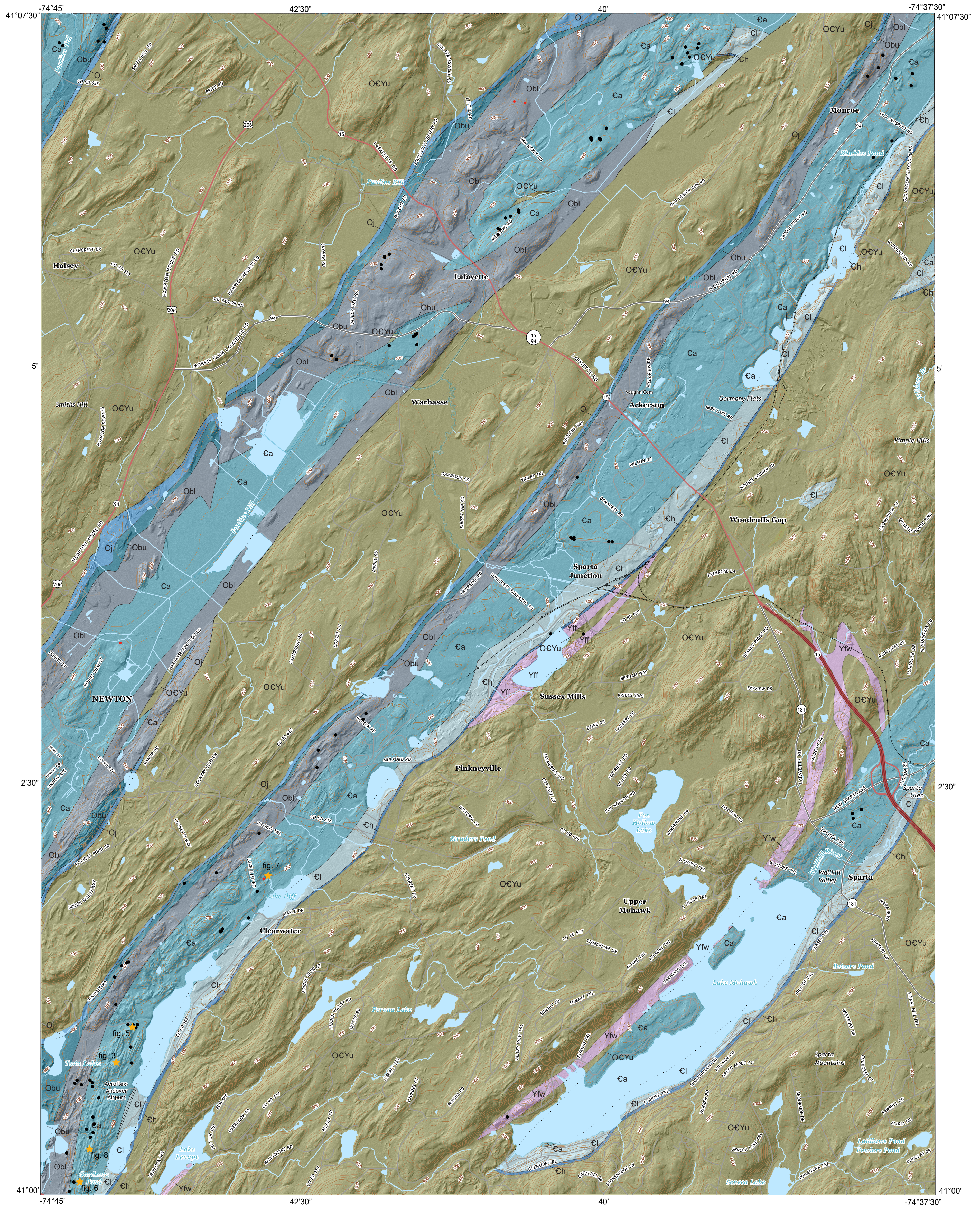
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WATER RESOURCES MANAGEMENT
NEW JERSEY GEOLOGICAL AND WATER SURVEY

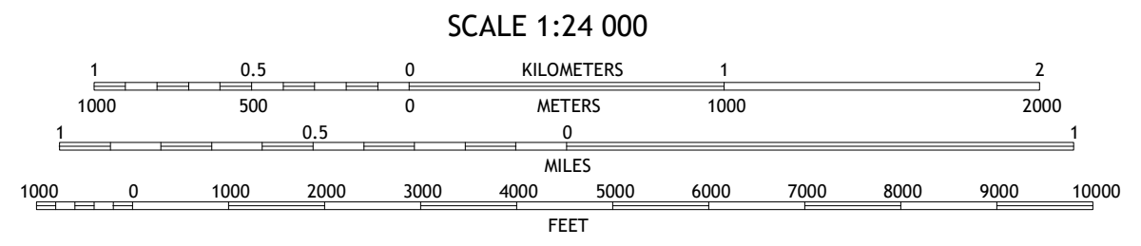
Prepared in cooperation with the
U.S. GEOLOGICAL SURVEY
NATIONAL COOPERATIVE GEOLOGIC MAPPING PROGRAM

KARST FEATURES OF THE NEWTON EAST QUADRANGLE
SUSSEX COUNTY, NEW JERSEY
OPEN-FILE MAP OFM 159



Produced by the U.S. Geological Survey
North American Datum of 1983 (NAD83)
World Geodetic System of 1984 (WGS84). Projection and
1 000-meter grid:Universal Transverse Mercator, Zone 18T
This map is not a legal document. Boundaries may be generalized for this map scale. Private lands within government reservations may not be shown. Obtain permission before entering private lands.
LiDAR base from New Jersey Office of GIS (State of New Jersey, 2018)
Roads..U.S. Census Bureau, 2016
Names...GNIS, 1979 - 2019
Hydrography...............................National Hydrography Dataset, 1899 - 2019
Contours...National Elevation Dataset, 2000 - 2013
Boundaries.............Multiple sources; see metadata file 2017 - 2018
Wetlands................FWS National Wetlands Inventory 2007

SCALE 1:24 000

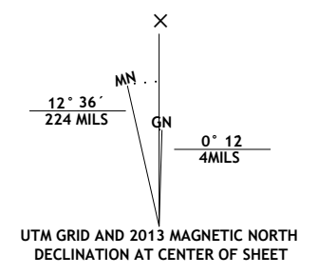


CONTOUR INTERVAL 20 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988

This map was produced to conform with the
National Geospatial Program US Topo Product Standard, 2011.
A metadata file associated with this product is draft version 0.6.18

Karst geology mapped by Z.C. Schagrin 2020-22.
Digital cartography by Z.C. Schagrin.
Bedrock geology mapped by D.H. Monteverde[1], R.A. Volkert[1], and G.C. Herman[1] in 1995-2000 and 2008-09 (Monteverde and others, 2022).
Research supported by the U. S. Geological Survey National Cooperative Geologic Mapping Program, under USGS award number G21AC10769.

The karst features depicted in this map represent only those that were studied at the time this map was published and does not include karst features that may develop subsequently.



UTM GRID AND 2013 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

U.S. National Grid
100,000-m Square ID
WL
Grid Zone Designation
18T

ROAD CLASSIFICATION

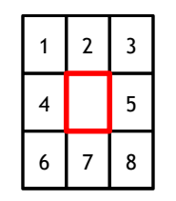
Expressway	Local Connector
Secondary Hwy	Local Road
Ramp	4WD
US Route	State Route

KARST FEATURES OF THE NEWTON EAST QUADRANGLE
SUSSEX COUNTY, NEW JERSEY

By

Zachary C. Schagrin
2023

QUADRANGLE LOCATION



1 Culvers Gap
2 Branchville
3 Hamburg
4 Newton West
5 Franklin
6 Tranquility
7 Stanhope
8 Dover

ADJOINING QUADRANGLES

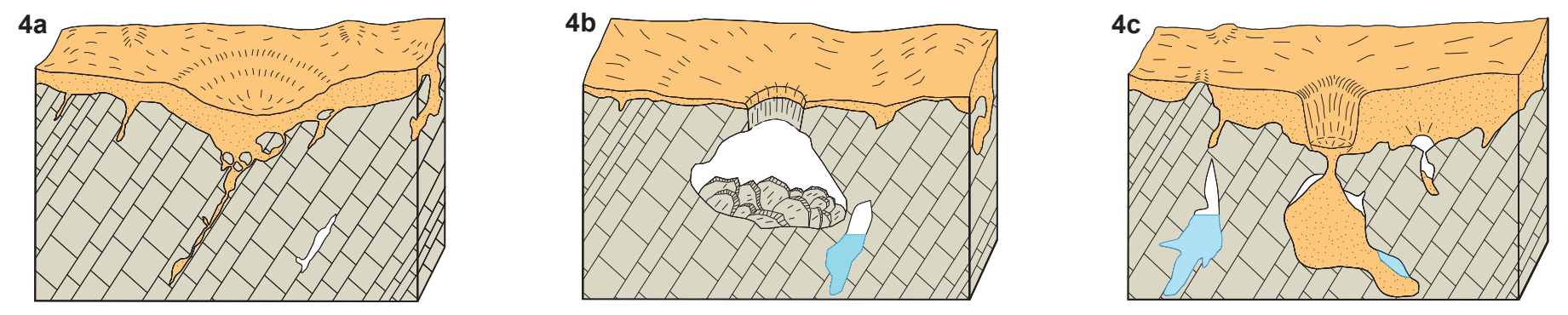


Figure 4. Diagrams showing a solution sinkhole (4a), a solution-collapse sinkhole (4b) and a cover-collapse sinkhole (4c). Diagrams from Dalton (2014).

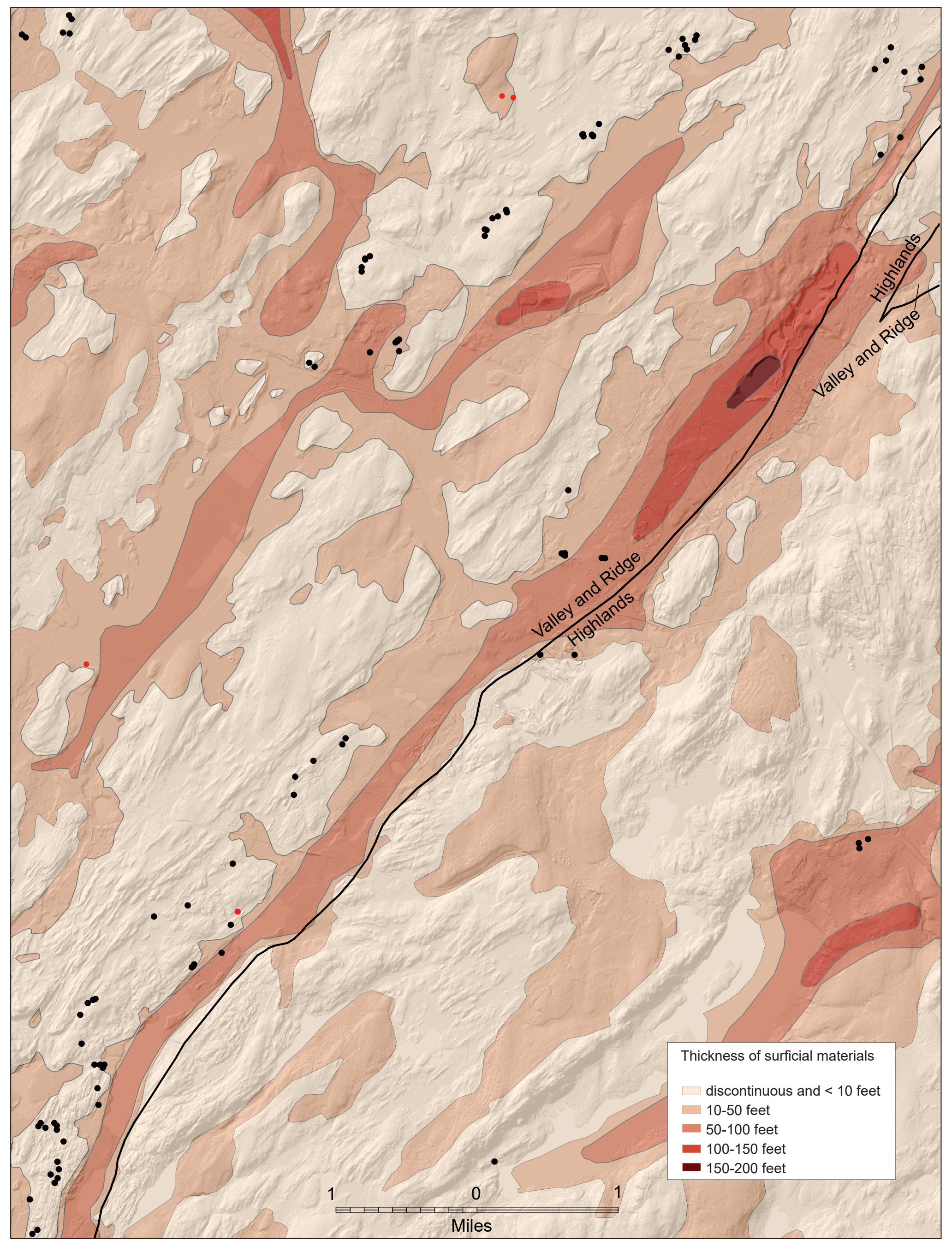


Figure 1. Map of thickness of surficial materials in the Newton East quadrangle over a hillshade base (State of New Jersey, 2018). The thickest surficial materials include late Wisonsinan till and glacial lake deposits along the border of the Valley and Ridge and Highlands physiographic provinces. Other surficial materials include postglacial deposits consisting of alluvium and swamp and bog deposits. Black dots are sinkholes and red dots are springs. Thickness map from Stanford and others (2007) based on Witte and Monteverde (2006).

INTRODUCTION

The Newton East 7.5-minute quadrangle in Sussex County, New Jersey hosts a karst terrain with active and inactive sinkholes, disappearing streams, springs, and caves with passages and chambers. These features occur in carbonates which were deposited in a shallow marine environment primarily in the Cambrian and Ordovician Periods and as far back as the Mesoproterozoic. Though these rocks were deposited up to 1.295 Ga (billion years ago), they still play a dynamic role in the health and public safety in the region. Draining sinkholes and springs exploiting, dissolving, and expanding bedding planes at and below ground surface, and surface and groundwater draining into caves, offer unique opportunities for unfiltered sources of water and contamination to reach aquifers. Furthermore, groundwater flow rates in karst landscapes are much greater than in nonkarst landscapes and present an increased risk of contamination. This constitutes a unique risk to public drinking water systems, private wells, and engineering projects through infastructure instability. Moreover, the continued active development of this karst terrain means it is not enough to just know where the existing features are, but it is critical to understand where they may occur and what geologic settings and formations are most prone to further karst development. A knowledge of these karst features and where they occur and may occur enables interested and affected parties to make decisions on the risk of geohazards for new and existing building construction projects, road and bridge work, use of natural resources, and contamination risks. This is especially important given increases in urbanization, and even more in New Jersey, the most densely populated state in the country.

This map identifies relationships between mapped karst features and the structure of the underlying bedrock geology in the Newton East quadrangle. This map, and others in the series of karst feature maps currently being developed by the New Jersey Geological and Water Survey (NJGWS) are critical tools for state and local governments, homebuyers and homeowners, public utilities, private consulting companies, and other parties. In northern New Jersey, where over fifty sinkhole-related incidents requiring remediation occur annually, these maps will provide guidance to interested parties to address and anticipate these occurrences (State of New Jersey, 2014).

The Newton East quadrangle is in the northwestern part of the state within both the Valley and Ridge and the Highlands physiographic provinces. The Valley and Ridge province underlies the northwestern part of the map area, while the Highlands province underlies the southeastern part (fig. 1). This map shows karst features using previous bedrock and surficial map data and new information gathered from field reconnaissance, remote sensing, and aerial imagery. The most recent updated mapping in this area includes a bedrock map (Monteverde and others, 2022), a surficial map (Witte and Monteverde, 2006), and a karst features map of the adjacent Newton West quadrangle (Monteverde and Witte, 2023).

A summary of the karst topography and an explanation of findings is provided below. A correlation of map units shows the age of karst-bearing units in the map area. Rose diagrams (fig. 9) offer orientation data and show a possible correlation between selected structural and karst features, and tables 1 and 2 show the distribution of sinkholes by geologic formation and by carbonate blocks. Further discussion explores geologic factors controlling the distribution of karst features among the formations and carbonate blocks.

KARST SETTING

Carbonate bedrock in the Newton East map area consists primarily of rocks of Cambrian and Ordovician age. These include the Cambrian and lower Ordovician rocks of the Kittatinny Supergroup—the Leithsville Formation (Єl), Allentown Dolomite (Єa), and the Beekmantown Group, here divided into upper (Obu) and lower (Obl) parts, and the Middle Ordovician Jacksonburg Limestone (Oj). 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 settings for significant sinkhole development. For this reason, this map includes the lower Cambrian Hardyston Quartzite (Єh) with carbonate rocks because parts of this unit have been described as dolomitic sandstone. The Mesoproterozoic Franklin Marble (Yff/Yfw) is the only carbonate Proterozoic unit in the map area.

The map area contains four informally named distinct southwest-northeast trending carbonate blocks (fig. 2). Three of these—the Paulins Kill Valley and the Upper and Lower Crooked Swamp blocks--continue into the map area from the neighboring Newton West quadrangle. The Paulins Kill Valley block is in the northwesternmost corner of the map area and the Upper and Lower Crooked Swamp blocks run through the central part and are separated by a belt in a synclinal trough of shale of the Martinsburg Formation that ends west of the quadrangle. The fourth carbonate block occurs in the southeastern portion of the map area and will be referred to as the Lake Mohawk block.

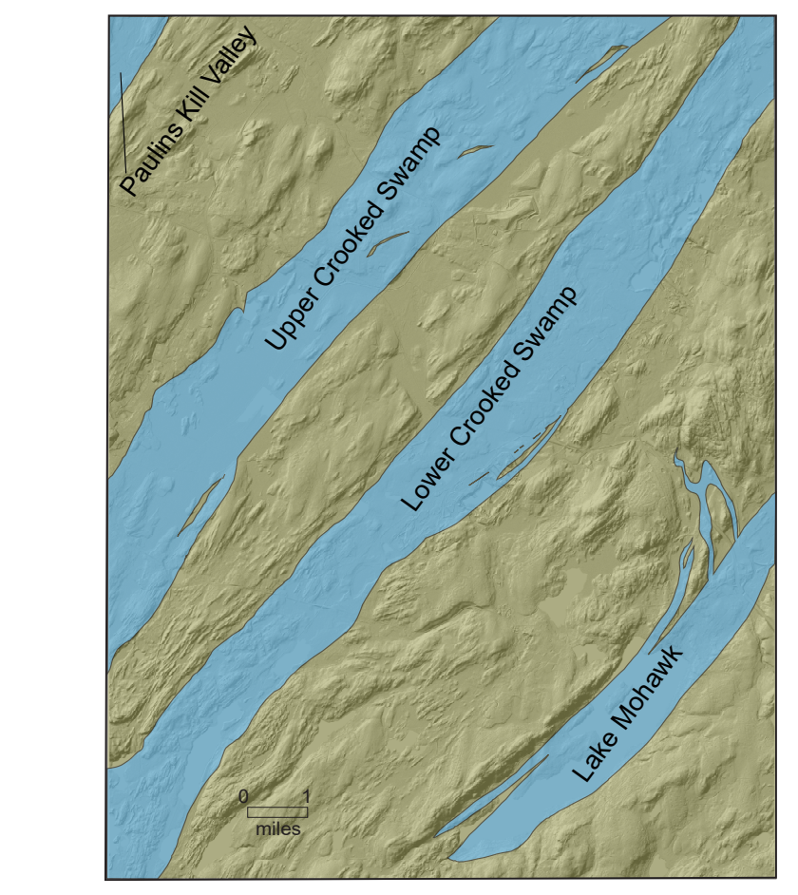


Figure 2. Map of the four carbonate blocks occurring within the Newton East quadrangle.

KARST FEATURES

Partially soluble carbonate rocks, such as limestone, dolomite, and marble, are more susceptible to weathering because of the slight acidity of water interacting with the soil. The dissolution of carbonate rock leads to the development of a karstic landscape often occurring along bedding planes when the rock is exposed to water (fig. 3). This also results in visible regional features within the map area, where carbonate bedrock forms valleys and more resistant bedrock forms ridges. It also results in more localized features such as sinkholes. The karst features observed in this study area include sinkholes, as well as caves, closed depressions, and springs.

Three main types of sinkholes occur within the map area (fig. 4). They are solution (4a), solution-collapse (4b), and cover-collapse sinkholes (4c). Solution, or dissolution, sinkholes (fig. 5) form at the soil-rock interface. Water comes into direct contact with carbonate bedrock through bedding planes, joints, and fractures, and dissolves carbonate bedrock. The water then transports the weathered material from the source and a small depression forms. This depression encourages movement of more water through dissolved channels and enlarges fissures in the underlying bedrock (Neuendorf and others, 2011). The depression gradually widens into a funnel shape. Most of the sinkholes and surface depressions in this map area demonstrate characteristics of solution sinkholes.

Figure 3. Dissolution of carbonate bedrock along a joint plane in the Allentown Dolomite in Kittatinny Valley State Park. Rock hammer for scale. Star in white box shows location in quadrangle. Photo by Z. Schagrin.

Figure 5. Solution sinkhole occurring in a meadow. This sinkhole became visible after a prescribed burn in the area cleared vegetation obscuring the feature. Rock hammer for scale. Star in white box shows location in quadrangle. Photo by Z. Schagrin.

The second type of sinkhole, solution-collapse sinkholes (fig. 6), sometimes called bedrock-roof collapse sinkholes, 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, which are sometimes referred to as caves. These types of sinkholes can be easy to identify at first because of the steep sides of the sinkholes, but over time the sides become less steep because of materrial collapsing in and can appear as solution sinkholes (Dalton, 2014). These 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.

Figure 6. Andover Pit solution-collapse sinkhole in Kittatinny Valley State Park. It is possible this sinkhole originally began as a cave and eventually the roof of the cave became unstable and collapsed into the void. Bedrock dissolution around this sinkhole continues, and the sinkhole is still enlarging. Expansion is in the southwest direction. Tire for scale. Star in white box shows location in quadrangle. Photo by Z. Schagrin.

The third type of sinkhole, cover-collapse sinkholes, form when cohesive materials form a clay layer in the soil above voids in the bedrock. Non-cohesive sediments spall into the void or cavity created by the dissolution of bedrock. The cohesive clay layer 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 at the surface.

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

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. Because of these, most water 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 work its way to the surface through other voids in carbonate rock. These karst features are known as springs (fig. 7).

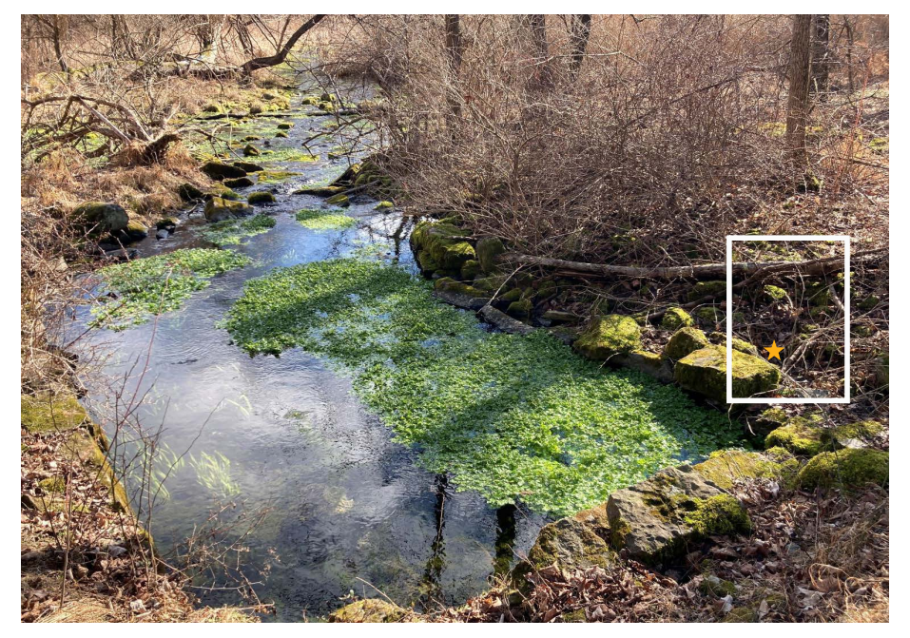


Figure 7. Spring in the southwestern part of the map area. This spring flows out of the Allentown Dolomite (Єa) and into Lake Iliff. There is a small pond northwest of the spring, perpendicular to strike, which could be a possible source. Spring is approximately 35 feet long by 15 feet wide. Star in white box shows location in quadrangle. Photo by Z. Schagrin.

Much of the carbonate bedrock in Newton East quadrangle is covered by glacial and postglacial surficial deposits. Late Wisconsinan till covers portions of each carbonate block, and late Wisconsinan glacial lake deposits overlay much of the Lower and Upper Crooked Swamp blocks, and some of the Lake Mohawk and Paulins Kill blocks. Postglacial deposits include alluvium and swamp and bog deposits of Holocene and late Wisconsinan age. They typically overlie glacial lake deposits and cover much of the Upper Crooked Swamp and some of the Paulins Kill blocks.

There are extensive areas of carbonate bedrock outcrop in the map area (fig. 10), and these are interpreted from the topographic map and LiDAR imagery. Locally, these areas are overlain by till and glacial meltwater deposits, notably in the area around the Lake Mohawk block and the nothern part of the Upper Crooked Swamp block.

MAPPING METHODS

Initial investigation into areas where sinkholes may occur included identifying areas underlain by carbonate rock. Once these areas were designated, LiDAR and aerial imagery, both recent and historic, were used to locate areas with outcropping bedrock and closed depressions. Particular attention was paid to areas of the Newton East quadrangle with less than 75 feet of unconsolidated cover (fig. 1). Closed depressions visible on LiDAR imagery (fig. 8) and potential karst features that appeared on aerial imagery were marked and field checked. In some cases, field checking showed these areas to be the result of non-karst processes like construction activity, subsidence of backfilled sites, abandoned mines, culverts, and fallen trees. These areas are not marked on the map. Features that were determined to be the result of karst activity are located on the map. Wherever possible, at each karst site measurements were taken to determine physical properties of each sinkhole—length, width, and depth—and which direction the long axis of the sinkhole was trending, if any trend was distinguishable. This was measured to compare and look for possible correlations with trends in bedding, joint, and cleavage planes. Farm fields provided a significant setting for recent sinkhole activity. Sinkholes that appeared over the winter and before spring plowing indicate active sinkhole formation at the surface. The difficulty in capturing this data lies in locating these sinkholes before they are filled in at the start of the farming season. 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 by using the springs database available from the NJGWS (Pallis and others, 2022).

RESULTS

In total, over 100 field-verified karst depressions were located and appear on this map. Few karst features occur in areas with a surficial cover greater than 75 feet.

Figure 9 offers a summary of measurements of the direction of the long axis of karst features with distinguishable trends (9a) and a comparison between these measurements and measurements of bedding planes (9b), cleavage planes (9c), and joint planes (9d) from carbonate rock in the map area. The average trend of measured sinkholes in the map area is N46E +/- 3.2°. This appears upon initial investigation to correlate with bedding of carbonate bedrock in the map area, which has an average trend of N42E +/- 3.6°. This matches the established tendency of caves in New Jersey to generally occur along strike.

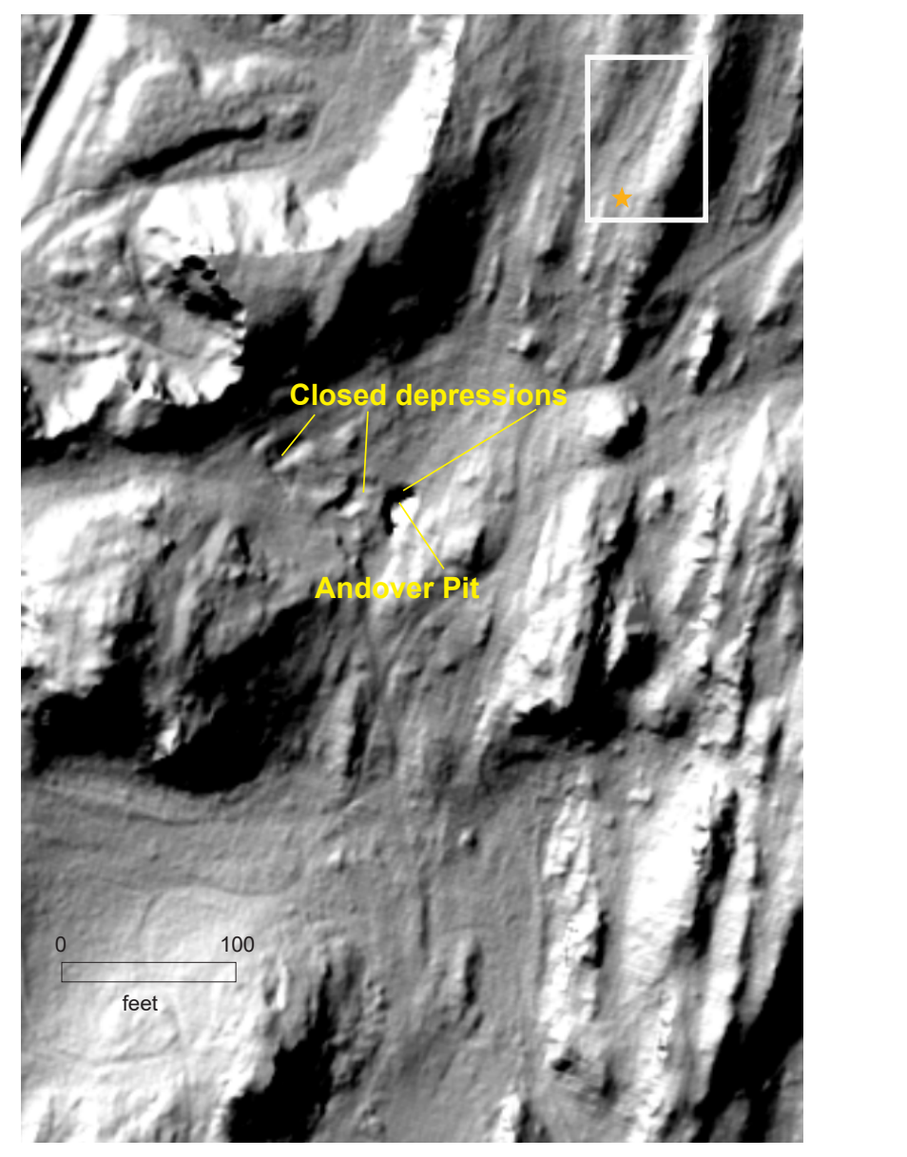


Figure 8. LiDAR imagery with hillshade of a part of the Newton East quadrangle in Kittatinny Valley State Park showing closed topographic depressions. These depressions were field checked to confirm that they are karst related. The large closed depression in the center of the image is the Andover Pit solution-collapse sinkhole (fig. 6). Star in white box shows location in quadrangle.

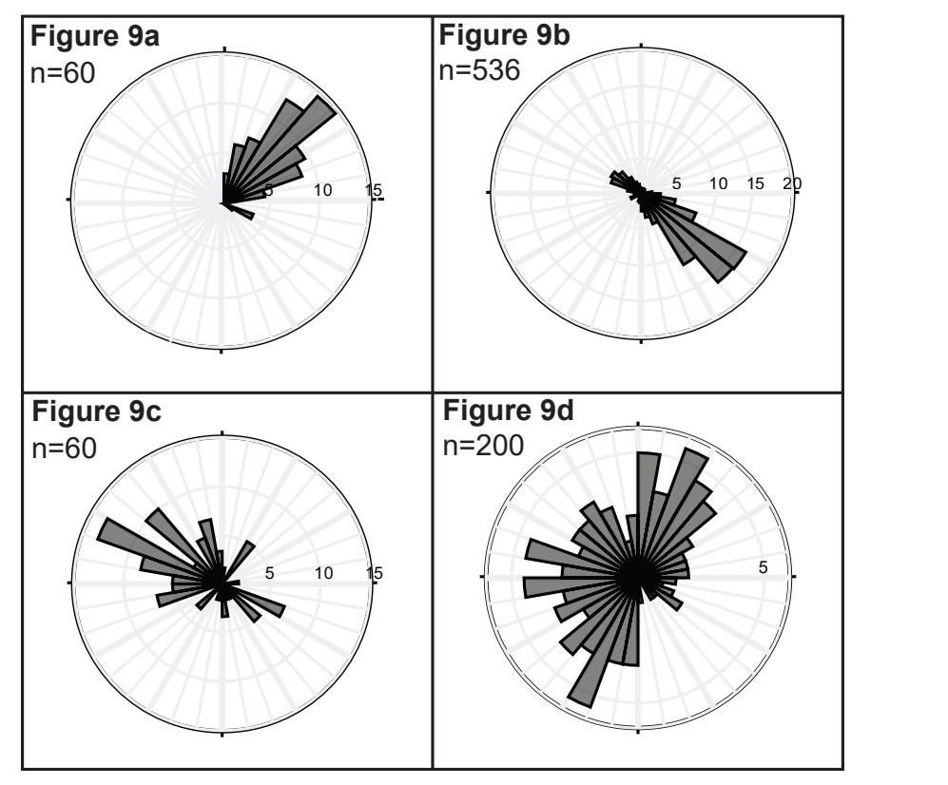


Figure 9. Rose diagrams showing the trend of the long axis of measured sinkholes in carbonate rocks (9a) and the dip direction of bedding planes (9b), cleavage planes (9c), and joint planes (9d) within carbonate rocks. n equals the number of measurements taken for each plot. Data from Monteverde and others (2022).

One factor that plays a large role in karst susceptibility is the significance that depth to bedrock plays in the development of karst features (Tipping and others, 2001). Green and others (2002) established that areas of bedrock outcrop and areas with minimal sediment cover are most conducive to karstification. In their study of karst hydrogeomorphic units, they 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, while areas with more than 75 feet of cover did not host karst features. The factors affect the karst landscape in the Newton East quadrangle. Figure 10 shows the distribution of bedrock outcrop. When comparing these with karst features on the map, it is evident that most occur in and near areas of extensive bedrock outcrop.

Table 1 shows a summary of the occurrence of karst features within each carbonate block. The total percentage of carbonate bedrock for each block is compared to the total percentage of karst features occurring within each block. From this summary, it is apparent that the Paulins Kill Valley block contains more than three times the percentage of karst features as it does the percentage of carbonate bedrock, while the Lake Mohawk block contains less than a quarter of the percentage of karst features (3.66%) as it does the percentage of carbonate bedrock (15.18%). In areas with significant surficial cover, especially greater than 75-100 feet, there is not enough groundwater recharge to dissolve cracks in bedding planes, cleavage planes, and joint planes (Tipping and others, 2001). So, while sinkholes may be covered by glacial sediment, the glacial sediment in these parts of the map area also actively discourages karst development. The contours showing the thickness of surficial materials further demonstrates this (fig. 1). In areas where the surficial materials are less than 75 feet thick, sinkholes are more common. However, where there is significant cover, less sinkholes have been located. Outcropping bedrock occurs within a significant portion of the Paulins Kill Valley block and most of the karst features identified in this block occur in the outcropping bedrock. The Lake Mohawk block contains till and glacial lake deposits over a significant portion of the total area. This is one reason for the underrepresentation of karst features in this block, as the surficial deposits have covered the karst features and have also impeded the development of new karst features.

The proportion of sinkholes in the Upper and Lower Crooked Swamp blocks is more similar to the proportion of carbonate outcrop area than it is in the Paulins Kill and Lake Mohawk blocks. Both contain late Wisconsinan till and the Lower Crooked Swamp block contains late Wisconsinan glacial lake deposits, while the Upper Crooked Swamp block contains postglacial swamp and bog deposits that overlie glacial deposits. However, these blocks also contain large areas of outcropping bedrock that account for most of the karst features present in each block.

Table 1. Table showing the percentage of carbonate area, total number of karst features, and percentage of total karst features for each carbonate block in the map area.

Carbonate Block	Percent of Total Carbonate Area	Total Karst Features	Percent of Total Karst Features
Paulins Kill Valley	1.59%	6	5.94%
Upper Crooked Swamp	37.76%	36	35.64%
Lower Crooked Swamp	45.47%	55	54.46%
Lake Mohawk	15.18%	4	3.66%

In addition to thickness of surficial cover, it has been shown in previous studies that larger and a greater number of sinkholes tend to form in areas with greater surface runoff. Poorly drained environments with ponding of surface water enable sedimentation and temporary plugging of sinkholes. As a result, sinkholes in these areas remain small and form at a slower rate. Alternately, well-drained environments rarely lead to ponding and sinkholes continue to develop and grow larger (Panno and others, 2008). Thus, lakes and large swamps and marshes (like the Newton Meadows along the Paulins Kill northeast of Newton) will inhibit sinkhole development.

Table 2 provides a summary of karst-bearing formations in the Newton East quadrangle. The Allentown Dolomite contains 59 karst features—the most of any formation in the map area. This is not surprising given the Allentown Dolomite comprises the highest percentage of carbonate bedrock. However, while the Allentown Dolomite covers just over 50% of all carbonate bedrock area on the map, it contains more than 58% of karst features. The larger percentage of total karst features versus total carbonate area comes largely at the expense of the Leithsville Formation, which comprises over 11% of the carbonate bedrock but contains only one located karst feature. In this map area, flatter, low-lying areas may have impeded sinkhole development in the Leithsville Formation through ponding and, as a result, many of the karst features are too small to identify or have been plugged by sediment. In tandem with this, another reason for the greater representation of some formations over others is the location of the formations relative to bordering gneiss and shale uplands. In Kittatinny Valley State Park, many of the karst features occur in the upper and lower Beekmantown, which border shales of both the Bushkill and the Ramseyburg Members of the Ordovician Martinsburg Formation. Likewise, many sinkholes were located in the Allentown Dolomite in Kittatinny Valley State Park. Studies in New Jersey have shown groundwater in gneiss bedrockwith pH values as low as 5.7 and groundwater in shale bedrock with pH values 6.7 to 7.0, whereas carbonate groundwater has had pH values recorded up to 7.5 (Miller, 1974). The Leithsville in the Kittantinny Valley State Park area and north to Monroe is bordered by gneiss to the east. Although few sinkholes are observed in the Leithsville here because of thick surficial cover and lakes, the low elevation of this Leithsville belt is likely the result of enhanced solution by runoff from the gneiss. Similar karst features occur to a lesser degree in the Paulins Kill Valley block in the northwestern part of the map area, where the Upper and Lower Beekmantown and Allentown Dolomite border shale uplands of the Martinsburg Formation.

Table 2. Table showing the total number of sinkholes, percentage of total sinkholes, and percentage of carbonate area for each geologic unit in the map area.

Formation	Number of Sinkholes	Percent of Total Sinkholes	Percent of Carbonate Area
Jacksonburg Limestone	1	0.99%	3.17%
Beekmantown Group, upper part	7	6.93%	5.37%
Beekmantown Group, lower part	31	30.69%	25.56%
Allentown Dolomite	59	58.42%	50.48%
Leithsville Formation	1	0.99%	11.48%
Franklin Marble	1	0.99%	4.46%

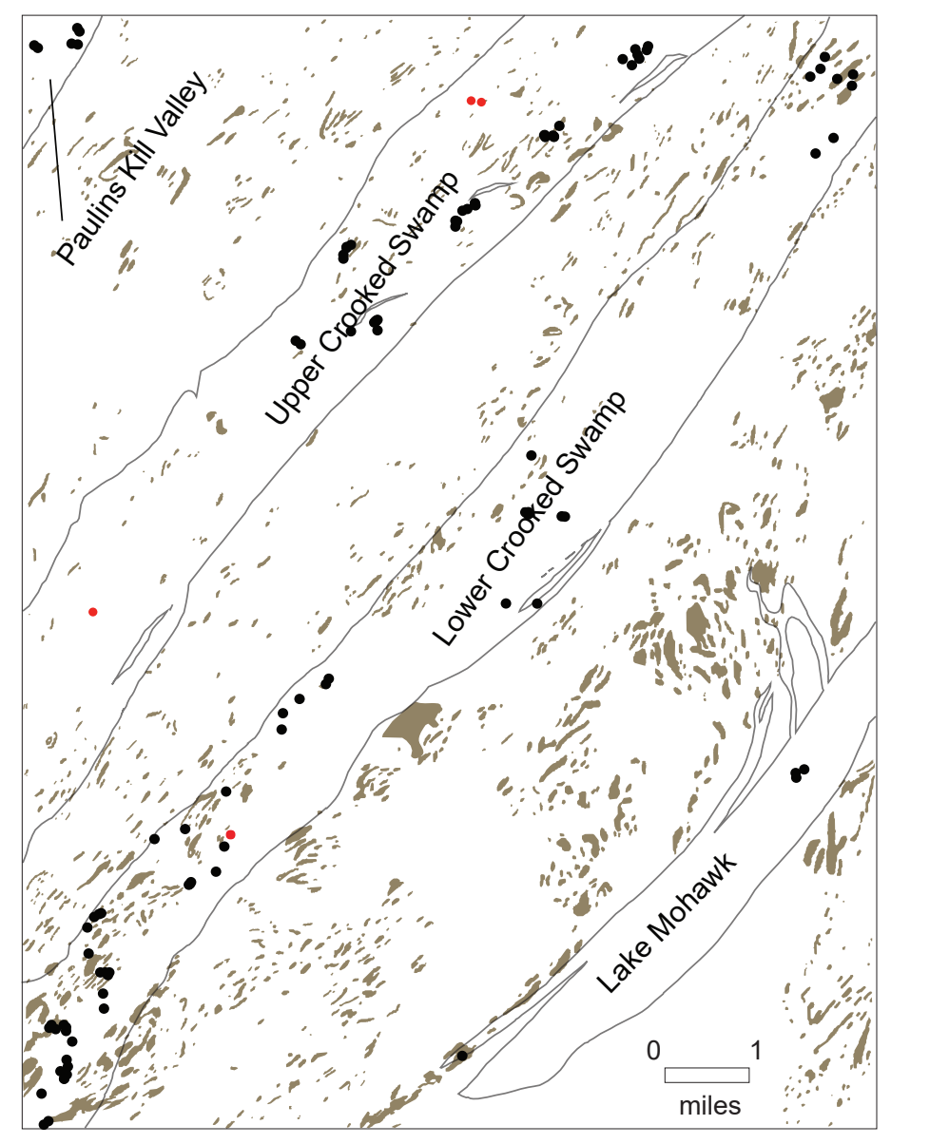


Figure 10. Bedrock outcrop in the Newton East quadrangle related to the four carbonate blocks. From Stone and others (2002) and Witte and Monteverde (2006). Brown polygons are bedrock outcrop. Black dots are sinkholes and red dots are springs.

DESCRIPTION OF MAP UNITS

(Monteverde and others, 2022)

PALEOZOIC VALLEY AND RIDGE

Oj **Jacksonburg Limestone (Middle Ordovician) (Kummel, 1908, Miller, 1937)** — Medium-dark-gray-weathering, medium-dark to dark-gray, laminated to thin-bedded, argillaceous limestone (cement-rock facies) and minor arenaceous limestone. 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). Thickness ranges from 150 to 1,000 feet regionally.

Beekmantown Group (Clarke and Schuchert, 1899)

Obu **Beekmantown Group, upper part (Lower Ordovician)** – Light- to medium-gray- to yellowish-gray-weathering 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. Contains pods, lenses and layers of dark-gray to black rugose chert. Thickness averages 200 feet, but locally as much as 800 feet.

Obl **Beekmantown Group, lower part (Lower Ordovician)** – 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, aphanitic 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. Locally, limestone may be completely dolomitized. 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 and others (1985) and Stonehenge Formation of Volkert and others (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.

Єa **Allentown Dolomite (upper Cambrian) (Wherry, 1909)** – Very light-gray- to medium-gray-weathering, light to medium-light- to dark-gray, fine- to medium-grained, locally coarse-grained dolomite and shaly dolomite. 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. Weathered exposures characterized by alternating light- and dark-gray beds. Ripple marks, oolites, algal stromatolites, cross-beds, edgewise conglomerate, mud cracks, and paleosol zones occur throughout but are more abundant in lower sequence. Lower contact gradational into Leithsville Formation. Approximately 1,800 feet thick regionally.

Єl **Leithsville Formation (middle to lower Cambrian) (Wherry, 1909)** – Light to dark grey, greyish red, and dark greenish grey weathering. Aphanitic to fine-grained, thin- to thick-bedded dolomite, argillaceous dolomite, dolomitic shale, quartz sandstone, siltstone, and shale. Quartz-sand lenses occur near 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.

Єh **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. Thickness ranges from 0 ft. to a maximum of 100 feet regionally.

PROTEROZOIC NEW JERSEY HIGHLANDS

Yff/Yfw **Franklin Marble (Mesoproterozoic)** – White- to light-gray-weathering, white or light gray, fine- to coarse-crystalline, calcitic to locally dolomitic marble containing calcite, graphite, phlogopite, chondrodite, and clinopyroxene. Separated into two lower Franklin marble bands (Yff) and an upper Wildcat marble band (Yfw) (Hague and others, 1956).

Other rocks

OЄYu **Undifferentiated non-carbonate rocks** – Paleozoic sedimentary rocks, including shale, sandstone, siltstone, and pebble conglomerate; Silurian alkalic dikes; Proterozoic conglomerate and sandstone; Proterozoic intrusive igneous rocks, including granite, alaskite, and monzonite; Proterozoic gneiss and amphibolite.

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EXPLANATION OF MAP SYMBOLS

LINE FEATURES

Contact - Dotted where location is concealed.

POINT FEATURES

- ● Locations of sinkholes and depressions suggested to be formed by karstification. Identified using LiDAR, air photos and field investigations.
- ● Locations of springs.
- ★ Location of photos used as figures.

CORRELATION OF MAP UNITS