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INTRODUCTION

Surficial materials in the Easton and Bangor quadrangles are highly variable, cover most of the bedrock, and are found in many types of landscapes. They include 1) weathered bedrock, derived from dolomite, gneiss, and granite that formed during the Quaternary and possibly Neogene Periods; 2) glacial drift of pre-Illinoian (older than 788 ka; ka = thousand years before present), Illinoian (150 ka), and late Wisconsinan age (21 ka); 3) colluvium of post pre-Illinoian age and chiefly laid down during the latter part of the Quaternary; and 4) alluvium of late Quaternary age. Surficial deposits are depicted based on their physical characteristics, readily distinguishable boundaries, and location on the landscape. They are further described and delineated by genetic and morphologic criteria. This promotes a better understanding of the study area surficial geology by providing a greater connection between the earth materials, and geologic processes related to their history.

Over the last two million years, the study area landscape has been shaped by multiple periods of glacial and periglacial weathering related to the growth and decay of the Laurentide ice sheet in North America. Although the effects of glaciation in modifying the landscape are pronounced, these modifications have been largely masked by periods of periglacial modification. Braun (1989) estimated that there may have been as many as ten glaciations of a magnitude sufficient to introduce a periglacial climate to New Jersey. During these periods, much cooler temperatures and increased precipitation enhanced the break-up and fragmentation of rock largely by frost shattering. Additionally, the transport of slope materials down slope by mass wasting became greater due to change to a shallow-rooted vegetative cover. Colluvium, a product of periglacial weathering, was shed off uplands onto the lower parts of hillslopes and onto the floor of narrow valleys and heads of drainage basins. This material was later partly eroded during interglacial periods by fluvial action.

The topographic position, degree of preservation, and difference in weathering characteristics of glacial drift in New Jersey show that continental ice sheets reached New Jersey at least three times (Salisbury, 1902; Witte and Stanford, 1995; Stone and others, 2002). Two of these, the pre-Illinoian and the Illinoian, reached the study area. The main effects of these glaciations were 1) the widening and deepening of valleys; 2) smoothing, streamlining, and wearing down of ridges; 3) erosion of preglacial soil and regolith; 4) change in drainage by derangement; 5) formation of many wetlands; and 6) the filling of valleys with stratified materials (sand, gravel, silt and clay). Most of the effects of the earlier continental glaciations have been masked by periglacial weathering during the last ice age.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The study area (Fig. 1) lies in the New Jersey Highlands physiographic province except for its northern part, which lies in the Great Valley Section of the Ridge and Valley physiographic province. These physiographic provinces are further described in Dalton (2006). The Delaware River is the major stream in this area and flows southward cutting across the southwest-trending rock formations. The area is a mix of urban and rural lands. Patchwork wood lots and cultivated fields cover large parts of valley floors and larger forested areas cover the mountains. The highest point is approximately 965 feet (294 m) above sea level on Scotts Mountain, and the lowest point lies on the Delaware River, approximately 140 feet (43 m) above sea level. Marble Mountain, Scotts Mountain, Pohatcong Mountain and Musconetcong Mountain form the major uplands in the study area. These uplands, which rise between 400 feet (122 m) and 800 feet (244 m) above the valley floors, are chiefly underlain by gneiss and granite of Middle Proterozoic age (Fig. 2). Topography here is rugged and the landscape is deeply dissected. Ridges chiefly follow layering in the surrounding country rock, although discordant trends are common. Rock outcrops are few because in many places the rock surface is covered by thick saprolite, fragmentation rubble, and colluvium.

The Delaware, Pohatcong, and Musconetcong valleys are underlain by Cambro-Ordovician dolomite and limestone. The Jacksonburg Formation, whose upper part is quarried for its use in cement, forms a southwest trending belt south from the town of Alpha, which is located in the southern half of the Easton quadrangle. Several abandoned quarries in the formation are relicts of this area's once extensive cement history. Areas underlain by carbonate rock form broad lowlands of gentle relief that in many places are covered by a mantle of pre-Illinoian till. The Delaware River and its tributaries are incised as much as 100 feet into the older valley floor forming narrow river valleys cut in rock. In most places, the streams flow along belts of carbonate rock, their course forming a rectilinear drainage pattern that suggests some control by cross-joints in the local rock.

The physiography of the Easton and Bangor quadrangles reflects a composite landscape shaped by periglacial, glacial and fluvial erosion. The study area consists of an assemblage of landforms that form uplands and valleys. These landforms may be grouped into geomorphic terrains based on their differences in elevation and topography. It is convenient to do this in order to discuss the history of the Easton-Bangor landscape in reference to erosional processes and lithotype. This methodology was successively applied to the Lehigh Valley and surrounding area by Germanowski (1999).

Upland terrains consist of:

1) broad, relatively undissected areas of low relief (< 60 feet), underlain by gneiss and granite. Surficial materials include weathered rock (thin to thick saprolite, scattered rubbly regolith) thin colluvium, and thin patches of older drift including scattered erratics.

2) narrow ridges and hills in areas of deeply dissected moderate to high relief (100 to 400 feet) underlain by gneiss and granite. Narrow ridge crests, extensive slopes, deep, very narrow valleys. Rock outcrops fairly common. Surficial materials include thin to thick colluvium, thin weathered rock (saprolite and rubbly regolith).

Valley terrains consist of:

1) modern valley floor. Deep (100 feet), narrow, rock walled, underlain by carbonate rock. Includes dissected areas of the old valley floor. Surficial materials include alluvium and colluvium.

2) old valley floor. Broad, areas of low relief and gentle slopes (typically < 40 feet) underlain by carbonate rock. Surficial materials include thin pre-Illinoian till (< 30 feet), till stone lag, weathered dolomite and limestone (solution residuum), and thin colluvium. In places carbonate bedrock is deeply weathered to depths exceeding 300 feet.

3) areas of intermediate elevation, rolling hills and narrow ridges underlain by shale. 100 to 200 feet higher than valley terrain 2. Surficial materials include shale-chip residuum and shale-chip colluvium.

Comparison between topography and bedrock clearly shows that rocks more resistant to weathering form areas of higher elevation. An idea presented by Hack (1960) and summarized here is that "topography is largely the result of differential erosion of rocks that have varying degrees of resistance to erosion". Carbonate rock underlies the lower areas, shale underlies areas of intermediate elevation, and gneiss and granite hold up the mountains. Johnson (1931) identified these three areas as base-leveled, the product of successive cycles of erosion and peneplanation. Over time the landscape will be reduced to an early level, gently-sloping seaward plain, regardless of lithotype and structure. A main argument against peneplanation is that Davisian erosion cycles (Davis, 1889) require extremely long periods of tectonic acquiescence. Recent work by Gardner (1989), Poag and Sevon (1989), and Pazzaglia and Gardner (2000) showed that the supposedly passive East Coast margin may not have been so passive after all. Deformation along the continental margin is largely attributed to lithospheric flexuring due to offshore sediment loading and the growth and decay of the Laurentide ice sheet. Changes in sea level related to southern and northern hemisphere glaciations also contributed to inland erosion by affecting stream gradients. Analysis of the offshore sediment record by Poag and Sevon (1989) showed that large pulses of sediment were deposited off the Atlantic Seaboard during the middle Miocene and later during the Pleistocene. Based on sediment volume they estimate denudation rates to be more than 3,600 feet (1.1 km) since the middle Miocene (15 Ma; Ma = million years before present), and more than 390 to 490 feet (120 to 150 m) since the start of the Quaternary (2 Ma). Assuming that these rates are reasonable (recycled coastal plain sediment, differential erosion, changes in nearshore depositional patterns related to inland changes in drainage will all act to lessen these numbers) the present day landscape is of a young geologic age. The summits of Musconetcong and Scotts Mountains therefore do not represent peneplains developed during the Cretaceous or early to middle Tertiary (Johnson, 1931), and valleys cutting below the Schooley surface could not account for the total volume of material eroded since the middle Miocene.

PREVIOUS INVESTIGATIONS

The surficial geology of the study area and surrounding area was first discussed by Cook (1880). He discussed the distribution of quartzose boulders and scattered patches of thin gravelly drift in Delaware, Pohatcong and Musconectcong Valleys. Most of this material was thought to be "modified glacial drift", possibly deposited by meltwater and reworked later by weathering and fluvial erosion. Upon greater inspection (Salisbury, 1893), this "modified glacial drift" was determined to be of glacial origin and called extra-morainic drift because of its distribution south of the Wisconsinan terminal moraine. Salisbury (1902) assigned the drift a Kansan age because of its deeply weathered appearance, which suggested it was the product of a glaciation that was much older than the Wisconsin glaciation. Salisbury also mentioned that the drift outside of the terminal moraine in a few places looked much less weathered than most of the extra-morainic drift. Bayley and others (1914) divided the extra-moranic drift into "early glacial drift" that was largely till deposited during the Jerseyan stage and "extra-morainic drift" that consisted of a mix of Wisconsin and early drift. In Pennsylvania, Leverett (1934) also assigned a Wisconsinan age to the terminal moraine and the glacial drift north of it and suggested that the pre-Wisconsinan drift was laid down during the Illinoian and Kansan glaciations. MacClintock (1954) divided the glacial deposits into Olean drift of early Wisconsinan age, and the Binghamton drift of late Wisconsinan age, based on the depth of carbonate leaching in glacial stream sediments. Crowl and Sevon (1980) suggested glacial deposits in eastern Pennsylvania consisted of the late Wisconsinan Olean drift, and that the older glacial deposits were represented by the Warrensville drift of early Wisconsinan age and the Muncy drift of Illinoian age. Cotter and others (1986) indicated the youngest glacial deposits New Jersey are of late Wisconsinan age and are correlative with the Olean drift in Pennsylvania. Ridge and others (1990) showed that older and weathered drift in the Delaware Valley north of Marble Mountain is late Illinoian age and not early Wisconsinan. Braun (1989), Witte and Stanford (1995), Stone and others (2002) also indicated that the youngest glacial deposits in New Jersey are of late Wisconsinan age, and that the two older drifts are of Illinoian and pre-Illinoian age. Gardner and others (1994) showed that the pre-Illinoian drift in central Pennsylvania is older than 788 ka, based on the reversed magnetic polarity of glacial lake-bottom deposits preserved near Antes Fort in the West Branch Susquehanna River valley.

PREGLACIAL DRAINAGE AND GEOMORPHOLOGY

The Delaware River and its tributaries were probably well established in their current courses before the Pleistocene. Transverse gaps in the Highlands Province are possibly relicts of an earlier Raritan River drainage system that flowed in a south-easterly direction (Witte, 1997b). The Delaware River, through headward erosion and stream capture, has enlarged its drainage area chiefly by extending its tributaries up-valley following the strike of bedrock less resistant to weathering and erosion. In response to the overall lowering of sea level during the Pleistocene, the drainage has further evolved by incision, which along the larger tributaries of the Delaware River has resulted in the formation of a much lower, narrower, river valley. Extensive headward erosion by first- and second-order streams has also resulted in the dissection of the older valley floor, and the surrounding Highlands. The location of Illinoian glaciofluvial deposits in the Delaware Valley (Ridge, 1983; Witte and Stanford, 1995) shows that the river valleys in the study area had been lowered or nearly lowered to their present levels by the time of the Illinoian glaciation.

QUATERNARY GEOLOGY

The topographic position, degree of preservation, and difference in weathering characteristics of glacial drift in New Jersey show that continental ice sheets reached New Jersey at least three times (Salisbury, 1902; Witte and Stanford, 1995; Stone and others, 2002). During each glaciation, valleys were deeply scoured and bedrock ridges, hills, and slopes were worn down by abrasion and plucking, smoothing and streamlining the bedrock surface. The many unweathered and lightly weathered bedrock outcrops that lie north of the terminal moraine show that most of the pre-existing weathered bedrock and surficial material had been removed by glacial erosion. Although outcrops of saprolite observed behind the late Wisconsinan border (Ridge, 1983; Witte, *in press*) show that some preglacial materials were not eroded. Most of the debris entrained by the ice sheets was deposited as till and meltwater sediment. The youngest glacial deposits laid down during the late Wisconsinan substage provide the clearest record of glaciation. The glacial record, indicated by the Illinoian and especially the pre-Illinoian deposits, is less clear due to an extensive and complex weathering history.

The oldest glaciation represented by the Port Murray Formation (Stone and others, 2002) covered the entire study area. The Port Murray drift appears to be chiefly till. It is deeply weathered, lies on weathered bedrock, and constructional topography is not preserved. The older drift lies well above (as much as 100 feet (31 m)) the modern river valleys in areas that are protected from mass wasting and fluvial erosion. The age of this glaciation is uncertain. Samples collected from a silty-clay bed in a deeply weathered fluviatile deposit in the Pohatcong Creek valley near the town of Kennedys, which is located along the southeastern edge of the Easton quadrangle, show that these sediments were laid down during a period of reversed magnetic polarity (J. C. Ridge, Tufts University, written communication, 1998). This places the age of the deposits at older than 788 ka. Based on the correlation of continental glaciations in the northern hemisphere with the offshore oxygen isotope record (Braun, 1989), this deposit may have been laid down during the early Pleistocene at around 2.4 Ma or perhaps later in the early Pleistocene at 1.1 Ma to 0.85 Ma. If the deposit is not outwash, but rather older alluvium laid down by Pohatcong Creek or the Delaware River, its position within the belt of older glacial drift shows that this older drift is the same age or older than the suspected outwash. Work on "older" glacial lake-bottom deposits in the West Branch Susquehanna River valley by Gardner and others (1994) show that these deposits were also laid down during a period of reversed magnetic polarity. They may be correlative with those preserved at the town of Kennedys.

The second ice sheet reached its most southerly limit on the north side of Marble Mountain during the late Illinoian stage, about 150 ka. This glaciation is represented by the Lamington and Flanders Formations (Stone and others, 2002). These deposits are moderately weathered, and the underlying bedrock is not as weathered as it is beneath the Port Murray deposits. The deposits lie in modern valleys and constructional topography is preserved, although it's subdued, and the drift in many places has not been eroded off hillslopes. The location of high-standing meltwater deposits north of Marble Mountain and Chestnut Hill show that the Marble Mountain Gap was probably blocked by a tongue of ice during the Illinoian maximum. This may have resulted in the formation of a high-standing glacial lake during the early phase of glacial retreat from the Illinoian terminal position.

The youngest ice sheet reached the northern part of Warren County, New Jersey during the late Wisconsinan substage of the Wisconsinan stage; approximately 22 to 19 ka (Cotter and others, 1986). Its furthest advance is generally marked by the terminal moraine (Salisbury, 1902), although in the Delaware Valley the ice extended about 0.5 miles south of the position marked by the terminal moraine at Foul Rift. The deposits of this glaciation are represented by the Rockaway Formation (outwash) and the Kittatinny Mountain, Rahway, and Netcong tills (Stone and others, 2002). They are lightly weathered, exhibit well-preserved constructional topography, generally lie on non-weathered rock, and lie in the modern drainage. Only outwash deposits are found in the study area. They form terraces that flank the course of the Delaware and Musconetcong Rivers.

The distribution of Port Murray till shows that the overall character of the Port Murray surface was similar to present time. It is doubtful if the overall height of the mountains above the older valley floors (valley terrain 2) was much greater than it is now. Since the pre-Illinoian glaciation, the Delaware River and its tributaries have cut down as much as 100 feet in the older valley floor. The position of Illinoian glaciofluvial deposits in the Delaware River valley suggests that most of the erosion took place well before the onset of the Illinoian glaciation. The narrow, rock-walled valleys that the Delaware River, Musconetcong River, and Pohatcong Creek flow through support the above hypothesis. Consequently, streams have renewed their attack on surrounding uplands, which is reflected by incision and retreat of hillslopes (formation of upland terrain 2). In places streams lie as much as 200 to 300 feet below ridge tops and terrain 1 flats and saddles.

Terrestrial (Fullerton, 1986) and oceanic records (Shackleton and Hall, 1984) showed that the growth and decay of continental ice sheets in the northern hemisphere during the Pleistocene was cyclic. In response to the growth and decay of the Laurentide ice sheet, the climate in the study area varied between temperate to boreal. During the warm interglacials, such as the Sangamon (135 to 70 ka), the relative rate of chemical weathering increased and an extensive cover of deeper-rooted vegetation helped reduce the rate of mass wasting. During this period thick soils were formed and bedrock was deeply weathered forming saprolite and decomposition residuum. In contrast, during the colder periglacial and glacial periods, there was a relative increase in the rate of physical weathering. This slowed pedogenic activity and because of a less extensive, and more shallow-rooted vegetative cover, the rate of erosion by mass wasting was greatly enhanced. Based on the offshore oxygen-18 record (Shackleton and Hall, 1984), Braun (1989) suggested that eastern Pennsylvania may have experienced about 10 periods of glacial or periglacial climate. This cyclicity is only partly preserved on land. Deposits of three glaciations and multiple colluvial deposits of pre-Wisconsinan and late Wisconsinan age in New Jersey record only the major climatic shifts during the Pleistocene.

Braun (1989) also suggested that erosion due to periglacial weathering could be on the order of a magnitude greater than fluvial erosion in modifying the landscape during the Pleistocene. Glacial/periglacial periods in New Jersey were short-lived and marked by intense physical weathering where large volumes of colluvium were produced. Colluvium in the study area is chiefly a monolithic diamict derived from weathered bedrock (chiefly by fragmental disintegration of outcrop and regolith by frost shattering) and transported downslope largely by creep. Over time it accumulated at the base of slopes, forming an apron of thick material, and it also collected on the floors of narrow valleys and first-order drainage basins. In places it is greater than fifty feet thick and it covers large parts of the landscape. Rates of sedimentation appear to be very high, typically overwhelming the capacity of the "fluvial system" to remove sediment. During periods of temperate climate, sediment production by periglacial processes presumably decreases, resulting in an increased rate of fluvial erosion. However, the total volume of material removed by fluvial erosion (gullying of slopes, incision of colluvially-filled valleys and first-order drainage basins, and alluvial fans, sapping by springs, lateral erosion of toe slopes) during temperate periods was probably less than it was during periglacial periods.

Following the late Wisconsinan glaciation, cold and wet conditions as well as sparse vegetative cover enhanced erosion of hillslope material by solifluction, soil creep, and slope wash. The mechanical disintegration of rock outcrops by freeze and thaw provided additional sediment, some of which forms aprons of talus at the base of large cliffs in the New Jersey Highlands. A few small boulder fields were formed where boulders, transported downslope by creep, accumulated at the base of hillslopes and in first order drainage basins. These fields, and other concentrations of boulders formed by glacial transport and meltwater erosion, were further modified by freeze and thaw, their stones reoriented to form crudely shaped stone circles. Gradually as climatic conditions warmed, vegetation spread and was succeeded by types that further limited erosion. Between 14,250 and 11,250 years before present day (Cotter, 1983) lacustrine sedimentation, which had been dominated by clastic material, became enriched in organic material. This transition represents a warming of the climate such that subaquatic vegetation could be sustained and it also marked a change in terrestrial vegetation from herb (tundra) to spruce and hemlock parkland, and eventually to a closed forest of spruce and hemlock. Forests of oak and mixed hardwoods started to populate the landscape around 9,700 years ago (Cotter, 1983).

SURFICIAL DEPOSITS

Surficial materials in the study area include alluvium, colluvium, glacial drift, and weathered bedrock. They are defined by their lithic characteristics (composition, texture, color, and structure), and bounding discontinuities. Their ages are based on a modified Midwestern nomenclature from Stone and others (2002).

Non-Glacial Deposits

Stream deposits (alluvium, stream-terrace deposits, and alluvial-fan deposits)

Alluvium (Qal) is chiefly Holocene age and it includes both channel (sand and gravel) and overbank (sand and silt) sediment laid down by streams in sheet-like deposits on the floors of modern valleys. Stream-terrace deposits (Qst, Qstl, Qstu) include both channel and flood-plain sediment, and they form terraces that lie 5 to 20 feet above the modern flood plain and below late Wisconsinan outwash terraces. Alluvial-fan deposits (Qaf) are scattered throughout the study area. They lie at the base of hill slopes where streams emerge from adjacent uplands, and their surfaces are entrenched by the modern drainage. These erosional channels show that the alluvial fan is not presently forming and that their formation is cyclic; influenced chiefly by climate and its effects on weathering, sediment supply, and amount and type of vegetative cover.

Hillslope sediment

Hillslope deposits include colluvium (Qcg, Qcu) and a mix of alluvium and colluvium (Qcal). These deposits are derived from underlying and upslope materials transported downslope by soil creep, solifluction, earth and debris flows, and rock fall. Colluvium is very widespread and is chiefly derived from weathered gneiss. It typically forms a monolithic diamict that mantles most slopes and forms thick aprons of material on their lower parts. It also collects in small first-order drainage basins in upland areas. In places, colluvium includes thin beds and lenses of sorted, stratified sheet- and rill-wash sand and gravel. Alluvium and colluvium assemblages consists of a mixture of diamict and sorted sand, gravel, and silt that has accumulated in thin sheets in narrow valleys and the heads of first-order drainage basins. These deposits in places also include the toe slopes of small colluvial aprons. In the Musconetcong and Pohatcong Valleys, colluvium of Wisconsinan age overlies weathered colluvium of presumably pre-Wisconsinan age, and a truncated red soil marks the contact between the two.

Glacial Materials

Till

Till is a poorly sorted, nonstratified to very poorly stratified mixture of clay-to boulder-sized material deposited directly by or from a glacier. In the study area till is represented by the Flanders (150 ka) and Port Murray Formation (>0.788 Ma). Till of Illinoian age (Qit) is preserved on many hillslopes, and it lies in the modern river valleys. In some places its surface is marked by a truncated red soil of presumably Sangamon age. Elsewhere, the soil has been stripped by colluviation. Generally, clasts and matrix material are moderately weathered, and dolostone and limestone clasts are leached to depths of at least 12 feet (4 m). Port Murray till (Qpt) is highly weathered, has a clayey matrix, is oxidized and leached of carbonate material, lies on weathered bedrock, and is only found in places where it has been protected from erosion, generally 60 to 100 feet above the modern drainage where it is typically found on the older valley floors of the Pohatcong and Musconetcong Valleys, and to a much lesser extent on flat upland surfaces. It was formerly much more extensive. In places it is represented by a till-stone lag consisting of pebbles and cobbles of quartzite, chert, and quartzose siltstone. In most places the till appears to be in place. Although, extensive surface and near-surface modification by cryoturbation, and minor colluviation is presumed based on the till's antiquity.

Deposits of glacial meltwater streams

Sediment carried by glacial meltwater streams was chiefly laid down at and beyond the glacier margin in meltwater-terrace deposits (Qwf) in the Delaware and Musconetcong Valleys. These late Wisconsinan outwash deposits form terraces of lightly weathered gravel and sand. These terraces may be remnants of an extensive valley train that extended downstream from the terminal moraine at Foul Rift and Hackettstown (Fig. 1). Weathered deposits of sand and gravel occur as scattered patches and terraces that sit slightly to well above the modern drainage. Meltwater deposits of Illinoian age (Qif) are found near Brainards in the Delaware Valley where a small terrace of weathered sand and gravel lies 40 feet above late Wisconsinan outwash. High-standing deposits of weathered sand and gravel (Qid) on the north flank of Marble Mountain may have been laid down in a proglacial lake formed at the terminus of the Illinoian ice sheet. Well records show thick deposits of silt and clay beneath weathered gravel and sand caps. Rock-terraces in the Delaware Valley and weathered outwash near Kennedys in Pohatcong Valley (Qps) are of pre-Illinoian age based on their elevation above the modern river valley.

Weathered bedrock

Weathered bedrock consists of saprolite, decomposition and solution residuum, and rock rubble. It was formed during the Quaternary Period when the climate varied between boreal conditions during glacial periods to temperate and subtropical conditions during interglacial periods. Weathered bedrock materials were chiefly derived from gneiss and foliated granite, and dolostone. They have only been mapped south of the late Wisconsinan border. North of the late Wisconsinan border, which is north of the map area, the bedrock is generally only lightly weathered. Weathered bedrock in this area has largely been removed by the erosive action of the last glaciation. In a few places it lies beneath late Wisconsinan drift. The large number of bedrock outcrops north of the late Wisconsinan glacial border highlight the difference between the most recently glaciated landscape and the older colluviated landscape that lies to the south.

Weathered gneiss and foliated granite (Qwg) consist chiefly of saprolite, grus and rock rubble. Structured saprolite extends deeply into bedrock along joints, fractures and foliations. Grus and rock rubble generally form a surface cover of varying thickness. In contrast to areas north of the late Wisconsinan glacial border, bedrock outcrops are few and generally lie only along ridge crests and very steep hillslopes. Outcrops form tors, ubtors, and disorganized masses of irregularly spaced joint block boulders that generally denote areas of subcrop. The surface of most outcrops is granular, and deeply etched.

Weathered carbonate rock (Qwcb) consists chiefly of solution residuum (Richmond and others, 1991), and karst-fill materials. Weathering extends deeply in the subsurface along fractures, joints and bedding planes. In many places the weathered bedrock alternates in the subsurface with nonweathered bedrock. Bedrock outcrops are widely scattered, most are marked by a pile of irregularly-shaped boulders along the crest of a ridge or on a hills-lope. The rock surface is very irregular and deeply etched along joints and fractures.

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EXPLANATION OF MAP SYMBOLS

Formation contacts - dashed where inferred, dotted where concealed.

12 Location of well or boring - geologic log is listed in Table 1.

Active sand and gravel pit - active in 2021.

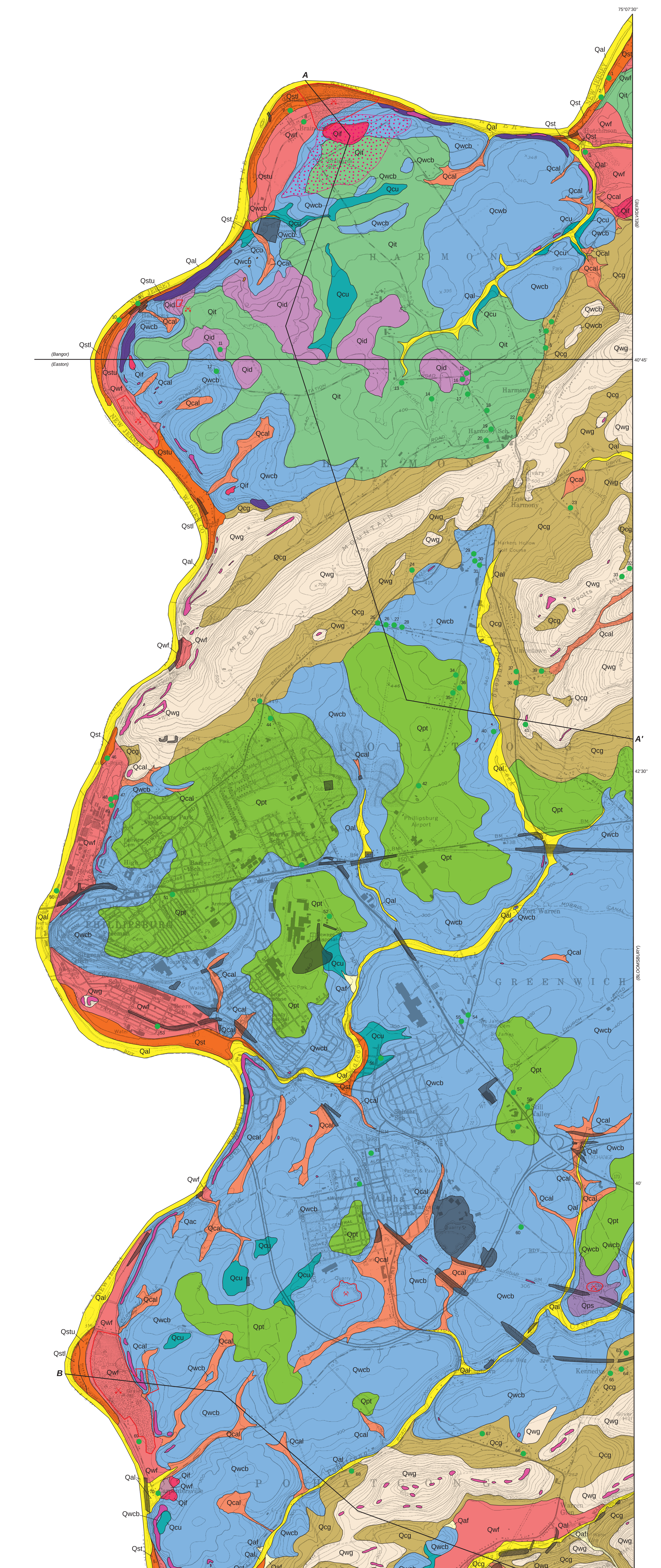
Inactive sand and gravel pit - inactive in 2021.

Inactive quarry - inactive in 2021.

Thin sheet of eolian sand (less than 3 feet thick).

Rock outcrops.

Regolith - chiefly rock waste on steep hillslopes and ridge crests, minor talus, scattered erratics, and a few small outcrops.



Basemaps mapped, edited and published by the U.S. Geological Survey Easton NJ-PA, 1956, photorevised 1994 and Bangor PA-NJ 1956, photorevised 1997. Coordinate tick marks are on 1927 North American datum.

SCALE 1:24 000

1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 1/2 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

Geology mapped 1985-1991. Cartography by R. Witte and A. Carone. Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under U.S.G.S. award number 01HQAG0106. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

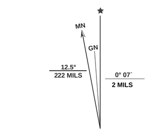
[1] Retired, New Jersey Geological and Water Survey

SURFICIAL GEOLOGIC MAP OF THE NEW JERSEY PARTS OF THE EASTON AND BANGOR QUADRANGLES, WARREN AND HUNTERDON COUNTIES, NEW JERSEY

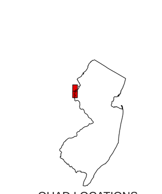
By

Ron W. Witte[1]

2021



1994 AND 1997 MAGNETIC NORTH DECLINATION



QUAD LOCATIONS IN NEW JERSEY

DESCRIPTION OF MAP UNITS

Map units denote unconsolidated materials more than 5 feet (1.5 m) thick. Color designations, based on Munsell Color Company (1975), were determined from naturally moist samples.

HOLOCENE AND LATE WISCONSINAN

ARTIFICIAL FILL- Rock waste from quarries, gravel, sand, silt, and manufactured materials emplaced by man. As much as 25 feet (8 m) thick. Not shown beneath roads, and railroads where it is less than 10 feet (3 m) thick. Primarily used to raise the land surface, construct earthen dams, and form a solid base for roads and railways.

Qal **ALLUVIUM** - Stratified, moderately- to poorly-sorted sand, gravel, silt, and minor clay and organic material. Locally bouldery. As much as 25 feet (8 m) thick. Includes planar- to cross-bedded gravel and sand in channel deposits, and cross-bedded and rippled sand, massive and parallel-laminated fine sand and silt in flood-plain deposits. In places, overlain by and interlayered with thin organic material and colluvium.

Qst, Qstl, Qstu **STREAM-TERRACE DEPOSITS** - Stratified, well- to moderately-sorted, massive to laminated, and minor cross-bedded fine sand, and silt in terraces flanking present or former stream courses. As much as 15 feet (4 m) thick. Overlies planar to cross-bedded cobble-pebble gravel and pebbly sand; as much as 20 feet (6 m) thick. Where sediments can be differentiated, Qst is broken up into younger lower stream terrace deposits (Qstl) and older upper stream terrace deposits (Qstu).

LATE WISCONSINAN

Qwf **MELTWATER-TERRACE DEPOSITS** - Stratified, well- to moderately-sorted sand, boulder-cobble to pebble gravel, and minor silt deposited by meltwater streams beyond the glacier margin in Delaware and Musconetcong Valleys. As much as 100 feet (30 m) thick. The proximal part of the deposit consists of massive to horizontally-bedded and imbricated coarse gravel and sand, and planar to tabular and trough cross-bedded, fine gravel and sand in bars, and channel-lag deposits with minor cross-bedded sand in channel-fill deposits. Clasts generally are smaller downstream, sand is more abundant, and trough and planar cross-bedding, and graded beds are more common. Overbank deposits of massive to laminated fine sand and silt are rare.

HOLOCENE AND WISCONSINAN

Qaf **ALLUVIAL-FAN DEPOSITS** - Stratified, moderately-to poorly sorted, brown to yellowish-brown, gray sand, gravel, and silt in fan-shaped deposits; as much as 35 feet (11 m) thick. Includes massive to planar-bedded sand and gravel and minor cross-bedded channel-fill sand. Bedding dips as much as 30 degrees toward the trunk valley. Locally interlayered with unstratified, poorly sorted, sandy-silty to sandy gravel.

Qcal **ALLUVIUM AND COLLUVIUM, UNDIFFERENTIATED** - Stratified, poorly to moderately sorted, brown to yellowish-brown, gray sand, silt and minor gravel; as much as 20 feet (6 m) thick. Interlayered with, or overlying, massive to crudely layered, poorly sorted sand, silt, and minor gravel.

MIDDLE PLEISTOCENE TO HOLOCENE

Qcg **GNEISSIC AND GRANITIC COLLUVIUM** - Massive to crudely layered, slightly compact, poorly sorted yellowish-brown (10YR /4-8) to dark yellowish-brown (10YR 4/4), brown (10YR 5/3), strong brown (7.5YR 5/6) silty sand and sandy silt, containing as much as 60 percent lightly to moderately weathered angular to subangular cobbles, pebbles, and boulders of gneiss and foliated granite; as much as 50 feet (15 m) thick. Matrix consists of a varied mixture of quartz sand, weathered feldspar, mica, amphibole, heavy minerals, silt, and clay. In the subsurface, older weathered colluvium typically underlies unit Qcg. This older colluvium is massive to crudely layered, slightly compact, poorly sorted red (2.5YR 4/8), strong-brown (7.5YR 5/6) clayey silt to sandy silt; as much as 25 feet (8 m) thick. Contains as much as 20 percent angular to subangular clasts of weathered gneiss and granite and minor subangular to rounded weathered carbonate rock, sandstone, and quartzite. Matrix is typically a mixture of quartz, clay, silt, rock fragments, minor mica, and heavy minerals.

Qcu **UNDIFFERENTIATED COLLUVIUM** - Poorly sorted, brown to yellowish-brown, gray sand, silt, and minor gravel derived from a mixture of weathered bedrock and till; as much as 10 feet (3 m) thick.

ILLINOIAN

Qit **FLANDERS TILL** - Massive, compact, poorly sorted, strong-brown (7.5YR 5.6), pale-brown (10YR 6/3), yellow (10YR 7/6) to yellowish-brown (10YR 5/4-6) clayey silt and sandy silt that typically contains 5 to 15 percent gravel as much as 60 feet (18 m) thick. Locally reddish in till rich in weathered carbonate rock. Clasts consist of gneiss, foliated granite, quartzite, quartz-pebble conglomerate, slate, sandstone, chert, and carbonate rock. Crystalline clasts have thick to thin weathering rinds (0.5 in.); carbonate clasts are generally decomposed to depths exceeding 10 feet (3 m). Other clasts have thin weathering rinds (0.1 in.), and pitted surfaces. Matrix is a varied mixture of quartz, rock fragments, silt, clay, weathered feldspar, minor mica, and heavy minerals. Subvertical joints moderately developed to depths of at least 10 feet (3 m). Iron and iron-manganese stain the surface of clasts, sand grains, and joints to depths of at least 10 feet (3 m). In Delaware Valley some clasts are reddish due to a thin coating of iron oxide.

Qif **OUTWASH DEPOSITS** - Stratified, well- to moderately-sorted, reddish-brown to brown, gray sand, cobble-pebble and pebble gravel, and minor silt. Contains subrounded to well-rounded pebbles and cobbles of gneiss, granite, quartzite, sandstone, dolomite, and chert. Crystalline clasts have thin to thick weathering rinds, quartzite and sandstone clasts have thin weathering rinds and exhibit ferriginous staining, and carbonate clasts are weathered to depths of at least 15 feet (5 m).

Qid **GLACIAL LAKE DEPOSITS** - Stratified, well- to moderately-sorted, reddish-brown to brown, gray sand, cobble-pebble and pebble gravel, and minor silt. Contains subrounded to well-rounded pebbles and cobbles of gneiss, granite, quartzite, sandstone, dolomite, and chert. Crystalline clasts have thin to thick weathering rinds, quartzite and sandstone clasts have thin weathering rinds and exhibit ferriginous staining, and carbonate clasts are weathered to depths of at least 15 feet (5 m). Overlies sand and silt.

PRE-ILLINOIAN

Qpt **PORT MURRAY FORMATION (TILL)** - Deeply weathered, compact, massive to crudely layered reddish-yellow (7.5YR 6/6-8) to strong-brown (7.5YR 5/6-8)to yellowish-brown (10YR 5/6-8), or reddish-brown (5YR 4/3) to weak-red (2.5YR 4/3) sandy silt and clayey silt that typically contains 2 to 5 percent gravel; as much as 30 feet (9 m) thick. Gravel consists of pebbles and cobbles of quartzite, gneiss, quartzose sandstone and siltstone, shale, dolostone, and chert, and a few boulders of quartzite and gneiss. Gneiss clasts have thick weathering rinds or are completely decomposed; carbonate clasts are fully decomposed. Quartzite, sandstone, and chert pebbles and cobbles have pitted surfaces and thin weathering rinds. Matrix contains clay, quartz weathered rock fragments, minor weathered mica, and few heavy minerals. Subvertical joints are poorly to moderately developed to depths exceeding 10 feet (3 m). Clasts and joints are commonly coated with red iron and black iron-manganese oxide.

Qps **PORT MURRAY FORMATION (STRATIFIED DRIFT)** - Reddish yellow (7.5 YR 6/6-8) to strong brown (7.5 YR 5/6-8) sand and gravel, and sand. Clasts are subrounded to well-rounded quartzite, quartzose sandstone and siltstone, chert, slate, and gneiss. Gneiss clasts are decomposed to depths exceeding 15 feet. Quatzite and chert clasts have weathering rinds (< 0.1 in.), and are coated with a brown iron-manganese stain. Sandstone and quartzite clasts have pitted surfaces. Planar bedding with minor cross-stratification. Soils developed on these deposits form diamict sediments that may resemble the Port Murray till.

NEOGENE TO QUATERNARY

Qwg **WEATHERED BEDROCK DERIVED FROM GNEISS, FOLIATED GRANITE, AND MINOR SYENITE** - Massive to layered, noncompact to compact brown (10YR 5/3), yellowish-brown (10YR 5/6-8), strong-brown (7.5YR 5/6), white (5YR 8/1), and red (2.5YR 5/8) silty sand to clayey silt saprolite consisting of clay, quartz, minor mica and heavy minerals; and sandy, blocky rock rubble. As much as 100 feet (30 m) thick. Includes thin stony and blocky colluvium on hillslopes, and bouldery to cobbly mantle of angular to subangular gneiss and granite on very gentle hillslopes; as much as 10 feet (3 m) thick. Weathered zone grades downward through a bouldery zone of joint blocks into underlying unweathered bedrock, and extends deeply along joints, fractures, and bedrock layers. Joint blocks and rock rubble typically have thick weathering rinds.

Qwcb **WEATHERED BEDROCK DERIVED FROM DOLOSTONE AND LIMESTONE** - Massive, compact light-red (2.5YR 6/6) to red (2.5YR 5/6), reddish-yellow (7.5YR 7/8) to strong-brown (7.5YR 5/6) to yellowish-brown (10YR 5/6), or yellow (10YR 7/6), locally highly variegated, clay and silty-clay solution residum of clay, quartz, and iron oxide; generally containing less than 5 percent chert, vein quartz and minor quartzite; thickness is highly variable, typically less than 15 feet (5 m), but locally as much as 100 feet (30 m). Locally includes thin colluvium as much as 5 feet (1.5 m) thick on gentle hillslopes. Also may include sand, gravel, silt, and clay washed into sinkholes and solution cavities from overlying colluvial, alluvial, and glacial sediment. Weathered zone typically ends at an abrupt, very irregular contact with unweathered bedrock and also extends deeply along joints and fractures.

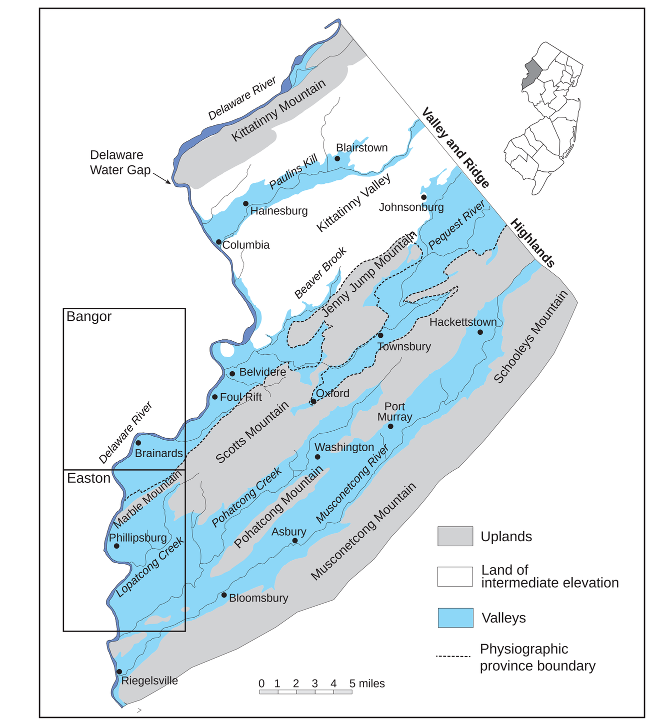


Figure 1. Physiography of the New Jersey part of the Easton and Bangor quadrangles and surrounding area in New Jersey.

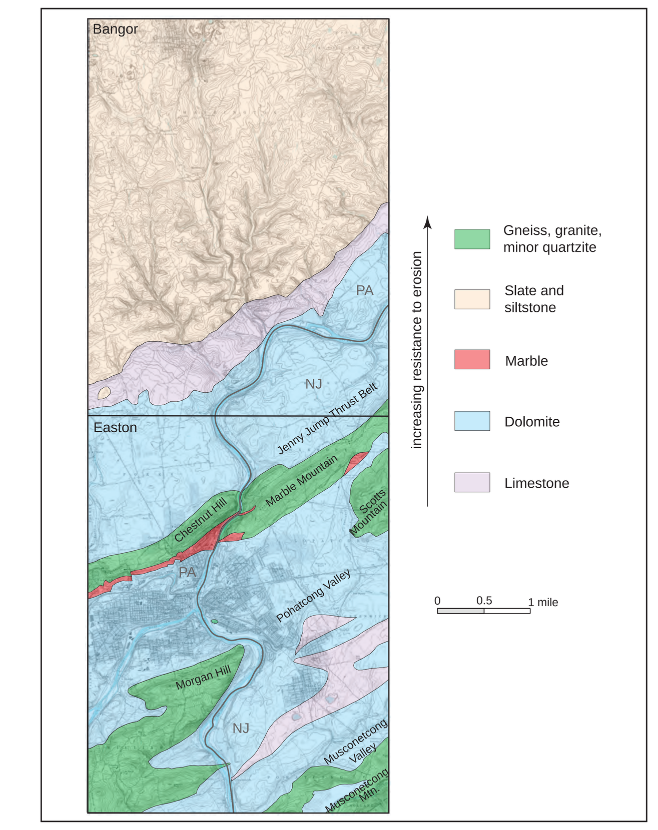


Figure 2. Simplified bedrock geologic map of the Bangor and Easton quadrangles. Lithotypes more resistant to erosion typically hold up higher areas while lithotypes least resistant to erosion underlie valleys. Data modified from Davis and others (1967), Drake (1967), Drake and others (1997), and Herman and others (1994).

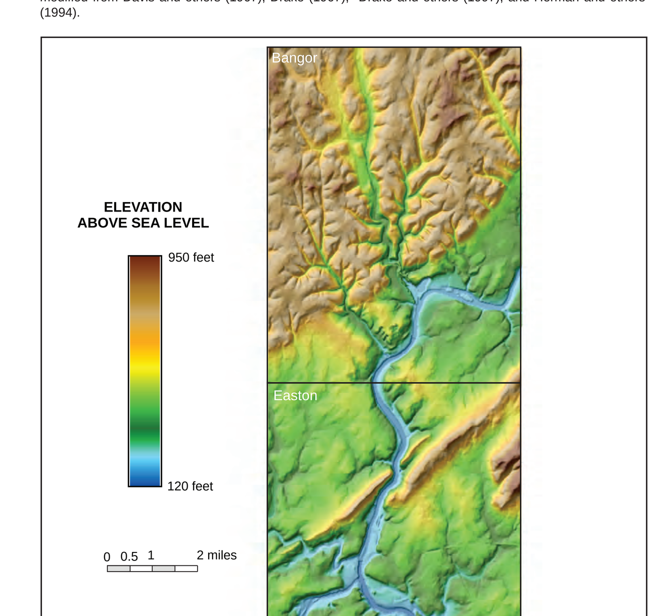
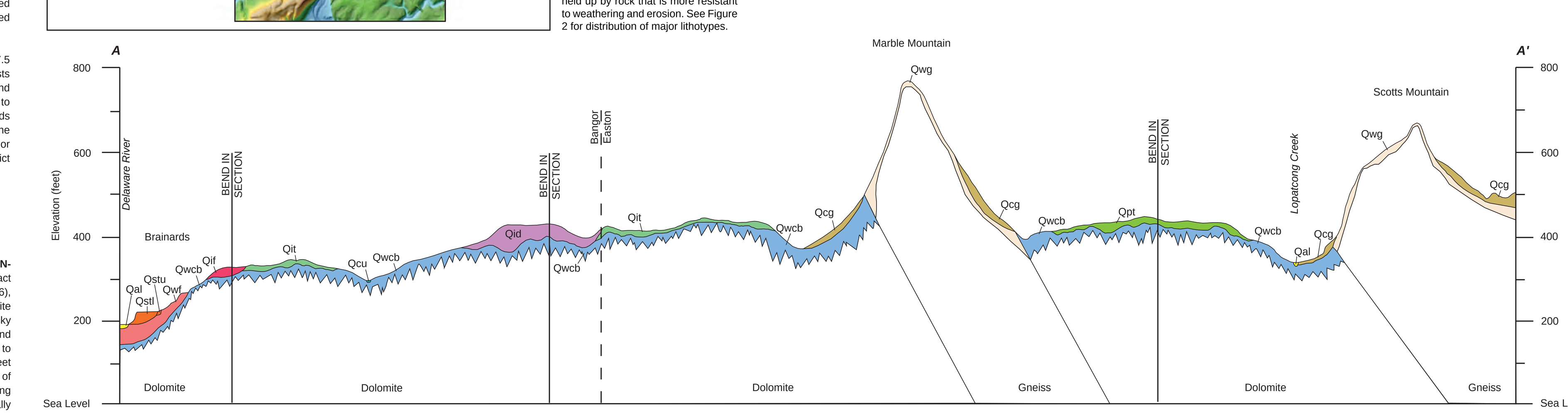


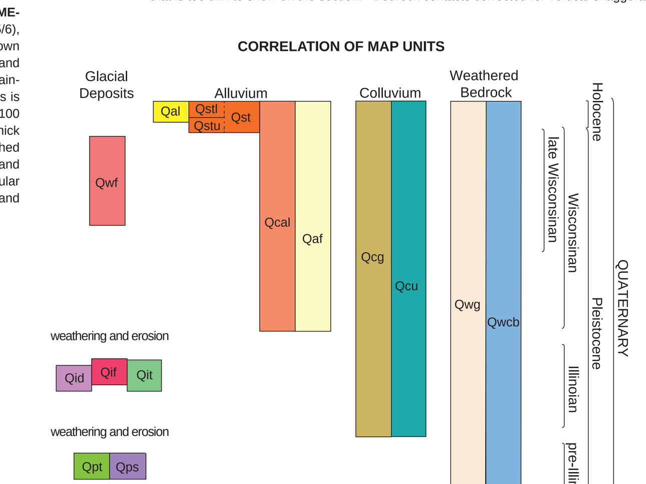
Figure 3. Colored-shaded relief map of the Bangor and Easton quadrangles. Areas of higher elevation are typically held up by rock that is more resistant to weathering and erosion. See Figure 2 for distribution of major lithotypes.

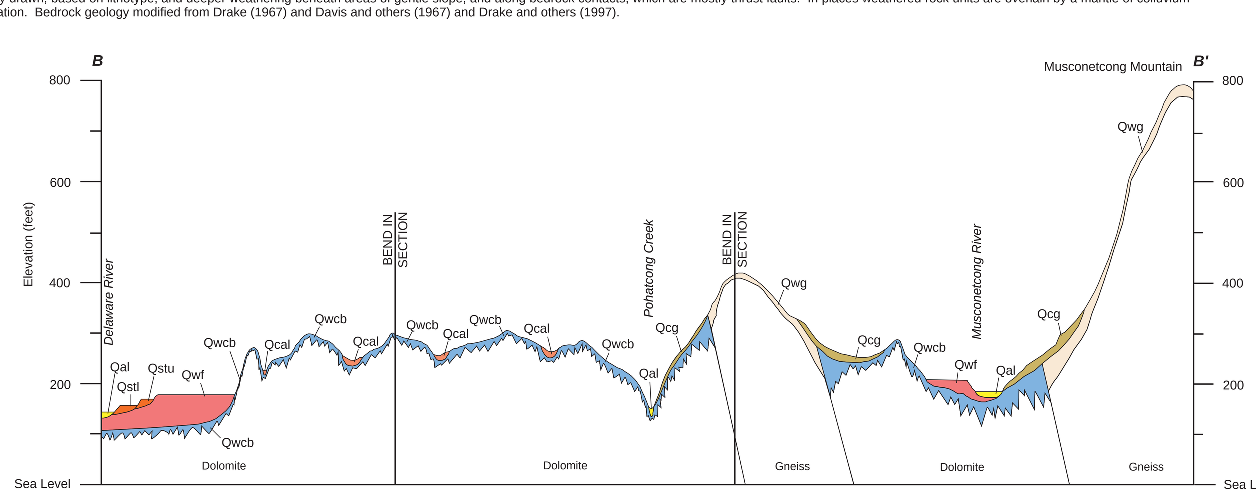
Well I.D.	NJDEP Permit No.	Location Accuracy	Discharge (gpm)	Depth (feet)	Driller's log
1	24-14513	s	8	0-10 10-49 49-50	clay clay and gravel granite ?
2	24-14899	s-f	25	0-12 12-20 20-50 50-125	brown soil sand and gravel brown clay granite ?
3	24-16175	s	25	0-80 80-250	overburden rock
4	24-01318	f-t	15	0-160	yellow clay; water-bearing gravel at bottom
5	24-01386	s-f	25	0-145 145-175 175-192	clay broken limestone limestone
6	24-21398	s	12	0-50 50-68 68-114 114-125 125-140 140-150 150-160 160-180	clay and gravel broken limestone clay, silt, and gravel broken limestone clay and gravel clay, gravel, and broken limestone broken limestone limestone
7	24-13815	s-f	6	0-2 2-18 18-80 80-625	topsoil clay broken limestone limestone
8	24-14509	s	10	0-32 32-75 75-150	sand and gravel brown clay and rock mix gray limestone
9	24-03851	f-t	15	0-40	sand and gravel
10	24-17107	f	30	0-30 30-100	gravel limestone
11	24-11669	s	5	0-4 4-150 150-170 170-190 190-198 198-240 240-245 245-260 260-265 265-423	overburden clay rotten rock rock void rock soft seam or void rock soft seam or void rock
12	24-16846	s	20	0-130 130-361	clay and gravel limestone
13	24-15070	s	20	0-8 8-120 120-160 160-195 195-250	brown soil brown rock and soil mix shattered limestone gray clay limestone
14	24-12931	f-t	20	0-100 100-320	clay and boulders soft limestone
15	24-13047	s-f	50	0-80 80-90 90-195 195-220	clay and sand limestone clay and sand limestone
16	24-22151	s	20	0-25 25-50 50-200 200-240 240-260 260-285	clay heavy clay gravelly clay shale shale-limestone broken limestone
17	24-18366	s-f	12	0-120 120-235	clay, sand, and gravel limestone
18	24-13912	f	20	0-25 25-75 75-185 185-250	brown clay and stone sand and gravel brown limestone
19	24-08860	f-t	10	0-35 35-298	yellow clay limestone
20	24-16981	s	8	0-356 356-455	clay and dirt soft limestone
21	24-16611	s	18	0-200 200-268	clay limestone
22	24-01635	f	5	0-40 40-55	yellowish-brown silt with pebbles fine to coarse sand with small pebbles
23	24-17648	s-f	30	0-80 80-100	clay limestone
24	24-15424	s	50	0-35 35-180 180-278 278-310	brown soil brown loam soil mix gray clay granite
25	24-15353	s	20	0-18 18-240	clay limestone
26	24-17218	s	30	0-130 130-200	sand, gravel, and clay limestone
27	24-17217	s	30	0-110 110-160	sand, gravel, and clay limestone
28	24-15644	s	15	0-22 22-80 80-150 150-225	brown soil brown clay shattered limestone limestone
29	24-14798	s	3	0-30 30-92 92-136 136-350	brown rock and soil mix brown clay gray clay limestone
30	24-15215	s	2	0-85 85-180 180-250 250-450	brown rock and soil mix brown clay gray clay granite ?
31	24-15531	s	20	0-90 90-115 115-146	clay broken limestone limestone
32	24-16795	s-f	4	0-25 25-50 50-310	sand and clay broken sandstone granite
33	24-15241	s	5	0-140 140-355	sand and clay granite
34	24-09559	s	20	0-25 25-178	clay overburden limestone
35	24-16015	s	4	0-25 25-400	clay limestone
36	24-32149	s-f	14	0-10 10-348	orange clay limestone
37	24-15838	s	12	0-18 18-205 205-240 240-255	brown soil brown clay brown soil and rock mix limestone
38	24-14991	s	25	0-110 110-190	clay limestone
39	24-16560	s	12	0-90 90-132	clay limestone
40	24-01051	f-t	115	0-40 40-45 45-360 360-418 418-440 440-560 560-574	hardpan red rock yellow clay hardpan yellow clay and rottem rock yellow clay granite
41	24-17116	s	6	0-60 60-185	clay and sand gravel
42	24-15205	s	20	0-30 30-90 90-170 170-258	brown clay gray clay brown rock and clay mix limestone
43	24-07333	f	10	0-40 40-220	clayey silt with very fine sand and small pebbles dolomite
44	24-15149	s	10	0-12 12-65 65-82 82-142 142-250	brown soil brown clay shattered limestone gray clay limestone
45	24-16215	s	15	0-22 22-55 55-100 100-114 114-152 152-173 173-177	clay limestone clay and gravel limestone clay limestone clay and wate
46	24-06549	s	300	0-10 10-25 25-35 35-45 45-50 50-60 60-84 84-87	boulders, sand and clay sand, silt, gravel and some silt coarse sand, gravel and some silt sand and boulders coarse sand and gravel fine to medium sand, some gravel fine to coarse sand sand, clay stones
47	24-08913	s	10	0-5 5-10 10-20 20-25 25-45 45-50 50-60	sandy loam sandy loam and gravel sand and gravel gravel and rock fragments sand, gravel and rock frag. gravel and rock fragments rock
48	24-08912	s	60	0-5 5-30 30-35 35-40 40-60	sandy loam and gravel sand and gravel gravel with some sand sand, gravel and rock frag. rock
49	24-14506	f	30	0-70 70-75	sand and gravel limestone
50	24-17233	f-t	75	0-55 55-160	sand and gravel limestone
51	24-17675	s	not measured	0-5 5-11 11-50	brown silty clay with trace of fine sand and fine to medium gravel fractured limestone limestone
52	24-10334	f	784	0-38 38-229	overburden limestone
53	24-15132	s	not measured	0-6 6-12 12-42	fill fine to medium sand with some medium gravel medium brown sand and gravel
54	24-15616	s	20	0-12 12-62 62-105 105-122 122-225	brown soil gray clay soil and rock mix shattered limestone limestone
55	24-11881	s	40	0-107 107-122 122-300	clay and rotten rock limestone slate
56	24-18056	s	20	0-16 16-150	sand and gravel limestone
57	24-15452	s	35	0-80 80-90 90-340	clay broken limestone limestone
58	24-04863	f	30	0-50 50-170	fine sand and yellowish-brown weathered soil limestone
59	24-04600	s	15	0-63 63-116 116-202	clay clay and gravel limestone
60	24-16291	f	10	0-25 25-155 155-265	clay soft rock and clay limestone
61	24-17161	s	12	0-60 60-200	overburden limestone
62	24-16044	f	not measured	0-1 1-5 5-15 15-20 20-34	asphalt dark brown silty fine sand, trace clay and gravel red-brown silt, trace clay and gravel orange-brown silt, trace fine sand and gravel red-brown silt, trace clay and gravel, refusal or rock (?) at 34 feet
63	24-15468	s	20	0-6 6-60 60-82 82-175	brown soil brown clay soil and rock mix limestone
64	24-15946	f	20	0-8 8-50 50-90 90-230 230-277 277-295	brown soil brown soil and rock mix sand and gravel brown clay brown loam and clay limestone
65	24-15250	s	10	0-150 150-185	clay limestone
66	24-13341	s	30	0-170 170-204	clay broken limestone
67	24-13907	s-f	20	0-60 60-110 110-185 185-200 200-208	brown clay brown sand and gravel gray clay brown sand and gravel brown sandstone
68	24-15349	f	8	0-85 85-130 130-162 162-190 190-350	brown soil and rock mix gray clay sand and gravel gray clay limestone
69	24-18398	f	15	0-33 33-125	clay weathered limestone
70	24-01172	s	10	0-87	clay and gravel
71	24-03210	f-t	15	0-10 10-20 20-68	reddish-brown silt reddish-brown silt with a few angular limestone pebbles limestone ?

Table 1. Records of selected wells in the Easton and Bangor quadrangles, Warren and Hunterdon Counties, New Jersey. The listed wells were drilled for private and public water supply. Wells listed with a New Jersey Department of Environmental Protection (NJDEP) permit number are from the files of the Bureau of Water Allocation and Well Permitting, Division of Water Supply and Geoscience, New Jersey Department of Environmental Protection. Well locations are based on property tax maps. Location accuracy designated by the letters "s", "f", and "t" indicate map location generally within 200 feet, 500 feet, and 1,000 feet of actual well location, respectively. Discharge listed as gallons per minute. Depth listed in feet.



VERTICAL EXAGGERATION 10x. Lower limits of weathered bedrock are conceptually drawn; based on lithotype, and deeper weathering beneath areas of gentle slope, and along bedrock contacts, which are mostly thrust faults. In places weathered rock units are overlain by a mantle of colluvium that is too thin to show on the section. Bedrock contacts corrected for vertical exaggeration. Bedrock geology modified from Drake (1967) and Davis and others (1967) and Drake and others (1997).





VERTICAL EXAGGERATION 10x. Lower limits of weathered bedrock are conceptually drawn; based on lithotype, and deeper weathering beneath areas of gentle slope, and along bedrock contacts, which are mostly thrust faults. In places weathered rock units are overlain by a mantle of colluvium that is too thin to show on the section. Bedrock contacts corrected for vertical exaggeration. Bedrock geology modified from Drake (1967) and Davis and others (1967) and Drake and others (1997).