STATE OF DELAWARE
UNIVERSITY OF DELAWARE
DELAWARE GEOLOGICAL SURVEY

OPEN FILE REPORT NO. 14

SINKHOLES, HOCKESSIN AREA, DELAWARE

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NEWARK, DELAWARE
MARCH 1981

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INTRODUCTION

Sinkholes are depressions in the land surface or holes in the ground caused by subsidence or collapse of surficial material into openings in soluble rock. Sinkholes usually develop in "karst" areas underlain by carbonate rocks. Karst is defined as "terrane with distinctive characteristics of relief and drainage arising primarily from a higher degree of rock solubility in natural waters than is found elsewhere" (Jennings, 1971, p. 1). In addition to sinkholes, other features associated with karst are: caves, disappearing streams, and well-developed subsurface drainage systems.

Karst areas in Delaware are confined to the Piedmont where two small valleys are underlain by carbonate rocks of the Cockeysville Formation (Figure 1). Hockessin Valley, the larger of the two areas, contains several typical karst features including sinkholes, a cave, and a subsurface drainage system. The hydrologic system sustains several high yielding public supply wells in addition to numerous low yielding domestic wells.

Pleasant Hill Valley is located about 3 miles south-southwest of Hockessin within the Pike Creek drainage basin. Limited geologic and hydrologic data from Pleasant Hill Valley suggest the presence of water-bearing subsurface cavities, although no known sinkholes or caves exist in the valley.

Sinkholes were not known to exist in Delaware prior to 1978. Six have been found in Hockessin Valley since early 1978. Three developed during periods of above average precipitation in the spring of 1978 and in the fall to early winter of 1979. Limited evidence suggests that the other three sinkholes also formed during those weather conditions and time periods. Several other closed, topographic depressions in the valley have been identified as probable sinkholes.

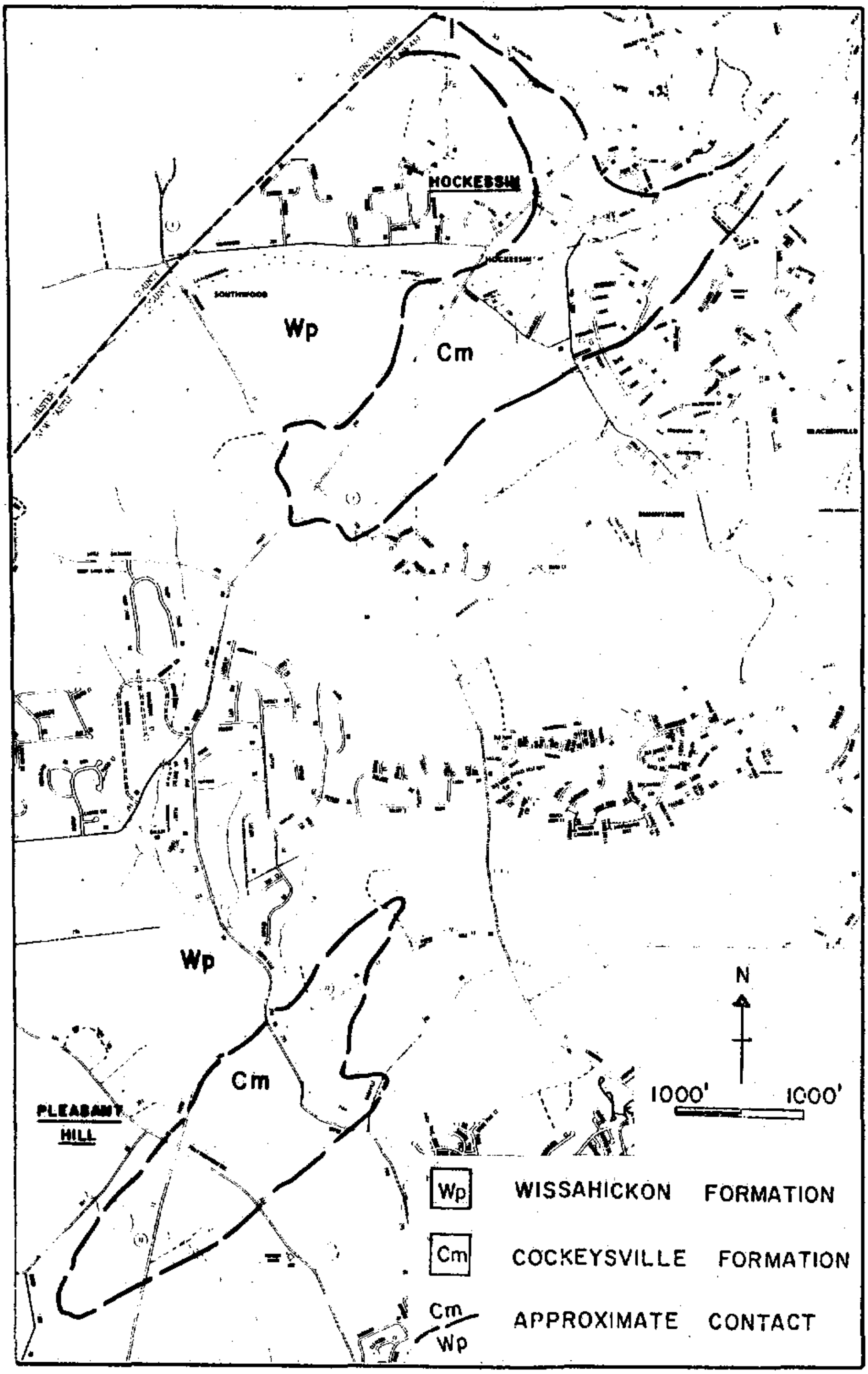


Figure 1. Geologic map showing the location of carbonate rocks (Cm) in Hockessin Valley and Pleasant Hill Valley (after Woodruff and Thompson, 1972).

Sinkholes are geologic hazards when they present risk or potential danger to life and to property. Ground failure may cause structural damage to buildings, roads, bridges, underground utilities, and septic systems. Solution of rock can also alter drainage resulting in pollution of ground water by sewage and industrial or agricultural wastes. An understanding of the geologic and hydrologic conditions under which sinkholes and subsidence develop is necessary, not only for current, but also for future planning, design, and development of areas underlain by carbonate rocks.

Purpose

This report has been prepared in response to increased public concern about sinkholes in northern Delaware. Its purpose is to discuss the occurrence and origin of newly discovered sinkholes in Hockessin Valley in order to provide a factual basis for evaluating any hazards that they may pose.

Acknowledgments

This report evolved in part from a recently completed project conducted by the Delaware Geological Survey in cooperation with New Castle County. Sinkholes were investigated and geologic and hydrologic conditions in Francis J. Swift Park evaluated. The New Castle County Department of Public Works and Department of Parks and Recreation provided financial support for test drilling, geophysical logging, and field and aerial reconnaissance.

Historical and current water levels at several locations in Hockessin Valley were provided by Mr. Bangalore Lakshman, Artesian Water Company. Precipitation data were obtained from Mr. Philip Janvier, National Vulcanized Fibre Company, Yorklyn, Delaware and from the National Weather Service Office, New Castle, Delaware.

Special thanks are expressed to several citizens who reported locations of sinkholes and to the many others who provided access to their properties.

GENERAL DISCUSSION OF SINKHOLES

A prerequisite to the development of sinkholes is the presence of rock soluble in water. Areas containing such rocks in

Delaware are underlain by the Cockeysville Formation composed primarily of calcium carbonate (limestone) and calcium-magnesium carbonate (dolomite).

Rainwater containing carbonic acid (H_2CO_3) is slightly acidic as a result of its reaction with carbon dioxide (CO_2) from the atmosphere and organic matter on the ground surface. The carbonic acid by reacting with calcite and dolomite forms calcium (Ca^{+2}), magnesium (Mg^{+2}), and bicarbonate (HCO_3^-):

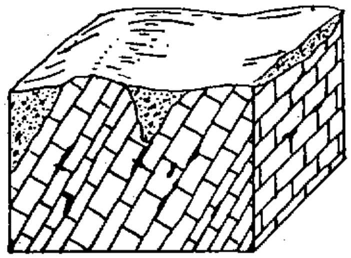
$$\underset{\text{calcite}}{CaCO_3} + \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{calcium}}{Ca^{+2}} + \underset{\text{bicarbonate}}{2HCO_3^-}$$

$$\underset{\text{dolomite}}{CaMg(CO_3)_2} + \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{calcium}}{Ca^{+2}} + \underset{\text{magnesium}}{Mg^{+2}} + \underset{\text{bicarbonate}}{4HCO_3^-}$$

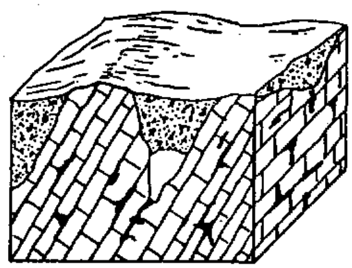
Solution is generally slow and particularly effective along joints, bedding planes, and other lines of weakness in the rock. In time, small openings may grow into a complex system of interconnected subsurface passageways.

Sinkholes are generally circular or elliptical in shape varying from 1 or 2 feet to several hundred feet in depth, and from a few feet to several thousand feet in diameter. Existing sinkholes in the Hockessin Valley are relatively small, reaching a maximum diameter of 20 feet and a depth of 10 feet. Heavy precipitation, seasonal fluctuations of the water table, earthquakes, man-induced effects such as lowering of water levels by pumping, altering natural surface drainage patterns, vehicular vibration, and blasting may precipitate collapse or subsidence.

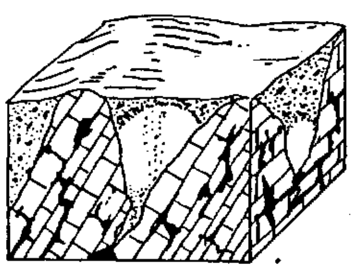
Because of their various sizes, shapes, and methods of formation, sinkholes are difficult to classify. Nevertheless, for purposes of this report, those in Hockessin Valley have been classified into three types: collapse sinks, subsidence sinks, and solution sinks. Collapse sinks are usually readily identifiable. They often develop rapidly, and have steep walls and flat bottoms. Where bedrock is at shallow depth, a cave or cavern through which the surficial material is carried away may be exposed. A void or cavity beneath the land surface is required for the formation of a collapse sink. At least three collapse sinks in the Hockessin Valley appear to have formed as a result of rapid infiltration of rainfall into subsurface cavities. The development of a collapse sink is shown diagrammatically in Figure 2.



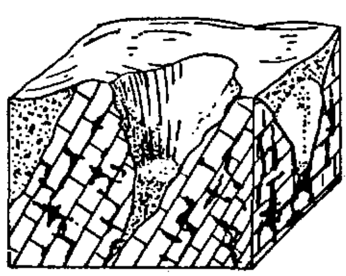
A weathered rock and soil zone of variable thickness and an irregular bedrock surface develop in response to differential weathering of carbonate rocks.



As solution proceeds, voids often form along zones of weakness in the rock. The weathered rock or soil roof of the cavity generally develops the shape of an arch.



Dissolving of the bedrock provides pathways for downward migration of material with consequent cavity enlargement. The arch loses its structural integrity as it becomes thinner.



The arch eventually collapses into the void and a new sinkhole is formed. Arch failure often occurs during or immediately following periods of intense precipitation.

Figure 2. Schematic diagram showing sinkhole formation (after McGlade, Geyer, and Wilshusen, 1972).

Subsidence sinks usually occur in areas underlain by thick sections of soil and/or weathered rock. Growth of subsidence sinks may be a slow process with the material continually migrating into voids. Rapid episodic growth of subsidence sinks can produce rather large features with nearly vertical sides that resemble collapse sinks (Figure 3).

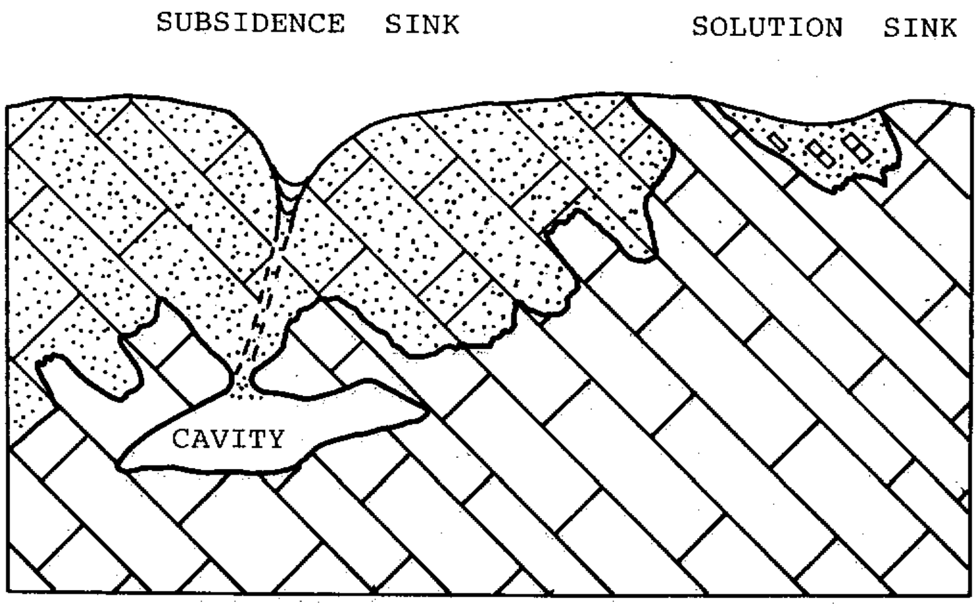


Figure 3. Hypothetical cross-section showing a subsidence sink and a solution sink (Dotted area represents weathered marble).

Generally, the development of solution sinks (Figure 3) is a very slow process. Initially solution sinks may appear as very shallow, circular, topographic depressions with interior drainage, and thus are very difficult to recognize. Circular vegetative patterns may be associated with solution sinks indicating variations in moisture content within and outside the depression. Water may be ponded on the surface of the sink if the soils within the depression are relatively impermeable. If, on the other hand, the depressions are underlain by well-drained soils, water will rapidly infiltrate into the subsurface and the sink may appear dry most of the time.

Damage resulting from sinkholes can be either minimal or severe depending upon their location and rate of formation. In urbanized areas sinkholes can cause damage to building foundations, roads, parking lots, utilities, and sewage disposal systems. Slow subsidence may cause subtle changes such as cracks in roadways, foundations, and walls. Rapid sinkhole development may bring about turbidity in adjacent water wells for short periods of time and provide a direct entrance for contaminated surface water into the ground-water system. In addition, exploration of sinkhole caves can be extremely hazardous as many caves are quite unstable. Sinkholes in open fields and woods generally do not cause any serious damage. However, livestock and farming operations may be adversely affected if the features are not identified and isolated.

METHODS OF INVESTIGATION

Existing data such as geologic maps, geologic logs, geophysical logs, water levels, and ground-water withdrawals were studied to establish a general geologic and hydrologic framework. The history of mining in Hockessin Valley was reviewed to determine the locations of abandoned clay and marble pits and quarries that could otherwise be confused with sinkholes. Aerial photographs covering the period 1932-1979 were examined for evidence of sinkholes and land subsidence.

Eleven test holes were drilled in Francis J. Swift Park with the University of Delaware drill rig assigned to the Water Resources Center. Gamma-ray geophysical logs were completed in eight test holes. Two test holes were converted to piezometers for water-level measurements.

GENERAL GEOLOGY AND HYDROLOGY OF HOCKESSIN

Hockessin Valley, a 4-square mile area in northern Delaware and southeastern Pennsylvania, is located in the upper Mill Creek drainage basin (Figure 4). The valley is underlain by rocks of the Cockeysville and Wissahickon formations. The Cockeysville occupies 1.5 square miles of a relatively broad flat part of the valley in the central portion of the basin. The Wissahickon Formation surrounds the Cockeysville on the flanks of the valley and occupies an area of about 2.5 square miles of the drainage basin.

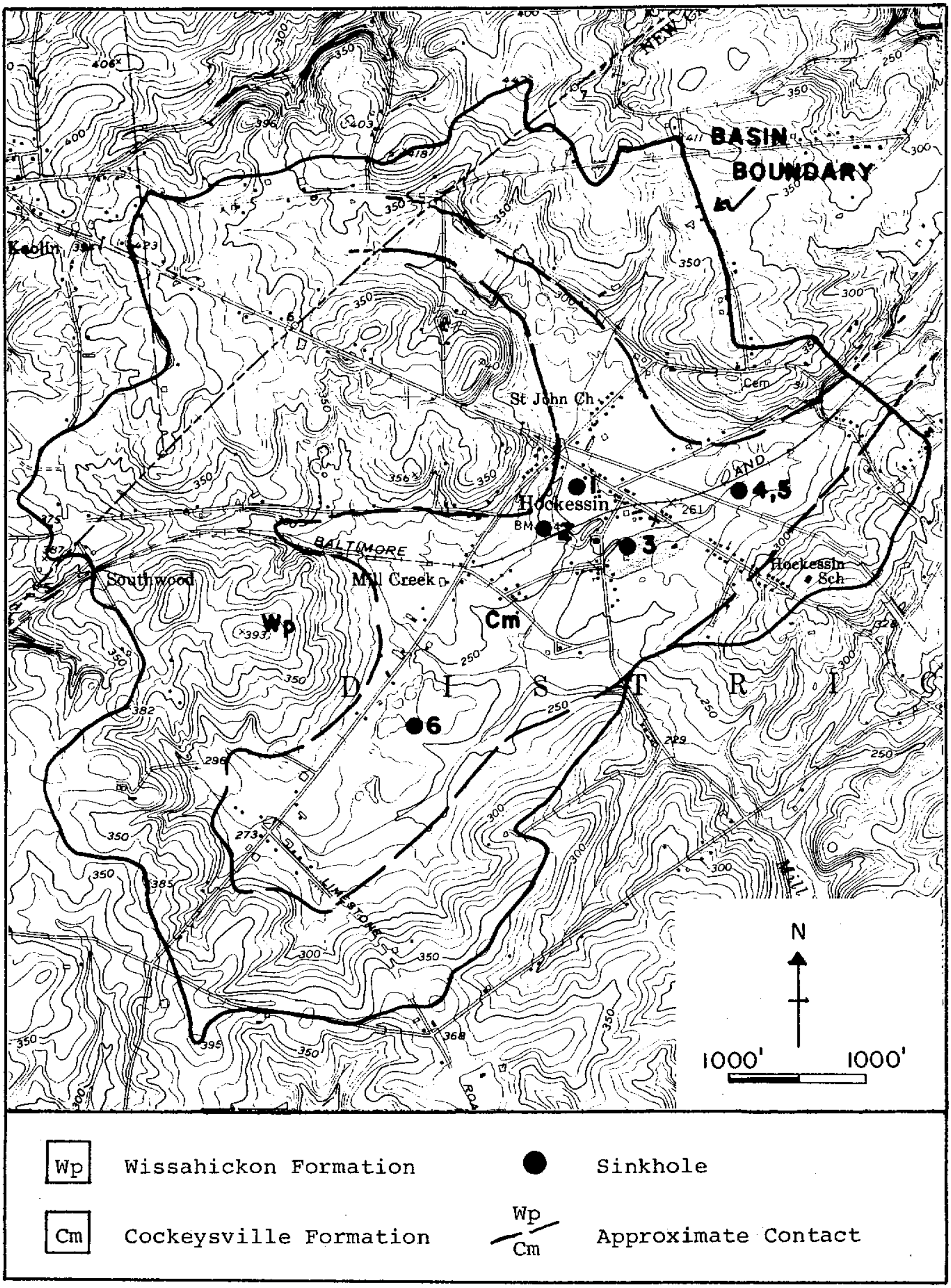


Figure 4. Geologic map of the Upper Mill Creek Drainage Basin (after Woodruff and Thompson, 1972).

The only exposures of marble in the valley occur in sinkholes 2 and 3 (Figure 4). Otherwise, the Cockeysville Formation is present only in the subsurface. It consists of fine- to coarse-grained white calcitic and dolomitic marble with interbeds of calcareous schist. The predominant soil type, Glenville silt-loam, is moderately to poorly drained and typically contains a layer of fragipan that usually retards the infiltration of surface water. Fragipan is "a loamy, brittle, subsurface horizon that is very low in organic matter and clay, but is rich in silt or very fine sand" (U. S. Soil Conservation Service, 1970, p. 95). During dry periods the firm and brittle fragipan soil may dry and crack thereby forming paths for rapid infiltration of surface water. Fluvial silts, sands, and gravels deposited along the present streams were derived from areas of higher elevation occupied by the Wissahickon Formation.

A highly variable but relatively thick section of weathered marble (10 to 120 feet) underlies the surficial soils and fluvial material. Well drillers often refer to this material as "sand." The presence of the sand has been known for several years. Examination of samples reveals a very fine to very coarse dolomitic and calcitic sand with minor amounts of silt and clay. This sand is generally white, tan, light brown, or grayish-white and contains persistent but variable amounts of phlogopite mica. Carbonate minerals are usually interlocked and appear to be compact and hard when undisturbed. The weathered rock zone (sand) is not entirely homogeneous; many zones consist of relatively fresh marble although other zones are highly weathered and contain small solution openings.

The weathered marble is a very important hydrologic unit in Hockessin Valley. The sand has been reported to have supplied about 80 percent of the water to house wells in the valley (Leis, 1975). Prior to development of the aquifer by a water purveyor, water levels in the sand were usually within 10 to 20 feet of land surface in the central portion of the valley. However, as a result of increased pumpage "about one-third to one-half of the saprolite (weathered rock) in the marble area was at least partially dewatered prior to 1974" (Williams, 1979, p. 14).

The contact between the weathered and the fresh marble is highly irregular and gradational. Drilling of deep wells into the marble beginning in the early and mid-1960's revealed the presence of water-bearing solution openings. Additional drilling and geophysical logging verified the presence of a complex hydrologic system of interconnected voids and solution openings capable of yielding large quantities of water to wells.

The strike of the marble is N 49° E to N 63° E and is consistent with the regional structural trend in this portion of the Piedmont. The dip of the marble is highly variable. For example, rocks in the north-central portion of the valley in Francis J. Swift Park are inclined at angles ranging from 45° to 52° to the northwest, but in the southern portion of the valley the rocks dip about 28° to 30° to the southeast. Joint sets measured in marble in Sinkhole No. 2 are oriented N 19° E, N 29° E, and N 34° E, with dips approaching 90° (Talley, 1980b).

The Wissahickon Formation consists predominantly of gneiss and schist and is not normally capable of storing and transmitting large quantities of water to wells; yields to individual wells are generally less than 10 to 20 gallons per minute. The thickness of the weathered Wissahickon rock is generally much less than that of the marble. The weathered rock is usually siltier and clayier and, therefore, less permeable than the weathered rock which overlies the marble. Because of the differences in the hydrologic characteristics of the marble and schist, the two formations are probably not interconnected to a large degree; each formation functions as a separate hydrologic unit.

SINKHOLE DEVELOPMENT IN HOCKESSIN

The locations of six sinkholes identified in Hockessin Valley are shown on Figure 4.

Sinkhole No. 1

A property owner reported that a shallow depression formed at the site of Sinkhole No. 1 in 1975 or 1976. This small depression developed into a large collapse-subsidence sink very rapidly in the spring of 1978 following several months of above normal precipitation. During that interval several storms were accompanied by precipitation exceeding 2 inches in a 24-hour period.

In May 1978, Sinkhole No. 1 was circular, about 18 feet in diameter, and 8.5 feet deep (Talley, 1980a). The walls were steep-sided, indicating rapid development (Figure 5). A small hole near the center of the bottom of the sink acted as a conduit for rapid infiltration of water and fine-grained soil into the subsurface. Marble was not exposed in this sinkhole.

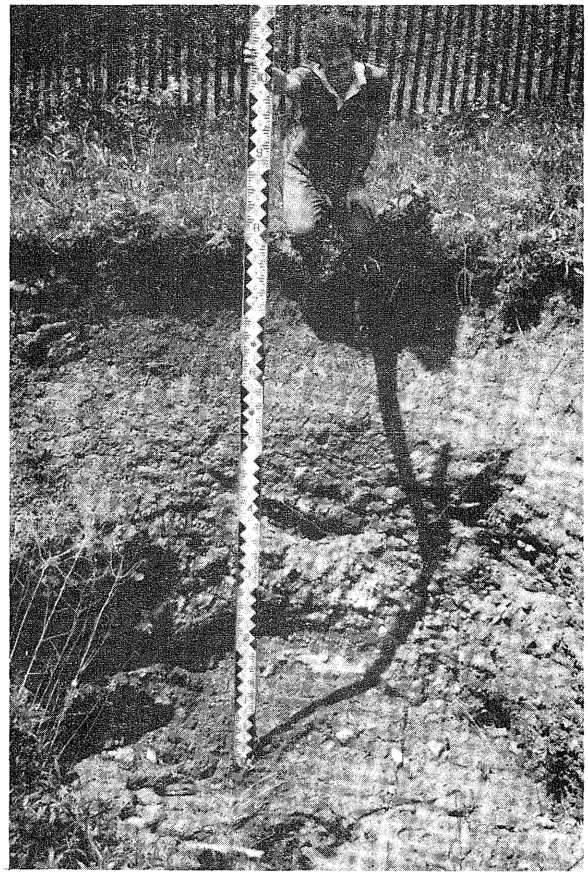


Figure 5. Sinkhole No. 1, Francis J. Swift Park (from Talley, 1980a).

Drilling around the sinkhole revealed the presence of a 2- to 9-foot thick section of soil, silt, sand, and gravel (Figure 5). A thick section of weathered Cockeysville marble extends from about 9 feet to 50-70 feet below land surface. Relatively hard, fresh marble underlies the weathered rock zone. In April 1979 the water level was about 35 feet below land surface.

Sinkhole No. 1 was repaired in late May 1980 by backfilling with medium to large crushed stone. Bentonite clay was placed over the stone to prevent the infiltration of surface water. Topsoil was in turn placed over the bentonite clay so that natural vegetation would grow over the sink. As of January 1981 no additional subsidence has occurred at this site.

Sinkhole No. 2

Sinkhole No. 2 was discovered during aerial reconnaissance of the valley on October 17, 1979. The sinkhole is located on the flood plain of a small tributary of Mill Creek and developed very rapidly immediately following a period of 14.19 inches of rainfall during September and October (Figure 6). Evidence supporting rapid development is: (1) vertical walls; (2) undisturbed vegetation draping into the hole and fresh roots entering the sink from sides; and, (3) fresh, moist soil on the bottom and sides of the hole.

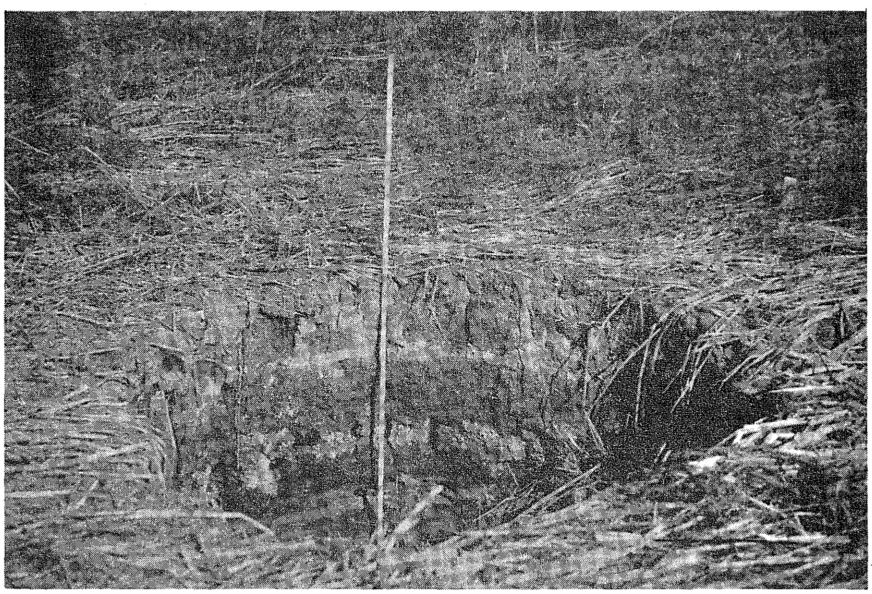


Figure 6. Sinkhole No. 2, Francis J. Swift Park. Photograph taken approximately one week after formation.

The feature was about 6 feet in diameter and 3 feet deep in June 1980. Excavation prior to repair revealed the existence of an irregular bedrock surface and a 3-foot wide zone of soft carbonate rock and clayey silt. The orientation of this zone is N 34°E, nearly parallel with a major joint set. A small hole that probably functioned as a throat into which the surficial material collapsed and was carried away is shown in Figure 7. A 3-foot by 3-foot pod of clayey silt is apparent above and to the left of the throat. The presence of this

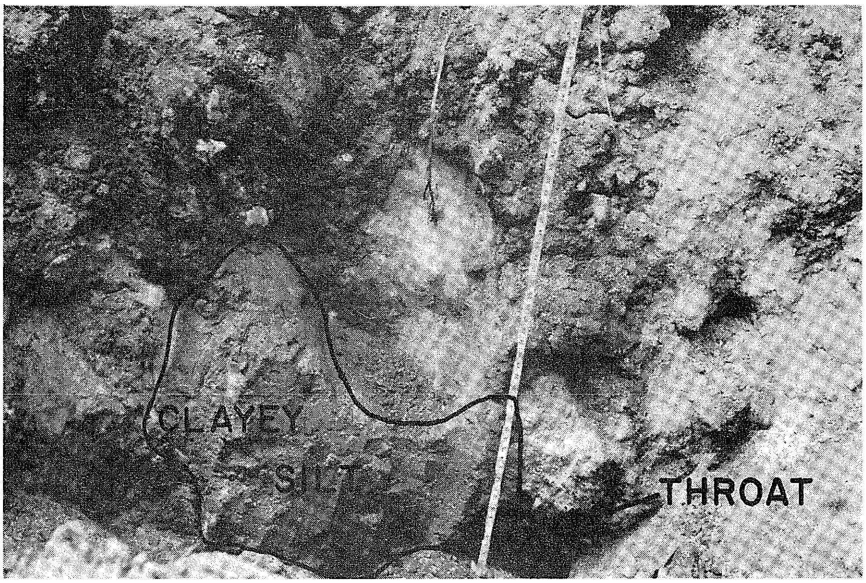


Figure 7. Sinkhole No. 2, Francis J. Swift Park. Note pod of clayey-silt and the throat.

clayey silt, which is incompatible with the adjacent bedrock, suggests that the material was implaced through collapse into a void at some time in the past.

Sinkhole No. 2 was repaired utilizing the same method as that used to repair Sinkhole No. 1.

Sinkhole No. 3

Sinkhole No. 3 is located on the flood plain of a small tributary of Mill Creek. Soil and debris on the ground surface near the sinkhole indicate that this portion of the flood plain is subjected to periodic flooding. Sinkhole No. 3 formed in the fall of 1979 during a period of above average precipitation and was, at that time, about 8.5 feet in diameter and 10 to 12 feet deep. Fresh soil exposed in the vertical walls and fresh roots suspended in the sinkhole (Figure 8) suggests rapid formation. A cave in the bottom of the sink reaches a length of 10 feet. The cave formed in marble and calcareous

Figure 8. Sinkhole No. 3. Note fresh roots extending into the sink.

schist that strikes N 48° E and dips to the southeast at an angle of 28° (Scheinfeld, 1980). The floor of the cave consists of broken carbonate rocks; the throat, through which approximately 12 cubic yards of soil was carried away, was not evident in the sinkhole.

Sinkholes No. 4, 5, and 6

Sinkholes No. 4 and 5 occur on the flood plain of a very small intermittent stream. These features are about 2 feet in diameter and 2 to 3 feet deep. There is no direct evidence as to the time of their formation. However, the growth position and age of the small saplings growing in the sinkholes suggest that the features formed sometime during 1978.

Sinkhole No. 6 is located in the western portion of the valley. This sinkhole is about 8 feet in diameter and 2 to 3 feet deep. Limited evidence indicates that it probably formed during the spring or summer of 1978.

CONCLUSIONS

Predicting where or when solution and collapse will occur is extremely difficult because of the complex subsurface drainage system and associated ground-water movement in the marble portion of the Hockessin Valley. Nevertheless, additional sinkholes are likely to occur because the following conditions conducive to their formation exist in the valley:

1. Relatively thick, but variable, sequences of unconsolidated and semi-consolidated weathered carbonate rock;

2. An irregular bedrock surface with relief exceeding 100 feet;

3. Porous and permeable calcitic and dolomitic sand (weathered rock) underlain by solution openings that provide means for rapid infiltration of surface water and easy movement of ground water;

4. Fluctuating ground-water levels that were originally near the surface but are now 30 to 40 feet below the surface in the central portion of the valley;

5. The occurrence of shallow, circular, undrained depressions;

6. Relatively high mean annual precipitation (greater than 40 inches) with recharge averaging about 32 percent (13 inches) of precipitation (Williams, 1979);

7. A relatively broad flat valley containing flood plains subjected to periodic flooding;

8. Complex structural deformation of the area with well developed joint sets.

Future planning and construction in Hockessin and Pleasant Hill valleys must take into account sinkhole development in those areas. Problems often associated with sinkholes include damage to foundations, roads, parking lots, and underground utilities as well as contamination of ground water by sewage and chemical spills. These problems can be minimized or avoided if all geologic, hydrologic, topographic, engineering, and soil information is utilized in the decision making process.

REFERENCES

Jennings, J. N., 1971, Karst: An introduction to systematic geomorphology: Australian National Univ. Press, Canberra, 252 p.

Leis, W. M., 1975, Geologic control of ground-water movement in a portion of the Delaware Piedmont: Univ. of Delaware Master of Science Thesis, 165 p. (unpublished).

McGlade, W. G., Geyer, A. R., and Wilshusen, J. P., 1972, Engineering characteristics of the rocks of Pennsylvania: Pennsylvania Geol. Survey, Fourth Series, Environmental Geology Report No. 1, 200 p.

Scheinfeld, R. A., 1980, Karst development in the Hockessin area, New Castle County, Delaware: Univ. of Delaware, Dept. of Geology, 18 p. (unpublished).

Talley, J. H., 1980a, Sinkhole study in Francis J. Swift Park, for New Castle County - Progress Report, 30 p. (unpublished).

______, 1980b, Sinkhole study in Francis J. Swift Park, for New Castle County - Supplemental Report, 14 p. (unpublished).

United States Soil Conservation Service, 1970, Soil Survey New Castle County, Delaware: U. S. Dept. of Agriculture, 97 p.

Williams, P. M., 1979, Ground-water availability, Hockessin, Delaware: Delaware Dept. Natural Resources and Environmental Control, 22 p. (unpublished).

Woodruff, K. D., and Thompson, A. M., 1972, Geology of the Newark area, Delaware: Delaware Geol. Survey Map Series No. 3.