50	28.70	32.30	26.10
Ce	45.60	29.40	36.60	--	--	43	37.80	59.30	66.10	59.60
Nd	22.60	16.70	21.40	--	--	22.20	20.70	27.70	37.80	37.50
Sm	3.82	3.29	5.04	--	--	4.31	3.80	4.53	6.70	9.04
Eu	1.07	0.88	1.18	--	--	1.09	1.01	1.25	1.94	3.25
Tb	0.39	0.36	0.70	--	--	0.46	0.41	0.38	0.75	1.45
Yb	0.95	0.86	2.19	--	--	1.11	1.04	0.77	1.60	3.78
Lu	0.14	0.13	0.34	--	--	0.16	0.16	0.12	0.24	0.57

* Total Fe as Fe_2O_3
--, not determined
Sample: Ywt, Wanaque tonalite gneiss; Ylo, quartz-oligoclase gneiss; Yh, hypersthene-quartz-oligoclase gneiss; Yd, diorite gneiss; Zd, diabase dike
Analyses by Activation Laboratories, Ontario, Canada.