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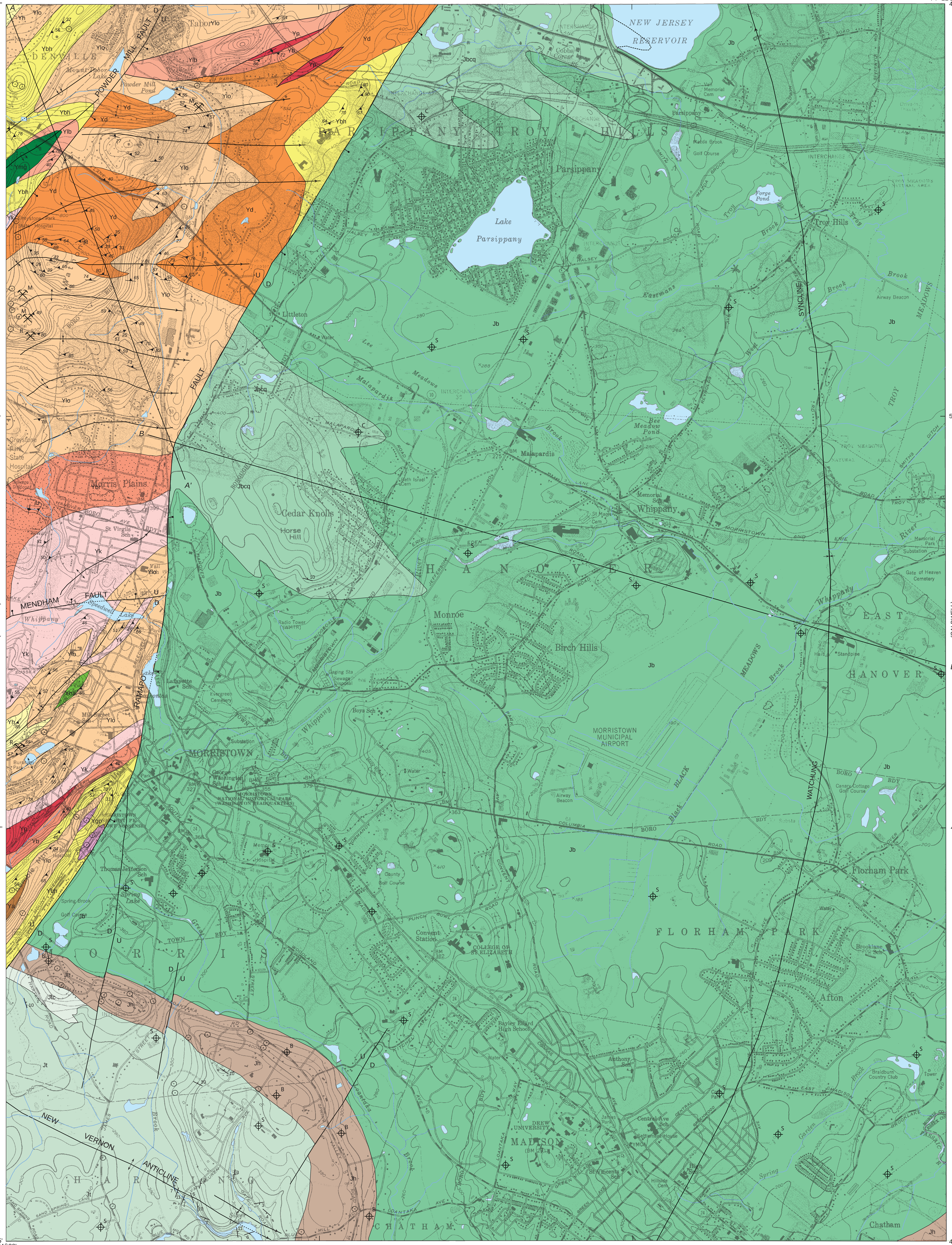
BEDROCK GEOLOGIC MAP OF THE MORRISTOWN QUADRANGLE
ESSEX AND MORRIS COUNTIES, NEW JERSEY
OPEN FILE MAP OFM 98



Base map from U.S. Geological Survey, 1954. Photorevised 1981

SCALE 1:24 000

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

Bedrock geology mapped by R.A. Volkert in 1986, 1998 and 2011
Digital cartography by M.W. Girard
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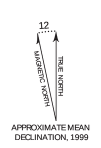
BEDROCK GEOLOGIC MAP OF THE MORRISTOWN QUADRANGLE
ESSEX AND MORRIS COUNTIES, NEW JERSEY

by

Richard A. Volkert

2013



INTRODUCTION

The Morristown quadrangle is located in north-central New Jersey, in a mixed commercial, industrial and residential setting. The quadrangle is mainly in the Whippany River Watershed and this stream flows eastward as it drains the central part of the area. The southeast part of the map area is drained by the south-flowing Passaic River. The north and east parts of the area include Lee Meadows, Black Meadows and Troy Meadows. These natural wetlands are underlain by the Boonton Formation of Mesozoic age and are capped by sediments of Quaternary and Recent age (Stanford, 2006).

The quadrangle straddles the boundary between the New Jersey Highlands and the Piedmont Provinces but is predominantly in the latter. Bedrock of Mesoproterozoic age in the Highlands underlies the northwest part of the area, and the rest is underlain by Mesozoic-age rocks in the Piedmont. The Ramapo fault is a structural and physiographic boundary between the two provinces.

The bedrock geology of the Morristown quadrangle has been studied for more than a century (e.g., Lewis and Kummel, 1910; Bayley et al., 1914; Lyttle and Epstein, 1987; Volkert, 1988; and Drake et al., 1996). However, detailed mapping was not performed previously, and bedrock lithologies and structures lack continuity with the recent mapping of adjacent quadrangles. Therefore, the interpretations presented here supercede those shown on previous bedrock geologic maps of the area.

STRATIGRAPHY
Mesozoic Rocks

The youngest bedrock in the quadrangle is Mesozoic in age and was deposited in the Newark basin that contains approximately 24,600 ft. of interbedded Upper Triassic to Lower Jurassic sedimentary and igneous rocks. Only the uppermost part of the stratigraphic succession is exposed in the map area. Sedimentary rocks of the Towaco and Boonton Formations underlie most of the Piedmont part of the area, but they crop out only sparsely because they are covered by widespread sediments of Quaternary to Recent age. Igneous rocks of the Hook Mountain Basalt support the minor relief in the southwest part of the map.

Mesoproterozoic Rocks

The oldest rocks are Mesoproterozoic in age. They include various granites and gneisses metamorphosed to granulite facies at about 1050 Ma, during the Ottawan phase of the Grenville orogeny (Volkert, 2004). Temperature estimates for this high-grade metamorphism are about 769°C from calcite-graphite thermometry (Peck et al., 2006).

Among the oldest Mesoproterozoic rocks are the Losee Suite, interpreted as a sequence of metamorphosed volcanic and plutonic rocks of calc-alkaline composition formed in a magmatic arc (Volkert, 2004). The Losee Suite includes quartz-oligoclase gneiss, biotite-quartz-oligoclase gneiss and hypersthene-quartz-plagioclase gneiss, and diorite gneiss. These rocks are spatially associated with a sequence of supracrustal rocks formed in a back-arc basin inboard of the Losee magmatic arc (Volkert, 2004). Supracrustal rocks include potassic feldspar gneiss, biotite-quartz-feldspar gneiss and pyroxene gneiss. Amphibolite is spatially associated with the Losee Suite and supracrustal rocks. Losee Suite and supracrustal rocks yield similar sensitive high-resolution ion microprobe (SHRIMP) U-Pb igneous crystallization ages of 1299 to 1248 Ma (Volkert et al., 2010).

Granitic rocks are widely distributed in the map area and they consist of hornblende granite of the Byram Intrusive Suite and microantiperthite granite of unknown age and affinity. Elsewhere in the Highlands, hornblende granite yields SHRIMP U-Pb igneous crystallization ages of 1184 to 1182 Ma (Volkert et al., 2010).

The youngest Mesoproterozoic rocks are small, irregular bodies of granite pegmatite that are undeformed and have discordantly intruded most other Mesoproterozoic rocks. Pegmatites regionally yield U-Pb igneous crystallization ages of 1004 to 987 Ma (Volkert et al., 2005).

STRUCTURE
Mesozoic bedding

Bedding in the Mesozoic rocks is somewhat varied and affected by two large, regional fold structures, the Watchung syncline and the New Vernon anticline. Beds dip mainly north, but in the southern part of the map they dip north and south, defining the limbs of the anticline, and in the axis of this fold they dip east. Bedding in the quadrangle displays two distinct trends. The dominant one strikes about N.80°W. and dips northeast, whereas the subordinate one strikes about N.05°E. and dips southeast. All beds range in dip from 3° to 21° and average 8°.

Proterozoic foliation

Crystallization foliation (the parallel alignment of mineral grains) in Mesoproterozoic rocks is an inherited feature from compressional stresses that deformed the rocks during high-grade metamorphism. Foliation is fairly uniform and strikes east to northeast at an average of N.61°E. (fig. 1). The dip of all foliation is southeast and, less commonly, northwest at 20° to 90° and averages 59°.

Folds

Mesozoic rocks are deformed into the Watchung syncline, a broad, upright, north-plunging fold that is cored by the Boonton Formation. Its location and axial trend in the quadrangle are inferred because the Boonton Formation is covered by surficial deposits. The New Vernon anticline, in the southwest part of the map, is an upright open fold that plunges southeast. Beds on either limb dip gently at 3° to 11°. This fold is cored by the Towaco Formation; Hook Mountain Basalt forms the limbs.

Folds that deform Mesoproterozoic rocks were formed during the Grenville orogeny. The folds deform earlier-formed planar metamorphic fabrics, so they postdate the development of crystallization foliation. Characteristic fold styles include northeast to east-plunging antiforms and synforms that are northwest-overturned to upright. These folds very locally have been refolded by southeast-plunging, open, broad, upright antiforms and synforms that are well exposed in the Mendham quadrangle, to the west, but display limited expression in the map area. The plunge of mineral lineations in all folds averages 28° to N.76°E., parallel to the axes of major regional folds, and to the axes of minor folds in outcrop.

Faults

The Ramapo fault is a dominant structural feature that extends from the Gladstone quadrangle northeast into New York State (Drake et al., 1996). The fault has a complex and protracted history of movement that began during the Proterozoic. Multiple episodes of subsequent reactivation have left overprinting brittle and ductile fabrics that record kinematic indicators consistent with normal, reverse, and strike-slip movement. Mesoproterozoic rocks are preserved on the footwall of the fault and Mesozoic sedimentary and igneous rocks on the hanging wall. The fault strikes due north to N.40°E. and dips 50° southeast, as indicated by borings drilled in the Bernardsville quadrangle (Ratcliffe et al., 1990) and borings for Route 287 in the Pompton Plains quadrangle (Woodward Clyde Consultants, 1983). However, outcrops of ductily deformed Mesoproterozoic rocks, especially to the north in the Pompton Plains and Ramsey quadrangles, record mylonitic foliations of probable Proterozoic and Paleozoic age that dip steeply southeast at 60° to 85°.

A north-trending, steeply-dipping fault that may be a splay of the Ramapo fault cuts the Boonton Formation, Hook Mountain Basalt and Towaco Formation in the southwest part of the map. It and other faults are characterized by brittle deformation fabric, and they appear to be of limited strike length and displacement.

The Powder Mill fault, named for its good exposure in the Powder Mill area of the map, extends from the Chester quadrangle northeast to the Boonton quadrangle, where it borders the east side of the Rockaway Valley. Mesoproterozoic rocks are present on both sides of the fault along its entire length. The fault strikes N.40°E. and dips about 60° southeast. It records dip-slip reverse movement sense, and it is characterized by brittle deformation fabric that includes retrogression of mafic mineral phases, chlorite or epidote-coated fractures or slickensides, and (or) close-spaced fracture cleavage.

The Mendham fault extends through the west part of the map area where it contains Mesoproterozoic rocks on both sides. This fault was named the Flemington fault by Volkert et al. (1990) and correlated to a Mesozoic border-fault segment, but it is here reinterpreted as an older fault that is cut by Mesozoic faults. To the east, the Mendham fault is cut off by the Ramapo fault, and to the southwest it merges with, or becomes, the Tewksbury fault in the Califon quadrangle. The Mendham fault strikes east-northeast and dips about 40° toward the north. It records reverse movement sense and is characterized mainly by brittle deformation fabric that overprints an earlier ductile deformation fabric.

Mesoproterozoic rocks are also deformed by small northeast or northwest-trending faults, most of which are limited to single outcrops. These faults are typically no more than a few feet wide and are characterized by brittle deformation fabric.

Joints

Joints are a dominant structural feature in all rocks in the quadrangle. Those in Mesozoic sedimentary rocks are characteristically planar, moderately well formed, and unmineralized, except near faults. Surfaces are smooth and, less commonly, irregular. Joints in sandstone are better developed than in siltstone and shale. Joints are spaced from 1 foot to several feet apart, except near faults where they are <1 foot apart. Two dominant joint sets are present in the sedimentary rocks that strike at an average of N.65°E. and N.39° W. Northeast-striking joints dip mainly northwest and northwest-striking joints dip mainly southwest. The dip of all joints averages 83°.

Joints in Mesozoic igneous rocks are of two types, columnar (cooling) and tectonic. Columnar joints are present in all basalt formations in the area. They are characteristically polygonal, arrayed radially and varied in height and spacing. A comprehensive study of the origin and orientation of cooling joints in the basalts was undertaken by Faust (1978). Tectonic joints are present in all basalt formations, but they are commonly obscured by the more pervasive cooling joints. Tectonic joints are planar, moderately to well formed, smooth to slightly irregular, steeply dipping, unmineralized, and are spaced from a few feet to tens of feet apart. In outcrops near faults, spacing is 1 foot or less apart and surfaces are locally mineralized by calcite and (or) chlorite.

The dominant joint orientation in Mesoproterozoic rocks is nearly perpendicular to the strike of crystallization foliation, and this relationship is a consistent feature observed throughout the Highlands (Volkert, 1996). Joints are characteristically planar, moderately well formed, moderately to widely spaced, and moderately to steeply dipping. Surfaces are smooth, and less commonly, slightly irregular. They are typically unmineralized except near faults where they are coated by chlorite and (or) epidote. Joints are variably spaced from 1 foot to tens of feet apart. Those developed in massive rocks such as granite are more widely spaced, irregularly formed and more discontinuous than joints in layered gneisses. Joints formed near faults are spaced 2 feet or less apart. The dominant joint set averages N.35°W. (fig. 2) and dips nearly equally to the northeast and southwest. A subordinate set strikes about N.50°E. and dips mainly northwest. The average dip of all joints is 75°.

ECONOMIC RESOURCES

Mesoproterozoic rocks were quarried for dimension stone and aggregate north of Morris Plains, and also north of Kemble Mountain. Small, unnamed mine workings that were exploratory prospects for iron ore (magnetite) are visable southeast of Powder Mill Pond, and at two places south of Watnong Mountain. They are not shown on historic maps of the area, nor are they described in the historic literature, so information about them is unavailable.

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 in the individual map unit descriptions. In general, basalts yield consistently low readings of about 6 Micro R/Hr regardless of stratigraphic position, texture, or composition. Sedimentary units yield higher, more varied readings that range from 9 to 21 Micro R/Hr and appear to be related mainly to grain size. Values recorded from sandstone and pebbly sandstone are lower than those in siltstone and shale, suggesting that clay minerals may be the hosts for radiogenic mineral phases.

DESCRIPTION OF MAP UNITS
NEWARK BASIN

Jb
Jbcq

Boonton Formation (Lower Jurassic) (Olsen, 1980) – Reddish-brown to brownish-purple, fine-grained, commonly micaceous sandstone, siltstone, and mudstone (Jb), 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 (Jbcq) that contains subangular to subrounded pebble-to-boulder clasts of Mesoproterozoic rocks and less abundant Paleozoic quartzite, shale, and dolomite, and Jurassic basalt in a matrix of coarse brown sand interfinger with the upper part of unit along the Ramapo fault. Maximum thickness 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 and conglomeratic sandstone.

Jh

Hook Mountain Basalt (Lower Jurassic) (Olsen, 1980) – Dark greenish-gray to black, fine-grained, amygdaloidal basalt composed of plagioclase, clinopyroxene, and iron-titanium oxides. Contains small spherical to tubular gas-escape vesicles above flow contacts, some of which are filled by zeolite minerals or calcite. Elsewhere unit contains dark-gray, coarse-grained gabbroid composed of clinopyroxene and plagioclase grains as much as 0.5 in. long at several stratigraphic intervals but 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 three major flows. Base of lowest flow is intensely vesicular. Tops of flows are weathered and vesicular. Maximum thickness regionally is 360 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 ft. of unit have been thermally metamorphosed along the contact with Hook Mountain Basalt. Conglomerate and conglomeratic sandstone (Jtc) that contains subrounded clasts of quartzite and quartz in matrix of buff or tan, sand to silt interfinger with the unit along the Ramapo fault. Maximum thickness 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 and conglomeratic sandstone.

Jp

Preakness Basalt (Lower Jurassic) (Olsen, 1980) – Dark greenish-gray to black, fine-grained basalt composed of plagioclase, clinopyroxene, and iron-titanium oxides. Contains small spherical tubular gas-escape vesicles above scoriaceous flow contacts, some of which are filled by zeolite minerals or calcite. 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 occurs at several stratigraphic intervals 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 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. A bed of reddish-brown siltstone 6 to 25 ft. thick separates the lower flows. Maximum thickness is about 1,040 ft. Levels of natural radioactivity range from 3 to 8 (mean=6) Micro R/Hr. Unit is not exposed in the map area and is shown in cross section only.

NEW JERSEY HIGHLANDS

Ygp

Granite pegmatite (Mesoproterozoic) – Pinkish-gray or buff-weathering, pinkish-white or light-pinkish-gray, very coarse-grained, massive, unfoliated granite composed of microcline microperthite, quartz, oligoclase, and hornblende. Commonly spatially associated with hornblende granite, but intrudes most Mesoproterozoic rocks in the map area.

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. Locally contains zircon, apatite, and magnetite.

Back Arc Supracrustal Rocks

Yk

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

Yb
Ybr

Biotite-quartz-feldspar gneiss (Mesoproterozoic) – Pale pinkish-white, pinkish-gray or gray-weathering (Yb), locally rusty (Ybr), pinkish-gray, tan, or greenish-gray, medium-grained, 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 pyroxene gneiss and (or) quartzite that contains biotite, feldspar, and graphite.

Yp

Pyroxene gneiss (Mesoproterozoic) – Light-gray or white-weathering, greenish-gray, medium-grained, layered and foliated gneiss containing oligoclase, clinopyroxene, and local quartz, titanite, magnetite, and scapolite. Spatially associated with pyroxene amphibolite and biotite-quartz-feldzpar gneiss.

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 and foliated gneiss composed of oligoclase or andesine, quartz, and variable amounts of hornblende, clinopyroxene and biotite. Commonly contains thin, conformable layers of amphibolite too thin to be shown on the map.

Ylb

Biotite-quartz-oligoclase gneiss (Mesoproterozoic) - White or light-gray-weathering, medium-gray or greenish-gray, medium- to coarse-grained, layered and foliated gneiss composed of oligoclase or andesine, quartz, biotite, and local garnet. Some outcrops also contain hornblende. Unit grades into quartz-olioclase gneiss with decrease in biotite.

Yh

Hypersthene-quartz-plagioclase gneiss (Mesoproterozoic) - Gray or tan-weathering, greenish-gray or brownish-gray, medium-grained, foliated gneiss composed of andesine or oligoclase, quartz, clinopyroxene, hornblende, and hypersthene. Commonly contains conformable layers of amphibolite and mafic quartz-plagioclase gneiss.

Yd

Diorite Gneiss (Mesoproterozoic) – Light-gray or tan-weathering, greenish-gray or brownish-gray, medium-grained, massive, foliated rock containing andesine or oligoclase, clinopyroxene, hornblende, and hypersthene. Locally contains thin layers having the composition of amphibolite.

Other Rocks

Ymg

Microantiperthite granite (Mesoproterozoic) – Tan or buff-weathering, light-greenish-gray, medium- to coarse-grained, massive, foliated granite composed of microantiperthite to microperthite, quartz that is locally brown rust-stained, oligoclase, and hornblende. Locally contains minor amounts of biotite, altered clinopyroxene, and magnetite. Relationship of unit to intrusive rocks of the Vernon Supersuite is unknown.

Ya

Amphibolite (Mesoproterozoic) - Gray or grayish-black, medium-grained, foliated gneiss composed of hornblende and andesine. Some variants contain biotite and (or) clinopyroxene. Amphibolite associated with the Losee 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.

REFERENCES CITED AND USED IN CONSTRUCTION OF MAP

Bayley, W.S., Salisbury, R.D., and Kümmel, H.B., 1914, Description of the Raritan quadrangle, New Jersey: U.S. Geological Survey Geologic Atlas Folio 191, 32 p.

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., Aleinikoff, J.N., and Volkert, R.A., 1991, The Byram Intrusive Suite of the Reading Prong-Age and tectonic environment, *in* Drake, A.A., Jr., ed., Contributions to New Jersey Geology: U.S. Geological Survey Bulletin 1952, p. D1-D14.

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.

Faust, G.T., 1978, Joint systems in the Watchung basalt flows, New Jersey: U.S. Geological Survey Professional Paper 864-B, 46 p.

Lewis, J.V., and Kümmel, H.B., 1910, Geologic map of New Jersey: New Jersey Department of Conservation and Economic Development, Atlas Sheet 40, scale 1:250,000.

Lyttle, P.T., and Epstein, J.B., 1987, Geologic map and cross sections of the Newark 1° x 2° quadrangle, New Jersey, Pennsylvania, and New York: U.S. Geological Survey Miscellaneous Investigations Series Map I-1715, scale 1:250,000.

Olsen, P.E., 1980, The Latest Triassic and Early Jurassic formations of the Newark Basin (Eastern North America Newark Supergroup): Stratigraphy, structure and correlation: New Jersey Academy of Science Bulletin, v. 25, no. 2, p. 25-51.

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.

Ratcliffe, N.M., Burton, W.C., and Pavich, M.J., 1990, Orientation, movement history, and cataclastic rocks of Ramapo fault based on core drilling and trenching along the western margin of the Newark basin near Bernardsville, New Jersey: U.S. Geological Survey Miscellaneous Investigations Series Map I-1982, 1 sheet, no scale.

Stanford, S.D., 2006, Surficial geology of the Morristown quadrangle, Essex and Morris Counties, New Jersey: New Jersey Geological Survey Open-File Map OFM-67, scale 1:24,000.

Volkert, R.A., 1988, Provisional geologic map of the Proterozoic rocks of the Morristown quadrangle, New Jersey: New Jersey Geological Survey Geologic Map Series GMS 88-4, scale 1:24,000.

________, 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.

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 1565C, 77 p.

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

Woodward Clyde Consultants, 1983, Logs of borings from the Ramapo fault. On file in the office of the New Jersey Geological Survey, Trenton, New Jersey.

EXPLANATION OF MAP SYMBOLS

Contact - Dotted where concealed

Fault - Dotted where concealed. Bar and ball show dip of fault plane.

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

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

FOLDS

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

Syncline

Anticline

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

Synform

Antiform

Overturned synform

Overturned antiform

PLANAR FEATURES

50 Strike and dip of inclined beds

Strike and dip of crystallization foliation

50 Inclined

Vertical

50 Strike and dip of mylonitic foliation

LINEAR FEATURES

20 Bearing and plunge of mineral lineation in Mesoproterozoic rocks

OTHER FEATURES

R Abandoned rock quarry

M Abandoned magnetite mine

Bedrock float used to construct map

Boring - Rock type at bottom: B, basalt; S, sandstone, siltstone, shale; C, conglomerate. Data from Stanford (2006).

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

CORRELATION OF MAP UNITS

NEWARK BASIN

Jbcq, Jb
Jh
Jtc, Jt
Jp

JURASSIC

Unconformity

NEW JERSEY HIGHLANDS

Ygp

Intrusive Contact

Vernon Supersuite
Byram Intrusive Suite

Ybh, Yba

Intrusive Contacts

Back Arc Supracrustal Rocks

Yk, Yb, Ybr, Yp

Magmatic Arc Rocks
Losee Metamorphic Suite

Ylo, Ylb, Yh, Yd

Other Rocks

Ymg
Ya

MESOPROTEROZOIC

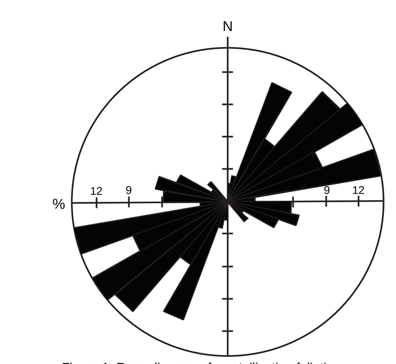


Figure 1. Rose diagram of crystallization foliation orientations in Mesoproterozoic rocks.
Sector size = 10°
n = 119

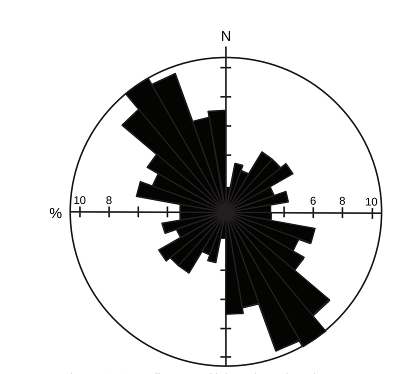


Figure 2. Rose diagram of joint orientations in Mesoproterozoic rocks.
Sector size = 10°
n = 225