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

INTRODUCTION

The Easton 7.5-minute quadrangle extends across the Delaware River and is located in Warren County and a small area of Hunterdon County in New Jersey, and in Bucks and Northampton Counties in Pennsylvania. In New Jersey, the quadrangle encompasses Alpha Borough, the town of Phillipsburg, and the townships of Greenwich, Harmony, Holland, Lopatcong, and Pohatcong. The landscape spans urban, suburban, and rural environments distributed across a varied terrain of valleys underlain by Paleozoic carbonate rocks flanked by ridges underlain by Proterozoic gneiss. The carbonate rocks underlying the valleys and the marble that comprises parts of ridges provide rock and mineral resources. This, in turn, has fostered a history of industrial activity (fig. 1) that includes active and inactive dolomite quarries that produce crushed stone and, in the past, lime fertilizer; and near Alpha Borough, limestone quarries that produced cement. Proterozoic marble from Harmony Township has also been quarried as dimension stone and for lime. While the carbonate rocks have proven to be an economic resource, they also pose a natural hazard risk because of sinkholes.

Figure 1. Historic photograph of a lime kiln near Carpentersville, Pohatcong Township. Photograph from the New Jersey Geological and Water Survey permanent note file 24.31.124 (NJGWS, undated). Star shows location of photograph in map area.

The Easton quadrangle hosts a karst terrain with active and inactive sinkholes, disappearing streams reemerging as springs (figs. 2 and 3), and caves. These rocks formed from carbonate deposition in a shallow marine environment, primarily during the Cambrian and Ordovician Periods; some date to the Mesoproterozoic. Though these rocks were deposited up to 1.3 Ga (billion years ago), they still play a dynamic role in the health and public safety of the region. Draining sinkholes and disappearing streams exploiting, dissolving, and expanding bedding planes at and below the ground surface, and surface and groundwater draining into caves, provide many locations for unfiltered sources of water and contamination to reach aquifers. This makes karst geology especially critical to understand since groundwater in karst areas may travel up to thousands of feet per day (Behr, 2023).

Figure 2. Sinking stream emerging from a spring on the western slope of Marble Mountain. The main flow direction from the spring is southwest, but part of the stream backflows into a swallow hole. Star shows location of photograph in map area. Photograph by Z. Schagrin.

Figure 3. Rising stream reappearing nearby and flowing into the Delaware River. Star shows location of photograph in map area. Photograph by Z. Schagrin.

The distribution and nature of karst features in the map area have a significant impact on sinkhole hazards and groundwater and surface water resources. For decades, karst features such as springs have provided water for consumption and for streams and hatcheries, supporting recreational fishing (fig. 4).

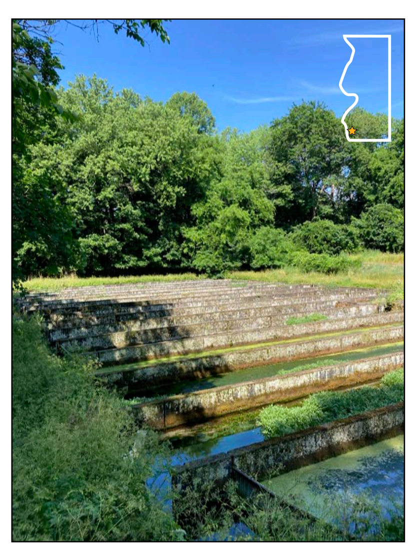

Figure 4. Abandoned fish hatchery fed by a spring in the Jacksonburg Limestone (Oj) near Carpentersville, Pohatcong Township. Star shows location of photograph in map area. Photograph by Z. Schagrin.

While karst features provide some economic opportunities, they also present a serious risk to public drinking water systems, private homes and wells, and engineering projects. Moreover, the continued active development of karst terrain means it is not enough to know the location of existing karst features. It is also critical to understand where these features occur, why they occur, and where the areas of highest karst susceptibility are. It is also essential to understand underground flowpaths. This is critical in the Easton quadrangle, which includes high population density areas with active development and industrial history and is traversed by Interstate 78 on carbonate bedrock through the map area. This has led to issues with sinkholes opening along roadways and surrounding areas, and many of the mapped features from this study occur on and along these roadways (figs. 5 and 6). Knowledge of these karst features, and where they occur and may occur, enables interested and affected parties to make decisions on the risks of geohazards for new and existing building construction projects, road and bridge work, and water contamination risks.

Figure 5. One of several sinkholes that opened during construction of I-78 in the Phillipsburg area in 1989. Photograph from New Jersey Department of Transportation. Star shows location of photograph in map area.

Figure 6. Another view of the sinkhole from Figure 5 that opened during construction of I-78 in the Phillipsburg area in 1989. The area above this sinkhole collapsed just before the highway was due to open and delayed the highway opening by several months. Sinkholes like this demonstrate the impact of human activity on sinkhole development. Photograph by H. Kasabach. Star shows location of photograph in map area.

The New Jersey part of the Easton quadrangle is in the northwestern part of the state along the Delaware River. The quadrangle is primarily within the Highlands physiographic province. A small segment of the northern part of the quadrangle lies within the Valley and Ridge physiographic province. This map shows karst features that have been identified using past bedrock and surficial map data and new information gathered from field observation, remote sensing, and aerial imagery. The most recent mapping in this area includes a 1:24,000-scale bedrock map (Monteverde et al., 2024), which updates an earlier 1:24,000-scale bedrock map (Drake, 1967), and a 1:24,000-scale surficial map (Witte, 2021). There have been investigations by the New Jersey Geological and Water Survey (NJGWS) of karst activity in the Easton quadrangle as far back as the 1930s (NJGWS, 1934).

This map is part of a series of karst features maps developed by the NJGWS. A summary of the karst topography and an explanation of findings is provided below. A correlation of map units shows the age of geologic formations and the map shows the distribution of carbonate and non-carbonate units and their structural relationships. Rose diagrams offer a structural summary and a table shows the distribution of karst features by geologic unit. Further discussion explores the geologic factors contributing to the distribution of karst features among these units.

KARST SETTING

Carbonate bedrock in the Easton quadrangle is of Cambrian and Ordovician age. These include the Upper Ordovician Jacksonburg Limestone (Oj), Lower Ordovician and Cambrian rocks of the Kittatinny Supergroup—the Beekmantown Group, here divided into upper (Obu) and lower (O€bl) parts, the Leithsville Formation (€l), and the Allentown Dolomite (€a). Aden and Parrick (2022) have shown that formations composed primarily of non-carbonate units but with some thin interbedded carbonate units and minor carbonate composition can serve as sites for significant sinkhole development. For this reason, this map incorporates the Lower Cambrian Hardyston Quartzite (€h) with carbonate rocks because this unit includes dolomitic sandstone. The northern part of the map area includes a Mesoproterozoic marble (Ymr) primarily along the northwestern side of Marble Mountain. This unit contains both active karst development and evidence of past karst development in the form of solution joints. Non-carbonate units (ZYu) are undifferentiated on the map and do not host karst features.

The landscape in the Easton quadrangle has been shaped and modified extensively by periods of glaciation. Two of these glaciations, the pre-Illinoian and Illinoian, reached the map area, and a third, the Wisconsinan, deposited outwash gravel along the Delaware and Musconetcong rivers; periglacial weathering has also had a profound impact on the map area. Till and stratified drift of the Port Murray Formation were deposited during the pre-Illinoian glaciation more than 788 ka (thousand years ago) throughout most of the central part of the map area (Witte, 2021). The Flanders Till, outwash deposits, and glacial lake deposits from the Illinoian glaciation, which reached its limit around 150 ka, are found in the northern third of the map area north of Marble Mountain near Harmony, and meltwater-terrace deposits from the late Wisconsinan glaciation, which reached its limit around 25 ka, occur along the Delaware and Musconetcong rivers (Witte, 2021). The distribution and characteristics of these glaciations have an effect on the formation and expression of karst features because of factors such as the thickness of surficial deposits. Periglacial weathering contributed to the landscape by breaking up upland rock and then transporting these materials down slope by mass wasting onto the lower parts of hillslopes, valley floors, and valley heads to form colluvium (Witte, 2021). This also has a pronounced impact on karst distribution for reasons similar to those associated with glacial activity. Other non-glacial deposits that overlie carbonate bedrock include Holocene and late Wisconsinan alluvium, alluvial-fan, and stream-terrace deposits.

There are no extensive areas of carbonate bedrock outcrop in the map area. The limited outcrops are on steep slopes visible on both the topographic map and hillshade imagery and occur predominantly along the Delaware River. Most carbonate bedrock is overlain by silty-clay weathering residuum over 200 feet thick in some areas. Along with glacial deposits and colluvium, the residuum forms a surficial mantle over the carbonate units. On the ridges bordering the carbonate valleys, clayey granular weathered gneiss as much as 100 feet thick mantles the gneiss bedrock, which is exposed on the narrow ridges and steep slopes of Scotts Mountain, Marble Mountain, and Musconetcong Mountain. This weathered material is the source for the colluvium and alluvial fans along the base of the ridges. Figure 7 provides a map of the New Jersey part of the quadrangle showing the thickness of surficial materials, the distribution of karst features, and bedrock outcrop areas.

KARST FEATURES

Carbonate rocks, such as limestone, dolomite, and marble, are susceptible to weathering because they are partially soluble in acidic groundwater and soil. The dissolution of carbonate rock leads to the development of voids and openings occurring along bedding planes where the rock is exposed to water. This results in visible regional features within the map area, where carbonate bedrock forms valleys and more resistant gneiss bedrock forms ridges. It also results in more localized features, such as solution-expanded joints and solution pans—shallow basins formed on bare carbonate bedrock. The karst features observed in this study area include both sinkholes and closed surface depressions (fig. 8), caves, springs, and sinking and rising streams.

Figure 8. Closed surface depression (outlined in dark green) in the lower Beekmantown (O€bl) near Alpha Borough, Warren County. This area has no drainage outlet and the center could contain a clogged sinkhole. Star shows location of photograph in map area. Photograph by Z. Schagrin.

Most of the sinkholes and surface depressions in this map area demonstrate characteristics of solution sinkholes (fig. 9a). Solution sinkholes form at the soil-rock interface. Water comes into direct contact with carbonate bedrock through bedding planes, joints, and fractures, and dissolves the rock. The water then transports the weathered material from the source and a depression forms. This depression encourages movement of more water through dissolved channels and enlarges fissures in the underlying bedrock (Neuendorf et al., 2011). The depression gradually widens into a funnel shape.

A second type of sinkhole, the solution-collapse sinkhole (fig. 9b), sometimes called the bedrock-roof collapse sinkhole, occurs when the dissolution of bedrock forms voids below the surface. As these voids enlarge, there is not enough bedrock support for the area above, and the surface material collapses into these voids. This type of sinkhole can be easy to identify at first because of its steep sides, but over time the sides become less steep because of material collapsing in and can appear as solution sinkholes (Dalton, 2014). Solution-collapse sinkholes can form in tandem with solution sinkholes. The dissolution of rock along surfaces can cause one or more sides of a depression to become unstable and collapse.

A third type of sinkhole, the cover-collapse sinkhole (fig. 9c), develops when cohesive clayey soil forms a layer that bridges above voids in the bedrock. Non-cohesive sediments spall into the void or cavity created by the dissolution of bedrock. The bridging soil remains at the surface while the void gradually migrates upward (Dalton, 2014). Eventually, the void breaches the surface and results in a sudden collapse of sediment into the void and a new sinkhole forms at the surface.

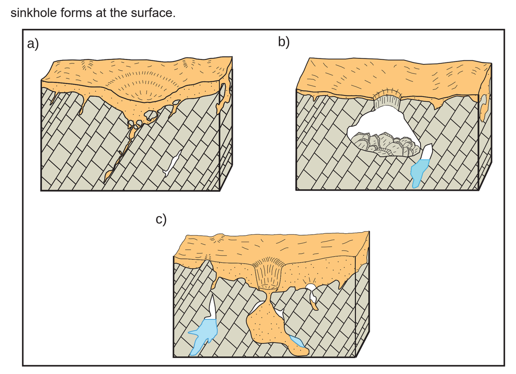

Figure 9. Diagrams showing a solution sinkhole (a), a solution-collapse sinkhole (b), and a cover-collapse sinkhole (c). Diagrams from Dalton (2014).

Caves in New Jersey are voids in the subsurface large enough to allow for human exploration and are generally oriented along regional strike of bedding (Dalton, 2014). The map area contains caves that occur due to dissolution of underlying carbonate rocks and the widening of fractures and joints in both soluble and insoluble rocks. These caves are not marked on the map but have been included in summaries of karst feature distribution. Most of the caves were previously mapped and are part of an NJGWS bulletin (Dalton, 1976) and a database maintained by NJGWS (Dalton, unpublished).

The dissolution of carbonate rocks leads to the formation of subsurface drainage networks whereby large quantities of water flow through fractures and joints, and along bedding planes and through caves. Because of this, most water flow in areas defined by karst topography occurs in the subsurface, rather than as surface streams (Kochanov and Reese, 2003). Water moving through these pathways can eventually discharge to the surface at springs (figs. 10 and 11).

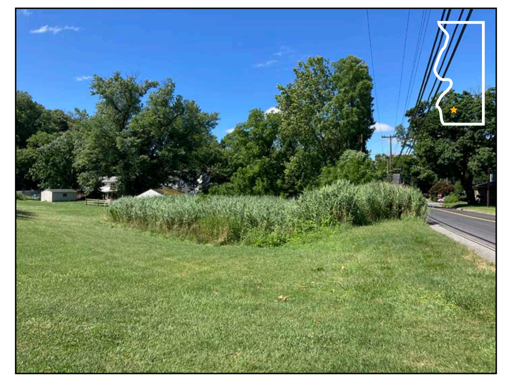

Figure 10. Topographic low point and closed depression surrounding a spring near Carpentersville, Pohatcong Township in the Jacksonburg Limestone (Oj). Star shows location of photograph in map area. Photograph by Z. Schagrin.

Figure 11. Spring inside the heavily-vegetated area from figure 10. The foundation of a springhouse is also present. Star shows location of photograph in map area. Photograph by Z. Schagrin.

MAPPING METHODS

Initial investigation into areas where sinkholes may occur included identifying areas underlain by carbonate bedrock. Once these areas were designated, hillshade imagery was created for the entire quadrangle using digital elevation data generated using a UTM coordinate system based on the NAD83 datum, with elevations referenced to NAVD88 and a spatial resolution of two feet (State of New Jersey, 2019). Aerial imagery, both historic and recent, were used to locate areas with outcropping bedrock and closed depressions. Particular attention was paid to areas of the Easton quadrangle with less than 50 feet of unconsolidated cover. Karst feature distribution proved to be unconstrained by surficial thickness in the map area, and this is discussed below. Closed depressions visible on hillshade imagery and potential karst features that appeared on aerial imagery were marked and field-checked. In some cases, field-checking showed these depressions to be from non-karst processes like construction activity, subsidence of backfilled sites, abandoned mines, culverts, and fallen trees. These depressions are not included on the map. Features determined to be the result of karst activity are located on the map. Wherever possible, measurements were taken at each karst site to determine the physical properties of each sinkhole or surface depression—length, width, depth, description of parapet—and which direction the long axis of the sinkhole was trending. If any trend was distinguishable, this was measured to compare and relate with structural trends. Additionally, on-site spot readings were taken of the closest point of bedrock, including bedding, joint, cleavage, and fault planes. This data is on file at the NJGWS. In some cases, it was not possible to field check suspected karst sites due to inaccessibility or sites that have been remediated.

Springs were located in the field and through hillshade and aerial imagery analysis. Additional spring locations marked on the map are from a publicly-accessible springs database managed by the NJGWS (State of New Jersey, 2022).

RESULTS

In total, 315 karst features (307 sinkholes and surface depressions and eight springs) were located and are depicted on this map. These include features mapped as part of this study and as part of a previous study from the 1990s of sinkholes throughout New Jersey that were identified using 1:12,000-scale stereo air imagery (Dalton et al., unpublished).

Figure 12 summarizes measurements of the long axis direction of sinkholes and surface depressions with distinguishable trends (12a), as well as measurements of the dip direction of bedding planes (12b), cleavage planes (12c), and joint planes (12d) of carbonate rock in the map area. Measurements of karst features were taken in the field and determined from hillshade imagery. Dip direction is perpendicular to the strike (or trend) of the bedding, cleavage, or joint planes. The average trend of measured sinkholes and surface depressions in the map area is N.37.1°E +/- 2.5° and appears, upon initial investigation, to correlate with the strike of bedding and cleavage of carbonate bedrock in the map area. This matches, in part, the established tendency of caves in New Jersey to generally extend along strike.

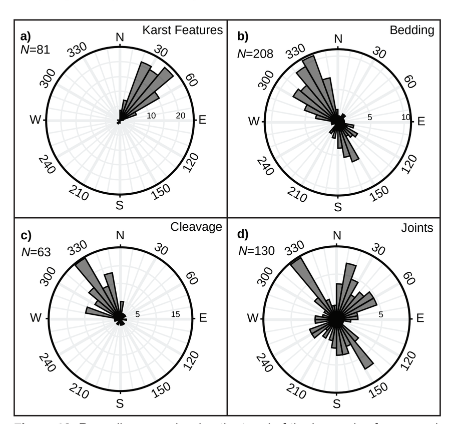

Figure 12. Rose diagrams showing the trend of the long axis of measured karst features (sinkholes and surface depressions) in carbonate rocks (a) and the dip direction of bedding planes (b), cleavage planes (c), and joint planes (d) with carbonate rocks. N equals the number of measurements taken for each plot. Bedding, joint, and cleavage data are from Monteverde et al. (2024). Diagrams produced using software from Allmendinger, 2013.

Depth to bedrock is a significant factor in the development of karst features (Tipping et al., 2001). Additionally, areas of bedrock outcrop and areas with minimal sediment cover are most conducive to karstification in some instances. Green et al. (2002) found that in areas with relatively thin layers of unconsolidated cover—those being areas with less than 75 feet of unconsolidated material—surface karst features may begin to appear. By comparison, areas with more than 75 feet of cover did not host surface karst features. Previous karst mapping in the Newton East quadrangle (Schagrin, 2023) included an analysis of karst feature distribution among areas of a wide range of surficial thicknesses. This analysis showed that carbonate bedrock in areas with thin surficial cover and more bedrock outcrop hosted more active sinkhole development and more karst features. In the Newton East quadrangle, there are areas of up to 200 feet of surficial cover and other areas with extensive bedrock outcrop, demonstrating the effect glacial activity plays in modern karst landscapes. In parts of New Jersey north of the terminal moraine, the landscape has been scoured most recently by the Wisconsinan glaciation and has more bedrock outcrop. The Easton quadrangle, located south of the terminal moraine, retains a thick mantle of residuum, and two factors contribute significantly to the development of sinkholes here despite this thick mantle: the geochemistry of gneiss uplands bordering carbonate lowlands and the drainage of streams incising the carbonate valleys.

Sinkholes can remain small and form at a slow rate because of poorly drained environments with ponding of surface water. This is because ponding enables sedimentation and temporary plugging of sinkholes. Alternately, well-drained settings are rarely ponded, and sinkholes continue to develop and grow larger (Panno et al., 2008). Incision of the Delaware River and its tributaries into the valleys underlain by carbonate rocks in the Easton quadrangle provided the topographic relief needed for drainage, and runoff from bordering gneiss uplands also contributes to sinkhole development here.

Studies in New Jersey have shown groundwater in gneiss bedrock with pH values as low as 5.7 and groundwater in shale bedrock with pH values ranging from 6.7 to 7.0, whereas carbonate groundwater has pH values recorded up to 7.5 (Miller, 1974). While the thick residuum mantling the carbonate bedrock in the valleys might typically impede sinkhole development, the acidic runoff from the gneiss ridges and active drainage of groundwater through the carbonate rocks expedite dissolution and prevent ponding that would enable sedimentation and slow dissolution.

The drainage of streams incising the valley floors enables more karstification in the map area. Rivers incise extensively into the carbonate valleys in the map area: 125 to 150 feet by the Pohatcong Creek flowing northeast to southwest through the southern portion of the quadrangle, over 100 feet by the Lopatcong Creek in the central part of the quadrangle, and over 200 feet by an unnamed tributary of the Delaware River in the northwestern part of the quadrangle. The hydraulic gradient created by this incision promotes groundwater movement through fracture, bedding, and joint planes in the carbonate rocks, which in turn causes more dissolution of the carbonate rocks and more karst development. Moreover, the varying structure and means of groundwater transport between karst areas and non-karst areas means there are different hydrologic systems in karst areas compared to non-karst areas (Li et al., 2023). Movement through fractures and expanded bedding and joint planes plays a critical role in the Easton quadrangle, especially given the less-permeable gneiss bedrock bordering the carbonate valleys. These conduits in the carbonate rocks are the fastest and most direct means for groundwater flow to the Delaware River.

Locally, karstification dramatically reduces drainage density on the surface, and in the Easton quadrangle this means that the dissolution and expansion of voids, fractures, and other fissures promote more groundwater movement and infiltration through these existing conduits (Le Mesnil et al., 2021). This, together with the high hydraulic gradient driving groundwater movement through these channels, means the carbonate areas experience high volumes of groundwater flow and the thicker surficial deposits do not impede sinkhole development in the map area. The impact of this, combined with bedrock type and distribution, is shown in table 1.

Table 1. Table showing the total number of karst features, percentage of total karst features, and percentage of the map area underlain by each carbonate geologic unit.

Formation	Number of Karst Features	Percent of Total Karst Features	Percent of Carbonate Area
Jacksonburg Limestone (Oj)	15	5%	14%
Beekmantown Group, upper part (Obu)	31	10%	14%
Beekmantown Group, lower part (O€bl)	31	10%	9%
Allentown Dolomite (€a)	190	60%	53%
Leithsville Formation (€l)	33	10%	7%
Hardyston Quartzite (€h)	5	2%	1%
Marble (Ymr)	10	3%	2%

The Allentown Dolomite (€a), which comprises 53% of the total area of carbonate bedrock in the map area, contains 60% of the 315 mapped karst features. This contrasts with the Jacksonburg Limestone (Oj), which comprises 14% of the carbonate area but contains only 5% of located karst features. In this quadrangle, ponding in flatter, low-lying areas further from the gneiss ridges and without much stream incision has impeded sinkhole development in the Jacksonburg Limestone (Oj), and, as a result, many of the karst features are too small to identify or have been plugged by sediment. Meanwhile, the Allentown Dolomite and other units bordering uplands underlain by Proterozoic gneisses with active drainage contain a higher percentage of total karst features because the acidic runoff contributed by these uplands accelerates the process of dissolution in the Allentown Dolomite. Combined with a well-drained setting, this leads to more sinkholes than surrounding areas (fig. 13). However, karst distribution also occurs throughout these formations and not just where they border gneiss uplands. This is mainly due to the well-drained conditions throughout much of the carbonate formations, caused by the incision of the Delaware River and its tributaries.

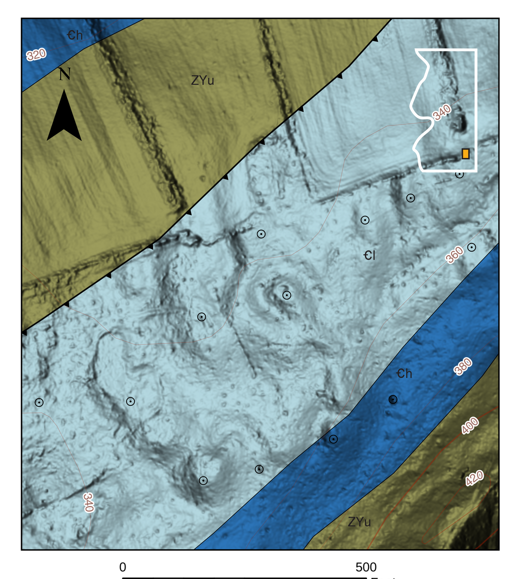

Figure 13. Hillshade imagery of the southeastern portion of the Easton quadrangle showing a granite and gneiss upland bordered to the northwest by a carbonate valley underlain by the Hardyston Quartzite (€h) and the Leithsville Formation (€l). Acidic runoff from the upland contributes to the karst topography in the valley, including sinkholes and large surface depressions. Imagery generated with two-foot digital elevation model data using a multidirectional hillshade analysis with a Z factor of five to highlight topographic features (State of New Jersey, 2019). Imagery is 1:2,500. Box shows location of imagery in map area.

This study has shown active sinkhole development, and previous investigations by the NJGWS have reached similar findings. A 1934 investigation into sinkhole development at an industrial site in Phillipsburg showed the active development of sinkholes closely aligned in a NW-SE direction and underlain by limestone at a depth of about 15 feet (NJGWS permanent note 24.21.514). The development of these sinkholes was expedited by the pumping of wastewater into sinkholes nearby for over 15 years. It was calculated that over time, at least a billion and a half gallons of wastewater had been pumped into the bedrock, expanding pathways for overlying glacial materials to spall into voids in the subsurface. This study has found similar active development of sinkholes. The most prominent setting for this has been on farmland, where sinkholes have been located throughout the map area (fig. 14). In these fields with less native vegetation to capture rainfall and other surface water runoff, water at the surface has a less impeded pathway to the underlying carbonate bedrock where it exploits joints, fractures, and bedding planes.

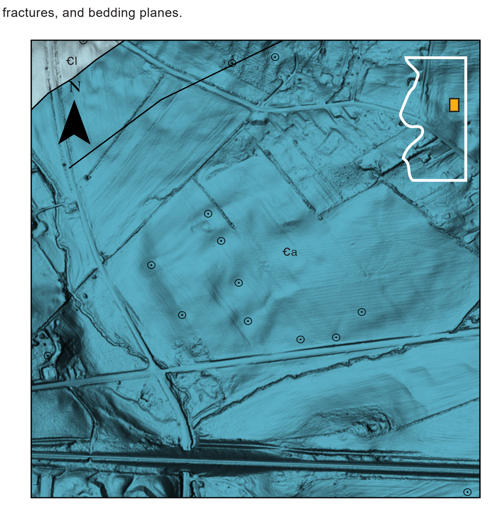

Figure 14. Hillshade imagery of the northeastern portion of the Easton quadrangle showing farmland underlain by the Allentown Dolomite (€a) and the Leithsville Formation (€l) with active sinkhole development and large surface depressions which could be clogged sinkholes. Imagery generated with two-foot digital elevation model data using a multidirectional hillshade analysis with a Z factor of five to highlight topographic features (State of New Jersey, 2019). Scale is 1:8,000. Box shows location of imagery in map area.

DESCRIPTION OF MAP UNITS
(Monteverde et al., 2024)

Paleozoic Rocks

Oj **Jacksonburg Limestone (Upper Ordovician) (Spencer et al., 1908; Miller, 1937)** – Medium-dark-gray-weathering, medium-dark to dark-gray, laminated to thin-bedded, argillaceous limestone (cement-rock facies). Grades downward into medium-bluish-gray-weathering, dark-gray, very thin- to medium-bedded, commonly fossiliferous, interbedded fine- and medium-grained limestone and pebble-and-fossil limestone conglomerate (cement-limestone facies). Regionally, unit ranges in thickness from 150 feet to 1,000 feet.

Beekmantown Group (Clarke and Schuchert, 1899)

Obu **Beekmantown Group, upper part (Lower Ordovician)** – Light- to medium-gray- to yellowish-gray-weathering, medium-light to medium-gray, aphanitic to medium-grained, thin- to thick-bedded, locally laminated, slightly fetid dolomite. Locally light-gray- to light-bluish-gray-weathering, medium- to dark-gray, fine-grained, medium-bedded limestone occurs near the top of unit. Grades downward into medium- to dark-gray on weathered surface, medium- to dark-gray where fresh, medium- to coarse-grained, medium- to thick-bedded, strongly fetid dolomite. In map area, unit correlates with the Epler and Rickenbach Dolomite of Drake (1967) and the Ontelaunee Formation of Markewicz and Dalton (1977). Unit averages about 200 feet in thickness but is as much as 800 feet thick.

O€bl **Beekmantown Group, lower part (Lower Ordovician to Upper Cambrian)** – Upper sequence is light- to medium-gray- to dark-yellowish-orange-weathering, light-olive-gray to dark-gray, fine- to medium-grained, very thin- to medium-bedded locally laminated dolomite. Middle sequence is olive-gray- to light-brown- and dark-yellowish-orange-weathering, medium- to dark-gray, micritic to medium-grained, thin-bedded, locally well-laminated dolomite which grades into discontinuous lenses of light-gray- to light-bluish-gray-weathering, medium- to dark-gray, fine-grained, thin- to medium-bedded limestone. Limestone has "reticulate" mottling characterized by anastomosing light-olive-gray- to grayish-orange-weathering, silty dolomite laminae surrounding lenses of limestone. Limestone may be completely dolomitized locally. Grades downward into medium dark- to dark-gray, fine-grained, well-laminated dolomite having local pods and lenses of black to white chert. Lower sequence consists of medium-to medium-dark-gray, aphanitic to coarse-grained, thinly-laminated to thick-bedded, slightly fetid dolomite having quartz-sand laminae and sparse, very thin to thin, black chert beds. Individual bed thickness decreases and floating quartz sand content increases toward lower gradational contact. Entire unit is Stonehenge Limestone of Drake et al. (1985) and Stonehenge Formation of Volkert et al. (1989). Markewicz and Dalton (1977) correlate upper and middle sequences as Epler Formation and lower sequence as Rickenbach Formation. Unit is about 600 feet thick.

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

€l **Leithsville Formation (Middle and Lower Cambrian) (Wherry, 1909)** – Medium-light- to medium-gray-weathering, medium-gray, fine- to medium-grained, thin- to medium-bedded dolomite. Quartz-sand lenses occur near the lower gradational contact with Hardyston Quartzite. Archaeocyathids of Early Cambrian age are present in formation at Franklin, New Jersey, suggesting an intraformational disconformity between Middle and Early Cambrian time (Palmer and Rozanov, 1967). Unit also contains *Hyolithellus micans* (Offield, 1967; Markewicz, 1968). Approximately 800 feet thick regionally.

€h **Hardyston Quartzite (Lower Cambrian) (Wolff and Brooks, 1898)** – Medium- to light-gray, fine- to coarse-grained, medium- to thick-bedded quartzite, arkosic sandstone and dolomitic sandstone. Contains *Scolithus linearis* and fragments of the trilobite *Olenellus thompsoni* of Early Cambrian age (Nason, 1891; Weller, 1903). Thickness is as much as 200 feet regionally.

Proterozoic Rocks

Ymr **Marble (Mesoproterozoic)** – White- or light-gray-weathering, white, grayish-white, or less commonly pale pink, fine- to medium-crystalline, calcitic to dolomitic marble with accessory graphite, phlogopite, serpentine, clinopyroxene, and magnetite. Contains abundant talc and serpentine along the northwest side of Marble Mountain, and pods and lenses of hornblende skarn near Lower Harmony. Unit locally displays relict karst features in the form of bedrock pinnacles and solution joints and openings.

Other Rocks

ZYu **Undifferentiated non-carbonate rocks** – Neoproterozoic diabase dikes; Neoproterozoic conglomerates and sandstones; Mesoproterozoic intrusive igneous rocks, including granite, alaskite, syenite, and monzonite; Mesoproterozoic gneisses and amphibolite.

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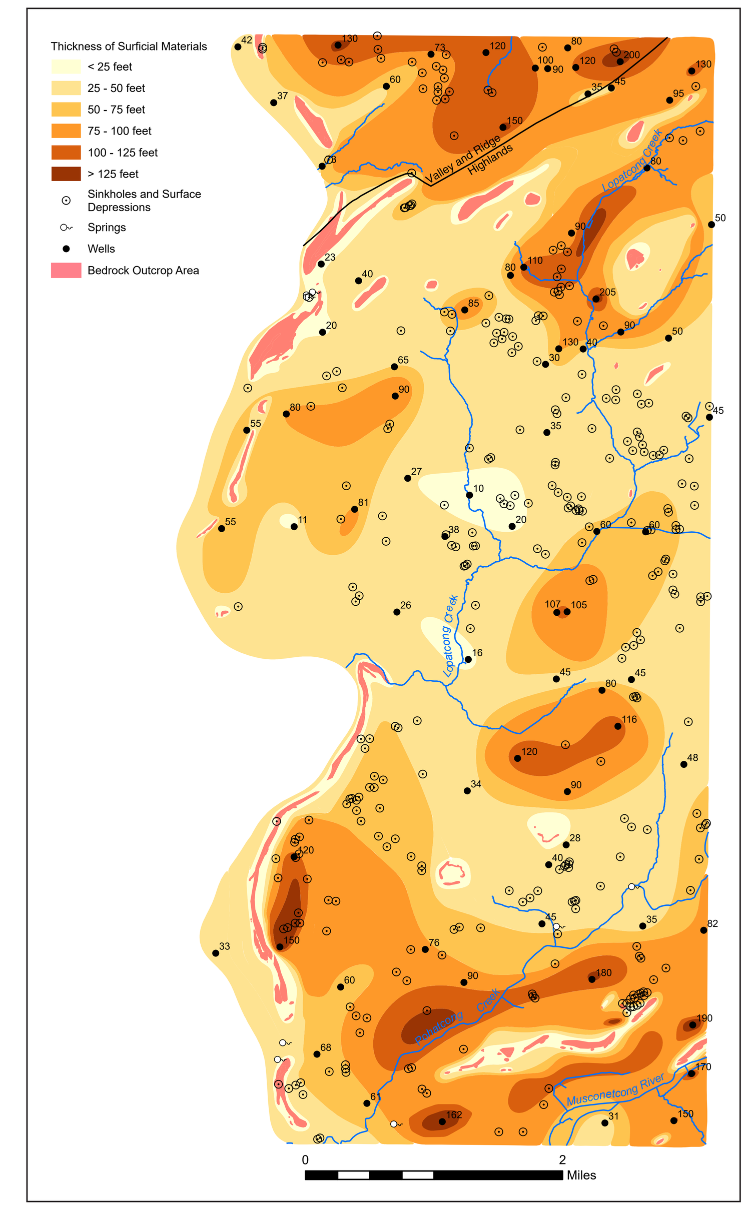
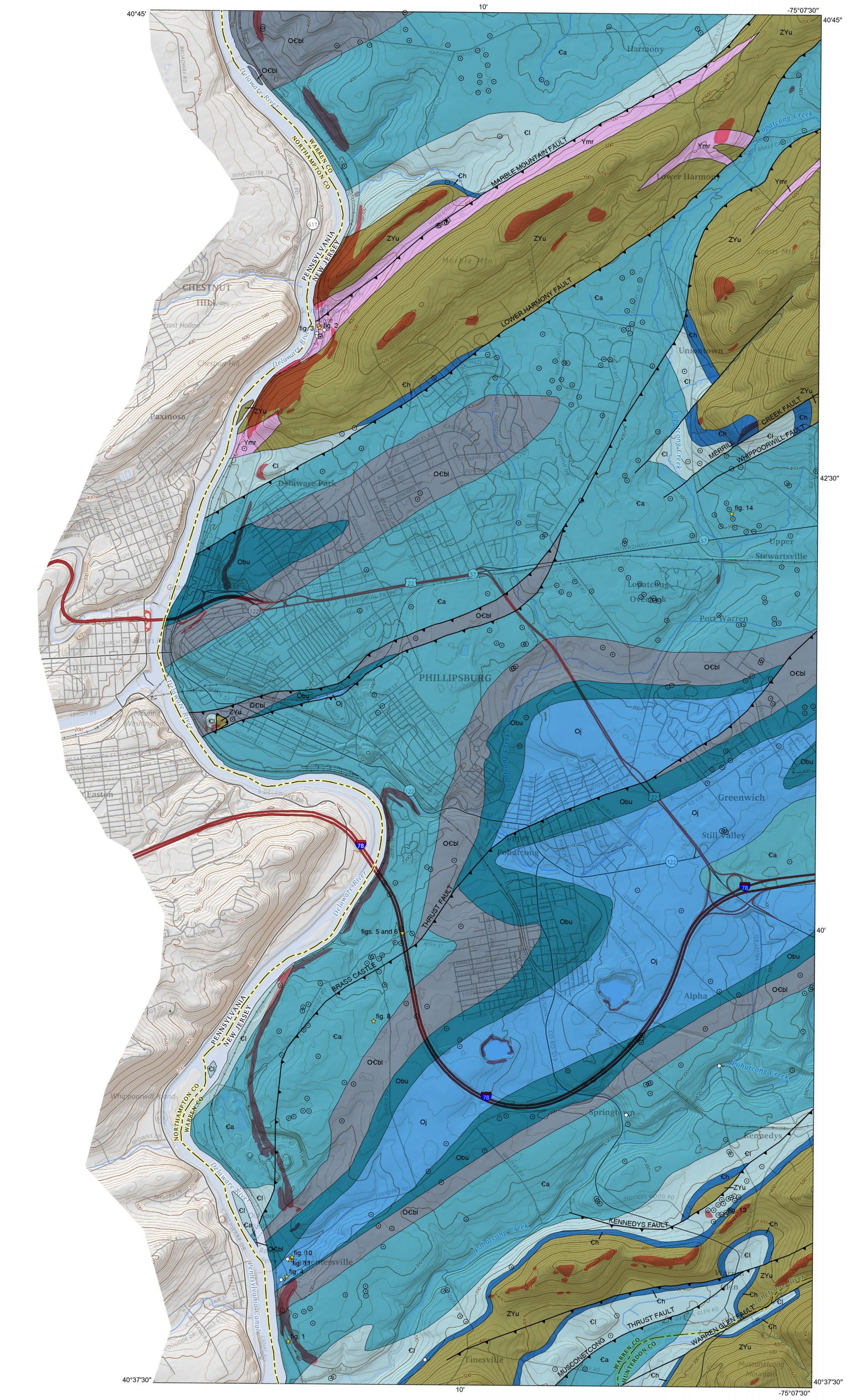


Figure 7. Thickness of surficial materials, including weathered rock, with distribution of karst features in the New Jersey part of the Easton quadrangle. Number next to well indicates thickness of surficial materials. Scale is 1:50,000.



EXPLANATION OF MAP SYMBOLS

LINE FEATURES

Contact - Dotted where concealed.

Fault

Normal fault

Inclined thrust fault - teeth on upper plate.

POINT FEATURES

Locations of sinkholes and surface depressions suggested to be formed by karstification. Identified using hillshade imagery, aerial photographs, and field investigations.

Locations of springs.

fig. 1 Locations of photographs. Identifier refers to figure number.

POLYGON FEATURE

Bedrock outcrop (from Witte, 2021).

CORRELATION OF MAP UNITS

Kittatinny Valley Sequence

Oj — ORDOVICIAN

Unconformity

Obu, O€bl — Beekmantown Group — Kittatinny Supergroup — ORDOVICIAN

€a, €l, €h — Kittatinny Supergroup — CAMBRIAN

Unconformity

ZYu, Ymr — PROTEROZOIC

Basemap produced by the United States Geological Survey
North American Datum of 1983 (NAD83)
Imagery....................NAIP, June 2017 - December 2017
Roads....................................U.S. Census Bureau, 2016
Names..GNIS, 1979 - 2016
Hydrography........National Hydrography Dataset, 2022
Contours................National Elevation Dataset, 2022
Boundaries.............Multiple Sources, 2021 - 2022

SCALE 1:24,000

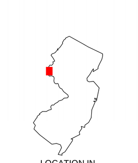
1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

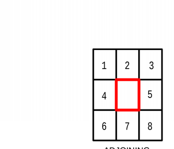
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1988

Karst geology mapped by Z. C. Schagrin 2022-24.
Digital cartography by Z.C. Schagrin.
Surficial geology mapped by Witte, 2021.
Bedrock geology mapped by Monteverde et al., 2024.
Well search performed by Jeremy Weremeichik.
External reviews provided by Patrick Finnerty of the Virginia Department of Energy and John Tudek of the West Virginia Geological and Economic Survey.
Prepared in cooperation with the U. S. Geological Survey National Geologic Mapping Program.
Submitted in fulfillment of U. S. Geological Survey Award Number G22AC00375. 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.



LOCATION IN NEW JERSEY

APPROXIMATE MEAN DECLINATION AT CENTER OF QUAD, 2025



1 Wind Gap
2 Bangor
3 Belvidere
4 Nazareth
5 Bloomsbury
6 Hellertown
7 Riegelsville
8 Frenchtown

ADJOINING QUADRANGLES

KARST FEATURES OF THE NEW JERSEY PART OF THE EASTON QUADRANGLE WARREN AND HUNTERDON COUNTIES, NEW JERSEY

By

Zachary C. Schagrin
2025