KARST FEATURES in NEW JERSEY

Introduction

The topography of New Jersey varies from the rugged mountainous Highlands to the gently undulating Coastal Plain (fig. 1). A unique topography known as karst occurs in areas of the State underlain by soluble rocks. The Glossary of Geology (2005) defines karst as, "A type of topography that is formed on limestone, gypsum, and other soluble rocks, primarily by dissolution. It is characterized by sinkholes, caves, and underground drainage."

Soluble rocks (fig. 1) such as limestone, dolomite, marble and limestone-clast conglomerate cover about 350 square miles in the Valley and Ridge, Highlands and Piedmont Provinces. In the Coastal Plain Province the Vincentown Formation underlies about 100 square miles, and consists locally of soluble lime sand and thin limestone layers. The limestone layers (fig. 2) are more common from western Monmouth County southwestward to the Delaware River. Also a few thin cemented shell beds occur locally in other Coastal Plain formations.

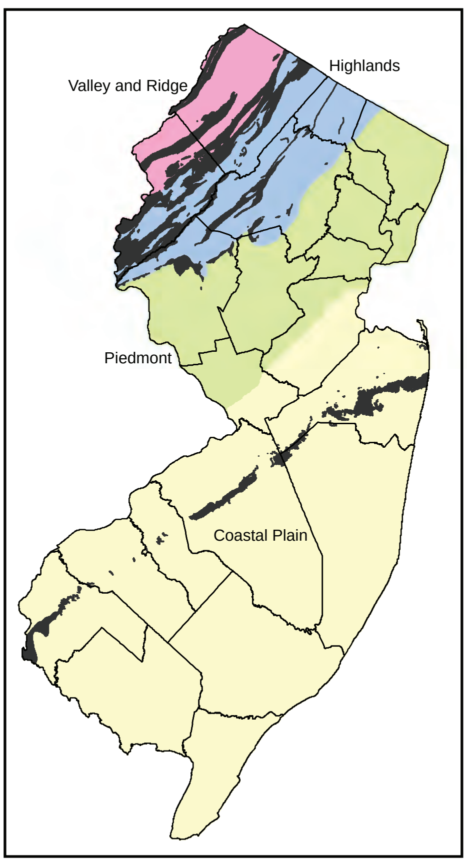

Figure 1. Map showing physiographic provinces and areas underlain by soluble carbonate rocks (in black) which may contain karst.

Figure 2. Thin, one-foot thick, limestone layers in the Vincentown Formation, Laurel Springs, Camden County (NJGWS Photo Collection, ca. 1899).

Almost all known karst features, including sinkholes and numerous caves, occur in the Precambrian and Paleozoic carbonate rocks of the Valley and Ridge, Highlands and Piedmont Provinces. Additionally, there is a small solution cave in the Mesozoic limestone of the Piedmont Province and two small caves in the Mesozoic sands and clays of the Coastal Plain. Both Coastal Plain caves have been destroyed but one was a solution cave directly below a lime-cemented shell bed (fig. 3). Many shallow depressions found in areas underlain by the younger Cenozoic Vincentown lime sand may be small shallow solution sinkholes.

Sinkholes (Dolines)

The term "sinkhole" is used by the media for any collapse feature, regardless of its origin, causing some to use the term "doline" for a karst depression. A "true" sinkhole is a closed, commonly circular depression, underlain by soluble rock, which drains to the subsurface. New Jersey sinkholes may be a few feet to hundreds of feet in diameter by 50 feet or more in depth. Individual sinkholes may coalesce to form a much larger irregular-shaped depression.

Figure 3. Small cave developed under a cemented shell bed in the Mount Laurel Formation, Mount Holly, Burlington County (NJGWS Permanent Notes, 1955).

There are three basic types of sinkholes: 1) the solution sinkhole, 2) solution collapse sinkhole, and 3) soil collapse sinkhole, all of which require dissolving the underlying bedrock. The process of solution is well understood. Rainwater dis-

Figure 4. Small solution openings in Epler Limestone, Hainesburg, Warren County (Don Monteverde).

Figure 5. Large solution opening in Onondaga Limestone, Vulture Cave, Sussex County (Ron Witte).

solves carbon dioxide as it falls and becomes slightly acidic. After it percolates into the ground it can pick up additional carbon dioxide from biological activity in the upper part of the soil zone to form a weak carbonic acid. This acidic subsurface water slowly descends to the soil-rock interface where it reacts with and dissolves the carbonate bedrock at the rock's top, and along its fractures, joints, and bedding planes, creating networks of tiny voids (fig. 4). This process neutralizes the ground water which becomes saturated with calcium carbonate ions. Clay and other insoluble mineral grains may be either deposited or moved with the ground water flow. The dissolution of the rock continues as long as there is new acidic water moving downward and flushing the carbonate-saturated water away. As the voids enlarge, a network of openings develops along select bedding planes, joints or fractures that capture more of the ground water flow. This network of voids may eventually become extensive enough to form a karst aquifer. Some of the voids are large enough to be caves (fig. 5).

The solution sinkhole (fig. 6) forms directly by dissolution of the

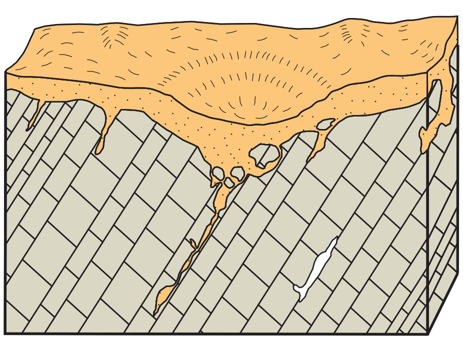

Figure 6. Diagram showing a solution sinkhole.

Figure 7. Solution sinkhole showing the rock-soil and residual soil filling, Greenwich, Warren County (Don Monteverde).

bedrock at the soil-rock interface leaving a funnel-shaped depression in the rock. The shape of the sinkhole is controlled by the orientation of bedding planes, joints or fractures (fig. 7). As solution continues the residual material may be transported by ground water into deeper voids. A thin layer of the residual soil mantles the rock so the surface depression mimics the depression in the underlying rock.

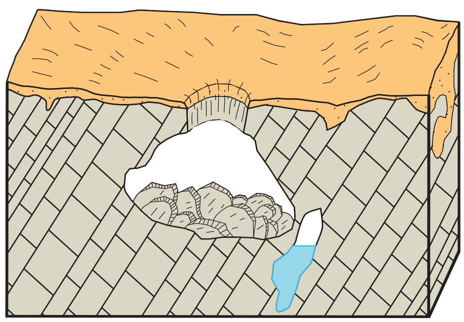

Figure 8. Diagram showing a solution-collapse sinkhole.

Solution collapse sinkholes (fig. 8) form when voids (caves) are close enough to the surface to cause the rock roof to collapse. As the cave widens, stress fractures in the roof allow blocks to break off and fall causing the opening to gradually work its way toward the surface. Eventually the roof can no longer support overlying material and it suddenly collapses into the underlying cave forming a sinkhole at the surface. Such a sinkhole is initially characterized by steep, rock-walled sides and rock rubble on its floor (fig. 9). Over time soil washes in and reduces the steepness of the sides making it difficult to separate it from other types of sinkholes.

Solution collapse sinkholes in New Jersey may be several hundred feet

Figure 9. Solution-collapse sinkhole, Andover Pit, Andover, Sussex County (Paul Steward).

wide by more than forty feet deep. Some linear, steep-sided, closed depressions a few hundred feet wide and a thousand or more feet long are identifiable on 7 1/2-minute quadrangles (fig. 10). These could

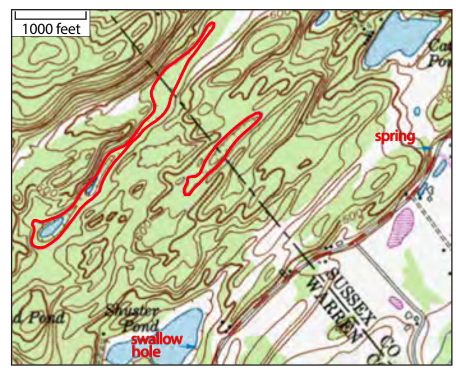

Figure 10. Portion of the Flatbrookville 7 ½-minute quadrangle showing several long closed depressions outlined in dark red. Also located is a spring and a swallow hole that are discussed in the section on springs.

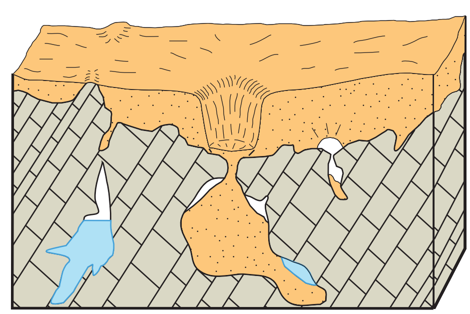

Figure 11. Diagram showing a soil collapse sinkhole.

be examples of caves that had their roofs eroded or collapsed by glaciers during the last ice age, about 21,000 years ago. They are similar to features in Indiana and Missouri termed "gulfs" (Powell (1961) p. 14 and Bretz (1956) p. 350-355).

Soil collapse sinkholes (fig. 11) form when a void in the soil overlying the carbonate bedrock suddenly collapses. As the rock weathers and decomposes, insoluble residual material may form a thick clayey soil layer. The clay content imparts some strength to the soil which may allow voids to form. Voids in soil form where soil particles are filtered down into the underling bedrock voids either as a saturated material or as dry crumbly soil. Over time a void in the soil will gradually work toward the surface (fig. 12). After a heavy rain the clayey roof over a void may lose strength and collapse forming a sinkhole. Over a short time the sides will begin to slope inward forming a conical-shaped depression. Generally the thicker the soil layer the larger the sinkhole.

Figure 12. Excavation showing a large soil void sinkhole, Greenwich, Warren County. The broken storm sewer pipe is three feet in diameter (Joe Fischer).

Soil collapse sinkholes are of great concern because they may form rapidly, sometimes almost instantaneously, and may occur at almost any time and under any conditions. In contrast, solution sinkholes in New Jersey rocks take thousands of years to form and solution collapse sinkholes require large shallow voids in the bedrock; these are uncommon in the State. A blast at a quarry, foundation or road cut can cause the roof of a cave to fail, leaving a feature similar to a solution collapse sinkhole. In 1958, after a blast at a quarry in Peapack, Somerset County, approximately 600 tons of rock dropped 18 feet into a cave leaving a hole in the quarry floor.

Figure 13. Water-treatment plant building in Warren County damaged by a soil collapse sinkhole (Greg Herman).

Sinkholes cause damage to roads and property each year, with some of the most significant collapses occurring in Warren County (figs. 13 and 14). In 1983, one of the largest documented soil collapse sinkholes in the State happened in Phillipsburg. This hole was large enough to cause a 2-story house to rotate on its foundation so that the front part of the house subsided to its second story and the back of the house moved at least 10 feet off its foundation. A second large depression opened between the house and the street. All this transpired in a few hours as a result of a broken water main. Water from the leak saturated the soil, allowing the soil to rapidly flow down into voids in the underlying carbonate bedrock causing the sinkholes.

Figure 14. Soil collapse sinkhole on Interstate Route 78 prior to the opening of the Phillipsburg bypass section, Warren County (NJDOT).

It is often difficult to determine the origin of a sinkhole. After a period of time the effects of weathering obscure the nature of its development. A thorough site investigation using aerial photography may be helpful in determining if sinkholes are present, and if so, possibly their type, and age. Borings and test pits are also helpful in a site assessment. They can indicate the thickness of the soil layer over bedrock and may disclose soil or rock voids susceptible to future sinkhole development.

Caves

A cave may be defined as a natural rock opening of large enough size to permit human exploration and extending into a region of sharply reduced or no light. Of the 128 known caves in New Jersey, 106 formed by dissolution of carbonate rocks; 20 are fracture, fissure or talus caves in insoluble rocks and 2 of unknown origin in the Coastal Plain sands and clays. New Jersey solution caves range in length from 8 to more than 1,250 feet with most of the their passages being low, less than 4 feet high (fig. 15). Some caves contain narrow fissure passages as much as 18 feet high.

Figure 15. Low wide solution passage in Fasalo's Cave. Note the ceiling pendent (upper left) which was formed by differential solution, (ca. 1960, Richard Anderson).

Most of the caves in the State have either linear or simple branchwork passages generally oriented along the strike of the formation. A few caves have network patterns of interconnected passages (fig. 16).

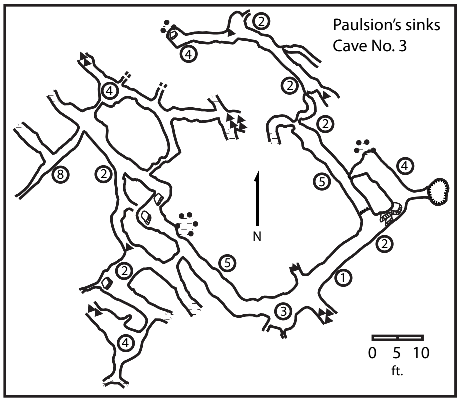

Figure 16. Map of Paulison's Sinks Cave No. 3 showing a network pattern of passage development along several sets of joints (surveyed by Northern New Jersey Grotto, 1955; Dalton, 1976).

Sinking Streams and Swallow Holes

Sinking streams are small streams that disappear underground. In areas underlain by karst they may gradually sink into the streambed or flow into a sinkhole or swallow hole. In New Jersey sinking streams are generally small tributaries with little to no normal flow and are classified as intermittent streams. Most flow occurs only after a heavy rain or in the spring when there is abundant runoff from melting snow and a high water table. Occasionally a sinkhole may form in the bed of a substantial stream. In July of 1965 Pohatcong Creek was dry for a distance of 5 miles upstream from Springtown toward Washington, Warren County. Field investigations indicated many areas where the stream sank into gravel. In one area several large sinkholes were found in the stream bed, one measured 6 feet in diameter by 3 feet in depth and another was 25 feet long by as much as 5 feet deep.

Springs

New Jersey springs occur in all rock types but those in insoluble rocks are generally small, discharging only a few gallons per minute (gpm). Some springs that occur in sand and gravel may be very large with flows exceeding 1000 gpm. Springs in carbonate rock areas range in size from very small to very large and commonly they vary more widely in flow than those in sand and gravel. For instance, the estimated flow of Bonnie Brook Spring (fig. 17) on September 10, 1947 was about 900 gpm and on May 22, 1967 the flow was about 5,000 gpm (NJGWS Permanent Notes).

Carbonate bedrock springs commonly show a faster and greater response to rainfall because they are discharge points for large networks of underground solution channels. In karst areas much rainfall runs off into sinkholes and sinking streams and is directed downward into open channels in the underlying carbonate bedrock aquifer. There is little to no filtration of any contaminants picked up by the rainfall because there usually is little soil between the surface and the aquifer, where water flow is in open channels.

Figure 17. Bonnie Brook Spring, spring house, Sussex County. The spring is dammed to form a large pool which has two outlets (Don Monteverde).

One of the largest documented karst drainage systems in New Jersey discharges at Bonnie Brook Spring. As part of a 1968 New Jersey Department of Health investigation to identify the source of bacterial contamination in the spring, the New Jersey Geological Survey recommended placing dye in the swallow-hole outlet of Schuster Pond, located more than 4,000 feet away from the spring along the strike of the local bedrock (fig.10). The dye appeared in the spring in less than two hours (Robert Meyers, Northern Regional Health Officer, personal communication, 1968). An unpublished report provided to the State by the spring's landowner in 1974 suggested drainage from Catfish Pond to Bonnie Brook Spring, but provided no direct evidence other than a water table diagram. This report did cite the 1968 Schuster Pond dye test to show a connection between the Schuster Pond and the spring.

Groundwater levels in karst aquifers respond quickly to rainfall events as much of the recharge is directly from sinkholes. The flow in the aquifer is along secondary (smaller or tributary) fractures and joints to the primary (main) solution network. A karst aquifer may consist of many individual drainage basins that discharge to a large spring or series of springs. The karst aquifer is extremely susceptible to contamination as there is little to no filtration of the subsurface water and any contamination can spread rapidly in the aquifer.

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