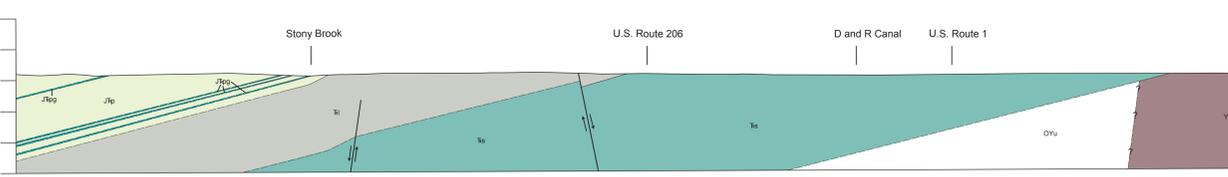


Bedrock Geologic Map of the Princeton Quadrangle,
Mercer and Middlesex Counties, New Jersey

By
Donald H. Monteverde, Gregory C. Herman, Richard A. Volkert and Scott D. Stanford
2012



Introduction

The Princeton 75-minute quadrangle is in west-central New Jersey, where it covers parts of Mercer and Middlesex Counties. Topographic elevations range from approximately 400 ft in the north to 80 ft in the south. The highest elevations are on Mount Rose, a prominent ridge of igneous diabase, commonly called trap rock, lying along the northern quadrangle boundary. Late Tertiary shale and mudstone that have been metamorphosed to hornfels surrounds the diabase and forms slightly lower elevations. Elevations remain fairly uniform with several small, broad hills in the northeastern third of the quadrangle where they block flow through sedimentary rock units. South of Princeton elevation drops slightly forming a broad flat landscape that is underlain by some less resistant sandstones. Crystalline metamorphic rocks create a slight positive landscape in the southwest corner of the quadrangle. Unfractured undeveloped the gentle landscape morphology on the southeastern third of the quadrangle up to 100 ft in elevation.

The Delaware and Raritan Canal is a prominent physical feature in the quadrangle. It runs northeast-southwest, close to, and approximately parallel to, US Route 1, a major northeast-southwest transportation corridor. The canal connects the Delaware and Raritan Rivers, and it facilitated commerce between Philadelphia and New York in the 1800's. It now serves as a local water supply source. The Route 1 corridor roughly separates areas of good to moderate bedrock exposures in the northeast from areas of less common and more deeply weathered exposures in the southwest. The Fall line separates bedrock of the Piedmont Province from the unconsolidated material of the Coastal Plain Province.

Stratigraphy

The Princeton quadrangle straddles the contacts between three primary bedrock groups. From the northeast to the southwest, these groups are: 1) Early Mesozoic sedimentary and igneous rocks of the Newark Basin; 2) Proterozoic and Paleozoic metamorphic crystalline rocks of the Trenton Group; and 3) Upper Cretaceous nonmetamorphosed to unconsolidated bedrock of the Coastal Plain. Rocks of the Newark Basin unconformably overlie the Trenton rocks which form the geologic basement for all the younger materials in the study area. Coastal Plain deposits also unconformably overlie Trenton Group units in the Princeton quadrangle. Outside the study area Trenton Plan units completely blanket the Trenton through Pleistocene rocks of the Newark Basin.

Early Mesozoic rocks include sedimentary and igneous varieties that were deposited in the Newark Basin, a regional half graben, fault bounded on its northern boundary, that extended from eastern Pennsylvania through New Jersey and into southeastern New York. The basin was filled with an estimated 20,000 feet of Late Triassic through Early Jurassic rocks. Fluvial systems developed between border basins and deposited Proterozoic and Paleozoic sediments into the basin from the Highlands to the north and west. Additional sediment came from the Trenton Group metamorphic rocks in the south through both draining rivers and streams (Gleason, Van Hooker, 1969). Extrusive lavas with associated deposits developed in the basin throughout much of its depositional history.

Sedimentary rocks of the Newark Basin include fluvial and lacustrine deposits that are locally interbedded with diabase and interbedded with basic rocks that are approximately 200 m in age (Molnar and others, 2003). The basal sedimentary unit in the Newark Basin is the Stockton Formation, a basal conglomerate and sandstone with red, light brown, gray and white interbeds. Conglomerate is more common near its base and the basin margins whereas sandstone, siltstone and mudstone are more common in the upper half of the unit and in areas away from the basin margins (McLaughlin, 1945; Gleason, 1969; Smoot, 1991) and Smoot and Olsen (1994) suggest that the Stockton was deposited by high-gradient, braided streams that cut down through a residual surface marked by gravel and colluvium, leaving toward the basin center eventually reduced cross gradients and resulted in deposition of an overall, fine-grained, fluvial sequence. The uppermost units gradually grade into typical lacustrine beds of the Lockington Formation. The Lockington is mostly gray and black siltstone and argillite and locally interbedded shale and sandstone. Smoot (1991) described the Lockington as a cyclic depositional deposit that alternates between glacial and interglacial and subglacial deposits with little to no associated fluvial facies. The Passaic Formation overlies the Lockington. The Passaic is a thick sequence of red-brown and red-brown mudstone, siltstone and sandstone, and lesser cycles of gray and black siltstone and rare sandstone. Its coarser grain size, marginal alluvial facies, and broader lateral extent compared to the Lockington, suggest a broadening of the basin through time (Smoot, 1991).

Cyclic color variations in beds of the Lockington and Passaic formations indicate deposition during alternating, wet and dry, climatic periods (Olsen and Kent, 1996; Olsen and others, 1999). Wet, deep lakes developed in the basin during wetter periods when the gray and black units of the deeper water environments were deposited. Red and brown units correlate to drier climatic periods when shallow lakes and seasonal wetlands deposited. Outcrops of the Lockington formation in the Princeton quadrangle are too low to enable mapping of individual beds or color sequences like those defined by Olsen and others (1996). In the Passaic Formation more numerous outcrops make such subdivision possible. Here gray-bed sequences have been mapped where possible within the red and brown beds. These thin, gray to black sandstone beds distinctive marker horizons that may be mappable for miles along strike. These beds help depict bed patterns. A sequence of these gray beds in the northeast corner of the quadrangle are thought to correlate with part of the Passaic member of the Passaic Formation, based on comparison of mapped units with the subsurface core results of Olsen and others (1996), and on unpublished, detailed bedrock mapping of units in the adjacent Pennington quadrangle to the west.

The northern edge of the Princeton quadrangle consists of a large diabase body intruded into Triassic sedimentary rocks. It forms an east-west ridge that includes Mount Rose and Rocky Hill farther to the east. The highest part of the body forms a dike which has been inspected subparallel to bedding. Along strike to the west, the diabase thin, crumpled, and cuts across bedding to form a dike. Much of it is disintegrated into fragments. The diabase is composed of hornfels and metamorphosed sedimentary rocks (hornfels) surround the diabase intrusion. A typical bedded sequence of gray, unaltered Passaic Formation rocks from more resistant hornfels and diabase at higher elevations. During and Houghton (1990) and Houch (1990) proposed that the Mount Rose - Rocky Hill diabase body is a lateral continuation of the Palisades.

The Trenton Group in the Princeton area is part of a larger metamorphic rock belt that plunges northwesterly from Pennsylvania into New Jersey, where it pinches out at the surface directly to the east, in the bordering Highlands 75-minute quadrangle. Trenton Group rocks include felsic, intermediate and mafic metamorphic varieties of probable Ordovician, Mesoproterozoic, and Neoproterozoic ages (Volkert and Drake, 1993). The Washington is dated at 480 Ma based on U-Pb zirconochronology (Boettcher and others, 2001). Fine-grained diabase dikes locally intrude the other metamorphic rocks. These dikes are similar in composition and petrology to diabase dikes in the New Jersey Highlands. They may have been emplaced during rifting and breakup of the Rodinia supercontinent about 600 Ma (Volkert and Puffer, 1992; Volkert, 2004). Washington is dated at 480 Ma and is a limited number of natural outcrops and elevated exposures facilitated delineation of its contact with other rocks of the Trenton Group.

Erosion of rocks of the Newark Basin and Trenton Group since the Cretaceous has supplied sediment to the Atlantic Coastal Plain. These sediments include the Potomac Formation and the overlying Magyly Formation. The Potomac Formation consists of interbedded sand and siltstone in a coastal near system in the Late Cretaceous, about 60 Ma. The Potomac sand and siltstone are typically red and white in color, due to weathering and soil development on the river plains in which they were deposited. The Magyly Formation also consists of interbedded sand, silt, and clay, although its sand is generally finer than that of the Potomac, and its clay and silt are more shaly than those of the Potomac. The Magyly is more commonly gray because it was not exposed to weathering and soil development. It was laid down in nearshore marine settings in the Late Cretaceous, about 60 Ma. Additional marine deposits were laid down during numerous sea level highstands through the Cretaceous and Tertiary periods, probably until the Middle Miocene (about 10 Ma). These deposits almost entirely covered the entire Princeton quadrangle and extended well to the north and west of the present Coastal Plain. Subsequently they were completely eroded by rivers, except for the remaining Magyly and Potomac sediments, during the late Miocene and Pliocene (10 to 2 Ma).

Surficial deposits, shown here by an overspread pattern where thicker than 10 feet, include alluvial, wetland, hillside, and wind-blown sediments of Pliocene through Quaternary age (Stanford, 1993).

Structure

In the Trenton Group, the Huntington Valley Fault is a major thrust fault interpreted to be of Paleozoic age. It strikes southwest-northeast and separates the Ordovician Washington Formation in the hanging wall from Mesoproterozoic and Neoproterozoic (?) rocks in the footwall. The footwall rocks are in a secondary thrust-fault site that plays off the Huntington fault to the east. The Huntington Valley Fault plunges eastward beneath rocks of the Newark Basin and is interpreted to correlate with the Cameron's Line thrust fault in the Manhattan Group (Volkert and others, 1996).

Rocks in the Newark Basin have been tilted, fractured, folded, and faulted (Schlichte, 1992; Olsen and others, 1996). Most tectonic deformation is probably Late Triassic to Middle Jurassic age (Lucas and others, 1986; de Boer and Cifelli, 1988). In the Princeton quadrangle, these rocks chiefly dip gently and uniformly to the north and northeast, except near faults where they dip moderately to steeply, or where they are locally folded into southeast-dipping beds. Faults within the Mesozoic rocks in the Princeton quadrangle are enigmatic. Abundant, complex fault movements are evident at stratigraphic levels in and near the Lockington Formation, but outcrops are sparse enough to obscure evidence as to whether these faults link with larger faults in adjacent areas that are covered with surficial material. Normal fault dip is seen in borehole-to-borehole images of the Lockington Formation north of Lawrenceville, but complex, reverse slip is documented at other nearby faults near Princeton, where the Stockton through Passaic formations are arched and locally faulted and folded. Herman and others (2010) interpreted these structures as part of a larger, regional oblique-slip transform-fault system that probably developed during late stages of basin extension. However, it is also possible that some of these faults were reactivated during late compression and inversion of the basin.

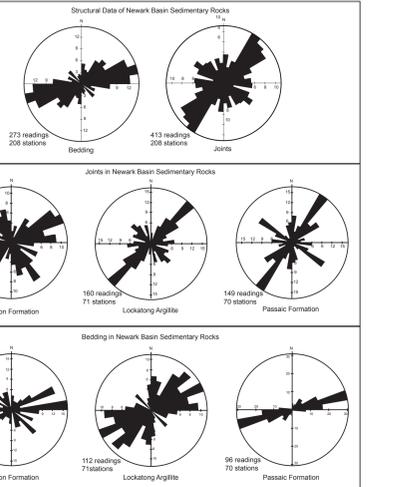
Rocks of the Trenton Group and Newark Basin are highly fractured. Three sets of systematic extensional fractures (joints) cut through the New Jersey part of the basin (Herman, 2005 and 2009). Together they record a counterclockwise rotation of the extensional stress field from northwest-southeast to west-southwest which developed during the extensional phases of basin development. The earliest of these part sets, striking northeast-southwest and complementary cross joints, are most abundant in the Princeton quadrangle. The latest set, striking north-south with complementary east-west cross joints is a less common.

DESCRIPTION OF MAP UNITS

- Surficial Deposits**
Quaternary and Pliocene/Undivided surficial sediments more than 10 feet thick.
- Coastal Plain**
Kmg Magyly Formation (Upper Cretaceous) - Quartz sand, fine-to-medium-grained, sparsely coarse-grained, and clay and silt, thin-bedded. Sand is white, yellow, light gray where weathered, gray where unweathered. Clay and silt are white, yellow, brown where weathered, gray to black where unweathered. Sand includes some lignite, pyrite, and minor mica. Clay and silt include abundant mica and lignite. As much as 35 feet thick. Late Cretaceous (Turonian-Cenomanian) in age, based on pollen (Christophel, 1979, 1982; Miller and others, 2004).
Kgs Potomac Formation (Upper Cretaceous) - Quartz sand, medium-grained to very coarse grained, sparsely fine-grained, and clay and silt, thick to thin bedded. Sand is white, yellow, red, brown, pink where weathered, light gray where unweathered. Clay and silt are white, red, yellow, brown, pink where weathered, gray where unweathered. Weathered clay and silt more abundant than in unweathered. As much as 150 feet thick. The Potomac Formation in the Princeton quadrangle is equivalent to the Potomac Formation Unit 3 (Doye and Roberts, 1977) based on pollen (Owens and others, 1993) and is of Late Cretaceous (early Cenomanian) age.
- Piedmont**
Jd Diabase (Lower Jurassic) - Fine-grained to very fine-grained dikes (?) and silt and medium-grained, discordant, sheet-like intrusion of dark gray to dark green-gray, sub-optic diabase, massive-textured, flat, and sparsely fractured. Composed dominantly of plagioclase, clinopyroxene, and opaque minerals. Contacts are typically fine-grained, display chilled, sharp margins adjacent to enclosing sedimentary rock. Underlies Mount Rose where it occurs as a sill that cuts across sections in the northwest of the quadrangle. Regional thickness of the diabase is approximately 1,325 feet.
Jp Passaic Formation - (Lower Jurassic and Upper Triassic) (Olsen, 1980a) - Interbedded sequence of reddish-brown to maroon and purple, fine-grained sandstone, siltstone, shaly siltstone, shaly mudstone and mudstone, separated by interbedded olive-gray, dark gray, and black siltstone, shaly mudstone, shale and lesser shaly argillite. Reddish-brown siltstone is medium to fine-grained, thin to medium bedded, planar to cross-bedded, micaceous, and locally contains mud cracks, ripple cross-lamination, root casts and leaf casts. Shaly siltstone, shaly mudstone, and mudstone from rhythmically-fingering upward sequences as much as 15 feet thick. They are fine-grained, very thin to thin-bedded, planar to ripple cross-laminated, locally blocky, and locally contain evaporite minerals. Gray bed sequences (Jp) are medium to fine-grained, thin to thick bedded, planar to cross-bedded siltstone and shaly mudstone. Clay to black mudstone, shale and argillite are laminated to thin-bedded, and commonly grade upward into desiccated purplish to reddish-brown siltstone and mudstone. Where possible gray bed sequences have been correlated based on downhole optical borehole data in Pennington to individual members designated by letters as described in Olsen and others, (1996). Thickness of gray bed sequences ranges from less than a foot to several feet. Unit is approximately 11,000 feet thick in the map area.
Jt Lockington Formation (Upper Triassic) (Kummel, 1987) - Cyclically deposited sequence of mainly gray to greenish-gray and upper part, locally reddish-brown siltstone to shaly argillite and dark gray to black shale and mudstone. Siltstone is medium to fine-grained, thin-bedded, planar to cross-bedded, with mud cracks, ripple cross-laminations and locally abundant pyrite. Shale and mudstone are very thin-bedded to thinly laminated, locally containing desiccation features. Lower contact gradational into Stockton Formation and placed at the base of somewhat black siltstone bed (Olsen, 1980a). Maximum thickness of unit generally is about 2,200 feet (Puffer and Houghton, 1990a, 1990b).
Js Stockton Formation (Upper Triassic) (Kummel, 1987) - Unit is interbedded sequence of gray, grayish-brown, or slightly reddish-brown, medium to fine-grained, thin to thick bedded, poorly sorted to clast-inclined conglomerate, planar to trough cross-bedded, and ripple cross-laminated across sandstone, and reddish-brown shaly fine-grained sandstone, siltstone and mudstone. Coarser units commonly occur as lenses and are locally graded. Fine-grained sequences are common, the fine-grained beds are thick-bedded. Conglomerate and sandstone layers are deeply weathered and more common in the lower half. Siltstone and mudstone are generally less weathered and more common in upper half. Lower contact is an erosional unconformity. Thickness is approximately 4,500 feet.
Jv Washington Formation (Lower to Middle Ordovician) (?) - Medium to coarse-grained, gray to pinkish-gray foliated and layered silt and green in alternating layers. Unit composed of quartz, plagioclase, microcline, and biotite. Has locally undergone partial melting, forming xenitic megacrysts of granitic composition. Unit does not crop out in the map area, but is known from artificial exposures and borings.
Jw Metabasalt (Neoproterozoic) (?) - Interbedded sequence of weakly metamorphosed granitoid and gneissic. Gneiss is a dark greenish-gray, crystalline, fine-grained rock composed essentially of plagioclase, altered clinopyroxene, and small amounts of orthopyroxene. Siltstone is fine to medium-grained, grayish-green, layered rock composed of quartz, plagioclase, and orthopyroxene. Locally contains garnet and thin conformable, sulfide-rich layers. Cut by veins of thin quartz. Unit does not crop out in the map area, but is known from artificial exposures and borings north of Central Mercer County Park.
Jx Gabbro and rocks of intermediate composition (Mesoproterozoic) (?) - Medium-grained, medium-gray to very dark greenish-gray, locally gray, layered, foliated rocks composed primarily of plagioclase (calcic to andesine), hornblende, clinopyroxene, and opaque oxides. Locally contain hypersthene, garnet, biotite, sulfides, and quartz. Typically contain thin, conformable layers of hornblende plagioclase amphibolite. Locally have been impacted and migmatized by thin, conformable layers of felsic magma composed of quartz and feldspar. Primary variscans of this unit are gabbro and/or orthopyroxene, biotite, orthopyroxene, and biotite and/or andesine.
Jy Gneiss, granitoid, and migmatite (Mesoproterozoic) (?) - Medium to coarse-grained, buff tan, light gray, greenish-gray, or pinkish white, foliated and/or layered gneiss, granitoid, and contact that include a wide variety of rock types, principally of felsic composition. Composed of quartz, microcline, plagioclase, clinopyroxene, hornblende, and biotite. Many rocks contain characteristic blue quartz. Some units are intruded by a medium- to coarse-grained gabbro of aaseitic composition. Unit represents a sequence of metaklastic and metasedimentary rocks impacted and migmatized by felsic magma.
Oyu Undivided metamorphic units (Ordovician to Proterozoic) - used only in cross section

EXPLANATION OF MAP SYMBOLS

- Contact - Dashed where approximately located; queried where uncertain; dotted where concealed.
Fault - Dashed where approximately located; queried where uncertain; dotted where concealed.
Normal fault - U, left-hand side; D, downthrown side; fall arrows show direction of dip.
Reverse fault - U, left-hand side; D, downthrown side; triangles show direction of dip.
Strike-slip fault, unknown sense relative motion.
High-angle fault of unknown motion.
Minor inclined fault observed in outcrop or with Downhole Optical Telescoper - showing strike and dip.
Folds
Syncline - showing trace of axial surface, direction of limbs, and direction of plunge.
Anticline - showing trace of axial surface, direction of limbs, and direction of plunge.
Planar features
Strike and dip of inclined beds.
Strike and dip of magnetic flow structure in igneous rocks.
Strike and dip of foliation in metamorphic rocks.
Other features
Bedrock-controlled strike ridge (from Stanford, 1993).
Abandoned rock quarry.
Location of Mercer County Park well.
Downhole Optical Telescoper interpretation. Marker beds identified in borehole projected to land surface based on dip of bedding in well. Data obtained by Optical Telescoper. Red dots show well location. Red boxes represent bed horizons within the otherwise gray-colored formation.



Rose diagrams of structural data within the map area. Data depicted consist of strike orientation of bedding and fracture planes. Bins are 10° sectors and numbers on X and Y axes represent percent of total data population. Trenton Group rocks are not shown due to paucity of outcrop locations.

Table 1. Lithologic log from the Mercer County Park Well, drilled in May 1987 by the New Jersey Geological Survey and logged in November 1987 by R.A. Volkert and S.D. Stanford.

Depth	Lithologic description
0-72	Surficial sand and gravel
72-138	Disconformable fine to medium-grained bottle-quartz-feldspar gneiss and possible trace garnet. Some seams composed of quartz and feldspar that appear to be local melt. Also decomposed bottle-quartz-feldspar gneiss. Contact with medium-grained, massive textured, intensely foliated, tan, chlorite-quartz-muscovite granitoid.
138-153	Mudstone, siltstone, massive-bedded, light gray weathering, greenish composition of hornblende, clinopyroxene, quartz, plagioclase, biotite, and trace sulfides. Quartz is reddish to medium blue. Zone of ductile deformation from 147-148 is overprinted by moderately-dipping to high-angle brittle fractures interbedded by quartz and plagioclase. Small offset along one fracture with normal movement sense.
153-169	Same as above. Also cut by high-angle fractures.
169-187	Same as above. Some variation in texture and mafic content. Foliation dips at moderate angle.
187-200	Same as above. Brittle deformation zone at 171 with abundant chlorite-coated fractures.
200-233	Same as above. Contains thin (1 cm), conformable layers of quartz and plagioclase. Some small mafic dikes of green clinopyroxene surrounded by rims of black amphibole at approximately 203.
233-234	Same as above. 216-217, below medium to coarse-grained, pinkish-white, north-trending coarse-grained hornblende siltstone containing blue quartz. Same gneiss from 222-224 but somewhat more succulent.
234-242	Same as above. 222, thin abrupt change to weathered, dark greenish-gray, argillite rock composed of plagioclase, orthopyroxene, trace sulfides. Appears to be a mafic dike (probably Neoproterozoic) intruding the basement sequence. Dike is coarse grained from 228 to end of run. Gneiss from 229-228 may be the chilled margin.
242-260	Same as above. Gneiss grades to 251 then fine-grained to 268 and argillite rock from 268-267, probably reflecting other chilled margin. Gabbro and/or biotite facies rocks located by Olsen.
260-270	Fall contact at 260 between argillite above and gneiss below. Gneiss is finely bedded from 260-261 and much less well bedded from 261-270. Gneiss is medium-grained, foliated, light greenish-gray, and composed of hornblende, clinopyroxene, quartz, plagioclase, and biotite. Foliation dips 60° to 45°.

REFERENCES CITED

Boettcher, H., Singh, L., Aherkar, J.N., Plank, M.O., Schenck, W.S., Crawford, M.L., and Williams, M., 2001. Tectonic overprints of recent geochronology and geochemical data in the central Appalachian Piedmont and Carolina Plateau. *Geological Society of America Bulletin*, v. 113, p. 6-21.

Christophel, R.A., 1979. Nonparallel and isoclinal outcrop assemblages from the Raritan and Magyly Formations (Upper Cretaceous) of New Jersey. *Palaeogeography*, v. 3, p. 73-121.

Christophel, R.A., 1982. The occurrence of Complexoidei-Antipodini Zone (paleomorphs) in the Eagle Ford Group (Cretaceous) of Texas. *Journal of Paleontology*, v. 56, p. 525-541.

De Boer, J.Z., and Cifelli, A.E., 1988. Mesozoic tectonics, development and deformation of Newark rift zones in the Appalachian region: emphasis on the Hartford basin, Connecticut. In *Mesozoic W. of the Triassic-Jurassic rift, continental breakup and the origin of the Atlantic Ocean and passive margins*, part A, Elsevier Science Publishers, B.V., New York, p. 275-308.

Doye, J.A., and Robbins, E., 1977. Angiosperm pollen stratigraphy of the Cretaceous of the Atlantic Coastal Plain and its application to deep wells in the Delaware embayment. *Paleogeography*, v. 1, p. 49-78.

Dunning, G.R., and Houghton, J.P., 1986. LIPs zones and backslate ages for the Palisades and Catskill plains of the northeastern United States: implications for the age of the Triassic-Jurassic boundary. *Geology*, v. 14, p. 758-768.

Fankhauser, S.D., ca. 1999, unpublished data on file in the office of the New Jersey Geological Survey, Trenton, New Jersey.

Faust, G.T., 1978. Joint systems in the Wabington Basalt flows, New Jersey. U.S. Geological Survey Professional Paper 984B.

Gleason, J.D., 1966, reprint 1974. Provenance, dispersal, and depositional environments of Triassic sediments in the Newark Graben Basin, Pennsylvania. *Geological Survey Bulletin*, v. 49, p. 81-78.

Herman, G.C., 2005. Joints and veins in the Newark Basin, New Jersey, in regional tectonic perspective. In *Gates, A.E., ed., Newark Basin - View from the 21st Century*, 22nd Annual Meeting of the Geological Association of New Jersey. College of New Jersey, Newark, New Jersey, p. 75-116.

Herman, G.C., 2009. Steeply-dipping extension fractures in the Newark basin, *Journal of Structural Geology*, v. 31, p. 169-181.

Herman, G.C., Doolley, J.H., and Mueller, L.F., 2010. Geology of the Pennington Trap Rocks (Dabney Group, Mercer County, Pennsylvania, USA). *Geological Society of America Bulletin*, v. 122, p. 525-541.

Houghton, H.F., 1985, unpublished data on file in the office of the New Jersey Geological Survey, Trenton, New Jersey.

Houghton, H.F., Herman, G.C., and Volkert, R.A., 1992. Igneous rocks of the Pennington trap zone, central Newark basin, New Jersey. *Geochimica et Cosmochimica Acta*, v. 56, p. 109-124.

Houghton, H.F., Herman, G.C., Volkert, R.A., and Puffer, J.H., and Bergquist, R.C., eds., Eastern North American Mesozoic Magmatism: Geological Society of America Special Paper 268, p. 219-232.

Houch, J.M., 1988. Significance of major and trace element variations in Mesozoic diabase, west-central New Jersey. *Journal of Petrology*, v. 29, p. 141-150.

Houch, J.M., 1990. Palisades rift origin of the Shive zone by separate magmatic injection rather than gravity settling. *Geology*, v. 18, p. 699-702.

Kummel, H.B., 1979. The Newark System - Report of progress. New Jersey Geological Survey Annual Report of the State Geologist for the year 1986, p. 25-88.

Kummel, H.B., ca. 1900, unpublished data on file in the office of the New Jersey Geological Survey, Trenton, New Jersey.

Lucas, M., Hull, J., and Manopze, W., 1988. A foreland-type fold and related structures in the Newark Rift Basin, in *Mesozoic W. of the Triassic-Jurassic rift, continental breakup and the origin of the Atlantic Ocean and passive margins*, part A, Elsevier Science Publishers, B.V., New York, p. 207-232.

Molone, J.G., and Puffer, J., 2003. Flood Basalt Provinces of the Pangean Atlantic Rift: Regional Extent and Environmental Significance. In *Lourenço, P.M., and Olsen, P.J., eds., The Great Rift Valley of Pangaea in Eastern North America*, Columbia University Press, p. 1, 141-154.

McLaughlin, D. B., 1945. Type sections of the Stockton and Lockington Formations. *Proceedings of the Pennsylvania Academy of Science*, v. 20, p. 89-98.

McLaughlin, D. B., 1946. The Triassic rocks of the Huntington Plateau, New Jersey. *Proceedings of the Pennsylvania Academy of Science*, v. 19, p. 102-103.

McLaughlin, D. B., 1959. Mesozoic rocks in Wilard, Bradford, and other localities and mineral resources of Bucks County, Pennsylvania. *Pennsylvania Geological Survey Bulletin*, v. 61, p. 1-114.

Miller, K.W., Sugamian, P.J., Browning, J.V., Kontro, M.A., Olson, R.K., Ferguson, M.D., and Hernandez, J.C., 2004. Upper Cretaceous sequences and sea-level history, New Jersey Coastal Plain. *Geological Society of America Bulletin*, v. 116, no. 3-4, p. 368-393.

Mitchell, J.P. ca. 1993, unpublished data on file in the office of the New Jersey Geological Survey, Trenton, New Jersey.

Olsen, P.E., 1980a. The latest Triassic and Early Jurassic formations of the Newark basin (eastern North America Supergroup): Stratigraphy, structure, and correlation. *New Jersey Academy of Science Bulletin*, v. 25, p. 25-51.

Olsen, P.E., 1980b. Fossil great lakes of the Newark Supergroup in New Jersey. In *Manopze, Warren, et al., Field studies of New Jersey geology and guide to field trips*, 52nd annual meeting of the New York State Geological Association, p. 292-298.

Olsen, P.E. and Kent, D.V., 1966. Mississippian detrital forming in the vicinity of Prange during the Late Triassic. *Paleogeography, Paleoclimatology, and Paleogeology*, v. 122, p. 1-26.

Olsen, P.E., Kent, D.V., Cornell, Bruce, Witte, W.K., and Schlichte, R.W., 1996. High-resolution stratigraphy of the Newark rift basin (early Mesozoic, eastern North America). *Geological Society of America Bulletin*, v. 108, p. 40-77.

Olsen, P.E., Schlichte, R.W., and Gore, P.J., 1989. Tectonic, depositional, and paleogeographic history of Early Mesozoic rift basins in eastern North America. *Field guidebook 1331, American Geological Union*, 174 p.

Owens, J.P., Sugamian, P.J., Soffel, N.F., Parker, R.A., Houghton, H.F., Volkert, R.A., Drake, A.A., Jr., and Osmundt, R.C., 1988. Bedrock geologic map of central and southern New Jersey. U.S. Geological Survey Miscellaneous Investigations Series Map 1-2540-B, scale 1:100,000.

Parker, R.A., and Houghton, H.F., 1990a. Bedrock geologic map of the Rocky Hill quadrangle, New Jersey. U.S. Geological Survey, Open-File Report 90-218, scale 1:24,000.

Parker, R.A., and Houghton, H.F., 1990b. Bedrock geologic map of the Monmouth Junction quadrangle, New Jersey. U.S. Geological Survey, Open-File Report 90-219, scale 1:24,000.

Paszagka, J., 1993. Stratigraphy, petrography, and correlation of late Cenozoic middle Atlantic Coastal Plain deposits: implications for late-stage passive-margin geologic evolution. *Geological Society of America Bulletin*, v. 105, p. 1617-1634.

Plog, C.W., and Sevon, W.D., 1989. A record of Appalachian denudation in post-Triassic Mesozoic and Cenozoic sedimentary deposits of the U.S. middle Atlantic continental margin. *Geomorphology*, v. 2, p. 119-157.

Schlichte, R.W., 1992. Structural and stratigraphic development of the Newark extensional basin, eastern North America: Evidence for the growth of the basin and its bounding structures. *Geological Society of America Bulletin*, v. 104, p. 1246-1263.

Schlichte, R.W., 1993. Anatomy and evolution of the Triassic-Jurassic continental rift system, eastern North America. *Tectonics*, v. 12, p. 1026-1042.

Smoot, J.P., 1991. Sedimentary facies and depositional environments of early Mesozoic Newark Supergroup basins, eastern North America. *Paleogeography, Paleoclimatology, and Paleogeology*, v. 84, p. 399-423.

Smoot, J.P., and Olsen, P.E., 1994. Climatic cycles as sedimentary controls of rift-basin lacustrine deposits in the Early Mesozoic Newark Basin based on continuous core, in *Lourenço, A.J., Schlichte, R.C., and Harris, P.M., eds., Lacustrine Reservoirs and depositional systems*, SEPM Core Workshop no. 19, p. 201-237.

Stanford, S.D., 1993. Surficial geology of the Princeton quadrangle Mercer and Middlesex Counties, New Jersey. New Jersey Geological Survey, Open-File Map, OFM-11, scale 1:24,000.

Van Hooker, F.B., 1989. Late Triassic Newark Group, north central New Jersey and adjacent Pennsylvania and New York. In *Sutton, S., ed., Geology of selected areas in New Jersey and eastern Pennsylvania and geosketch of excursions*, Rutgers University Press, New Brunswick, New Jersey, p. 314-347.

Volkert, R.A., 2004. Geochemistry and tectonic setting of late Neoproterozoic diabase dikes, New Jersey Highlands and Trenton Group. In *Puffer, J.H., and Volkert, R.A., eds., Field Guide and Proceedings of the 21st Annual Meeting of the Geological Association of New Jersey*, p. 27-41.

Volkert, R.A., and Drake, A.A., Jr., 1993. Geology of the Trenton group, west-central New Jersey [data]. *Geological Society of America Abstracts with Programs*, v. 25, no. 2, p. 86.

Volkert, R.A., Drake, A.A., Jr., and Sugamian, P.J., 1996. Geology, geochemistry, and tectonostratigraphic relations of the crystalline basement beneath the Coastal Plain of New Jersey and contiguous areas. In *Drake, A.A., Jr., et al., Geologic Studies in New Jersey and eastern Pennsylvania*. U.S. Geological Survey Professional Paper 1565-A, 22 p.

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

Whitlock, O.M., Olsen, P.E., and Schlichte, R.W., 1995. Tectonic evolution of the Fundy rift basin, Canada: Evidence of extension and shortening during passive margin development. *Tectonics*, v. 14, no. 2, p. 350-455.

