

GLACIAL LAKE SCHOHARIE: AN INVESTIGATIVE STUDY OF GLACIOLACUSTRINE LITHOFACIES IN CAVES, HELDERBERG PLATEAU, CENTRAL NEW YORK

JEREMY M. WEREMEICHIK AND JOHN E. MYLROIE

Department of Geosciences, Mississippi State University, MS 39762-5448, USA, jmw868@msstate.edu

Abstract: The glacially deranged karst topography of the Helderberg Plateau, central New York, contains glaciolacustrine lithofacies deposited at the end of the Wisconsin glaciation. Eight pre-glacial caves (Barrack Zourie Cave, McFail's Cave, Howe Caverns, Secret Caverns, Bensons Cave, Gage Caverns, Schoharie Caverns, and Caboose Cave), containing a unique sediment section, are located within the footprint of Glacial Lake Schoharie, Schoharie County. The lithofacies consist of three individual facies, stratigraphically uniform, with the middle facies in sharp contact with the facies directly above and below. This assemblage displays a similar stratigraphic sequence from bottom to top: tan/white to light-grey, very thinly bedded, silts and clays, rich in calcite, overlain by poorly sorted, matrix-supported gravels, in turn overlain by dark-brown very thinly bedded silts and clays. A post-glacial cave within the lake's footprint (Westfall Spring Cave) and a nearby pre-glacial cave outside the footprint (Knox Cave) were found to lack these lithofacies. The tan/white to light-grey sediment facies is interpreted to be a glacial rock flour deposited under stagnant lake conditions that limited fine-grained calcite particle dissolution. The overlying gravel facies were emplaced during lake termination and reestablishment of turbulent epigenic flow in the eight stream caves. The more recent dark-brown facies is perhaps soil-loss deposition following European settlement. Initial interpretations hypothesized that the deposits were laid down under ice-cover conditions, but similar deposits were not found in other glaciated cave settings in New York. The results presented here explain why the unusual tan/white and light-grey glaciolacustrine facies are not found in other caves in the glaciated central New York region, as those areas were not subject to inundation by glacial lake water.

INTRODUCTION

As glaciers advanced and retreated across northeastern USA during the late Pleistocene, sediment and exposed bedrock were stripped from the cave-rich Helderberg Plateau in central New York State (Fig. 1) and subsequently covered by allochthonous glacial sediment. The sediment was deposited on the surface of the plateau and in caves within the plateau. The glacial sediment deposited within the caves has been sheltered from surficial weathering and erosion, perhaps allowing for a more accurate record to be preserved. Interpretation and analysis of cave-sediment samples can assist in reconstructing the glacial surficial environment. In most glacially deranged landscapes, surficial deposits can be scarce and difficult to identify; this study focused and relied on samples collected from within caves. Specific horizons of sediment found within the caves in the area are thought to be associated with the existence of a glacial event (Mylroie, 1984; Palmer et al., 1991; Palmer et al., 2003). The work presented here re-interprets those earlier studies and classifies the unique cave sediments as being the result of a glacial lake inundating the caves. This lake, referred to as Glacial

Lake Schoharie, is believed to have existed during the Late Wisconsin glacial period approximately 23.0–12.0 ka in the present-day Schoharie Valley in central New York (e.g., Dineen, 1986).

To determine the nature of the surficial environment in the Schoharie Valley during the Late Wisconsin glacial period, multiple research trips were taken to select caves located in the Helderberg Plateau. From west to east, the caves in this study include: Barrack Zourie Cave (1 in Fig. 1), McFail's Cave (2), Howe Caverns (3), the Secret-Benson Cave System (4 and 5), Gage Caverns (6), Westfall Spring Cave (7), Schoharie Caverns (8), Caboose Cave (9), and Knox Cave (10) (Figs. 1 and 2). As documented by Lauritzen and Mylroie (2000), U/Th dating of stalagmites demonstrates that the caves of the Schoharie Valley are older than the onset of the most recent glaciation and, in some cases, several glaciations reaching back 350 ka.

The purpose of this study was to reconstruct the paleo-environment of a proglacial lake, Glacial Lake Schoharie, located primarily within Schoharie County, New York. The glacial lake is thought to have endured at least four readvances of the Mohawk and Hudson glacial lobes during the Woodfordian Substage of the Late Wisconsin

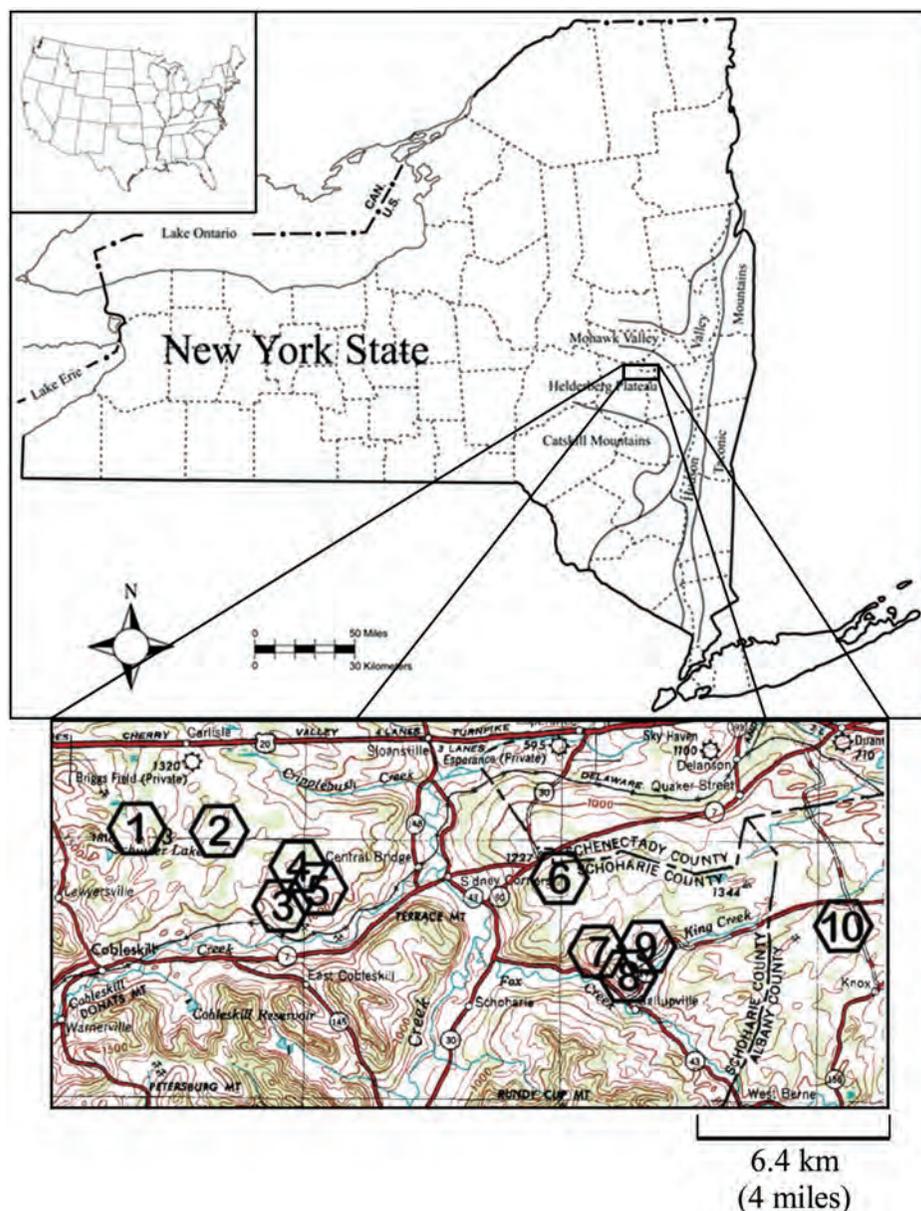


Figure 1. Map showing the general location of the Helderberg Plateau in east-central New York as well as the locations of the caves included in this study. 1 = Barrack Zourie Cave, 2 = McFail's Cave, 3 = Howe Caverns, 4 = Secret Caverns, 5 = Benson's Cave, 6 = Gage Caverns, 7 = Westfall Spring Cave, 8 = Schoharie Caverns, 9 = Caboose Cave, 10 = Knox Cave. Re-drawn and modified from Dineen (1986). The topographic map is a USGS Digital Raster Graphic of the Binghamton Quadrangle (1:250,000 scale).

glaciation; see Dineen (1986) for more detail on the nature of the readvances. The multiple readvances caused the shoreline of the lake, and hence its footprint, to be modified multiple times throughout its existence. The caves selected for investigation were chosen because of the known or suspected existence of what had been presumed to be glacially deposited clastics, in particular a characteristic white or tan clay that is sometimes varved (e.g., Mylroie, 1984; Dumont, 1995) (Figs. 3 and 4). It was also the purpose of this study to determine the composition

of the “white” clay horizon, as well as the composition of other associated sediment horizons (Fig 4).

Initial interpretation of Mylroie (1984) was that the sediments found in the caves were caused by stagnant sub-ice conditions during the last glacial maximum. Under these conditions, Mylroie (1984) thought that the stagnant water would soon saturate with CaCO_3 and that any further fine-grained particulate CaCO_3 introduced to the caves would not dissolve and could collect as a sediment deposit. There was no disagreement in the literature about

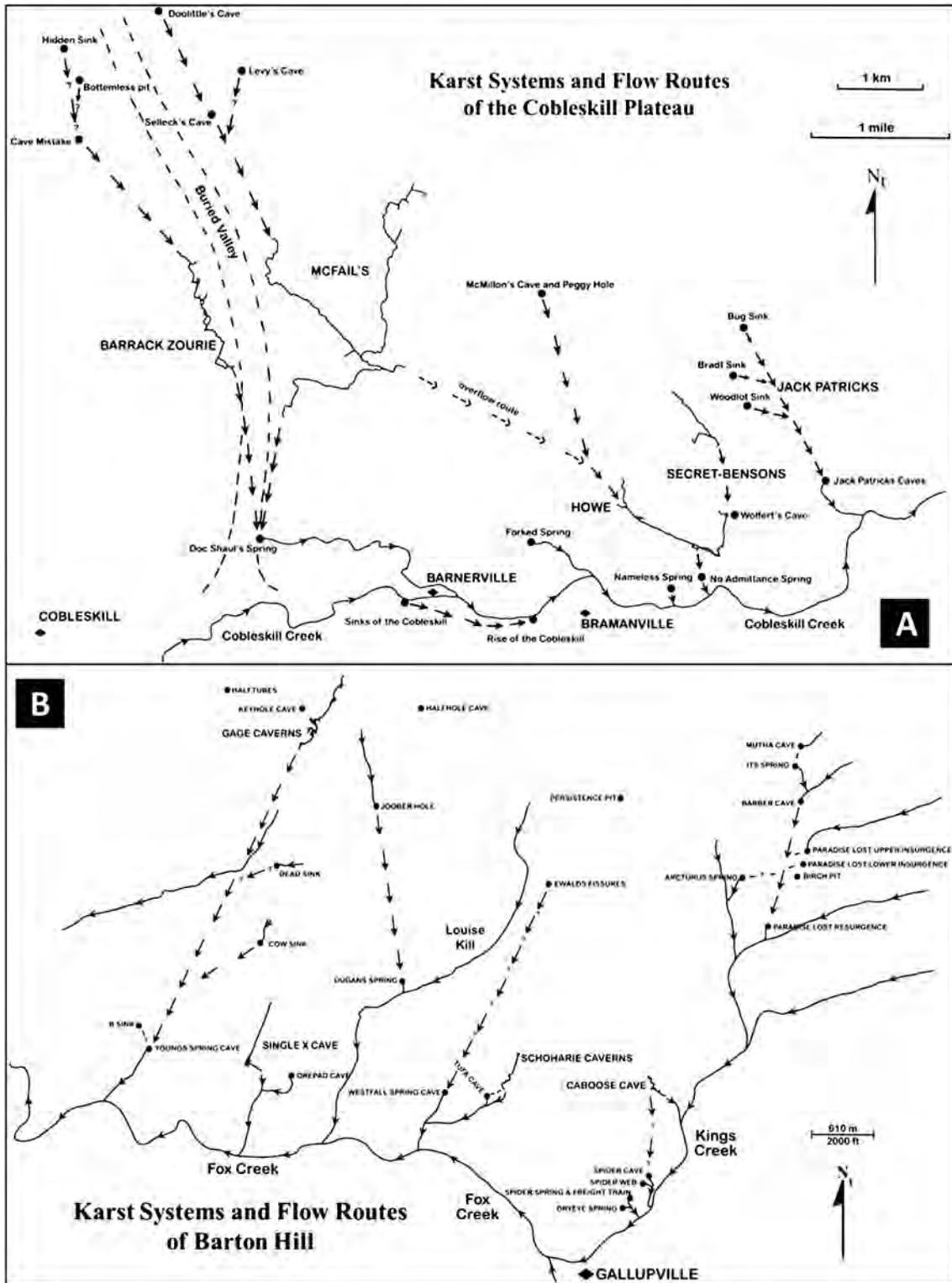


Figure 2. A: Map of the karst systems and flow routes of the Cobleskill Plateau. The buried valley is located between Barrack Zourie Cave and McFail's Cave (re-drawn from Dumont, 1995). B: Map of the karst systems and flow routes of Barton Hill (re-drawn from Mylroie, 1977).

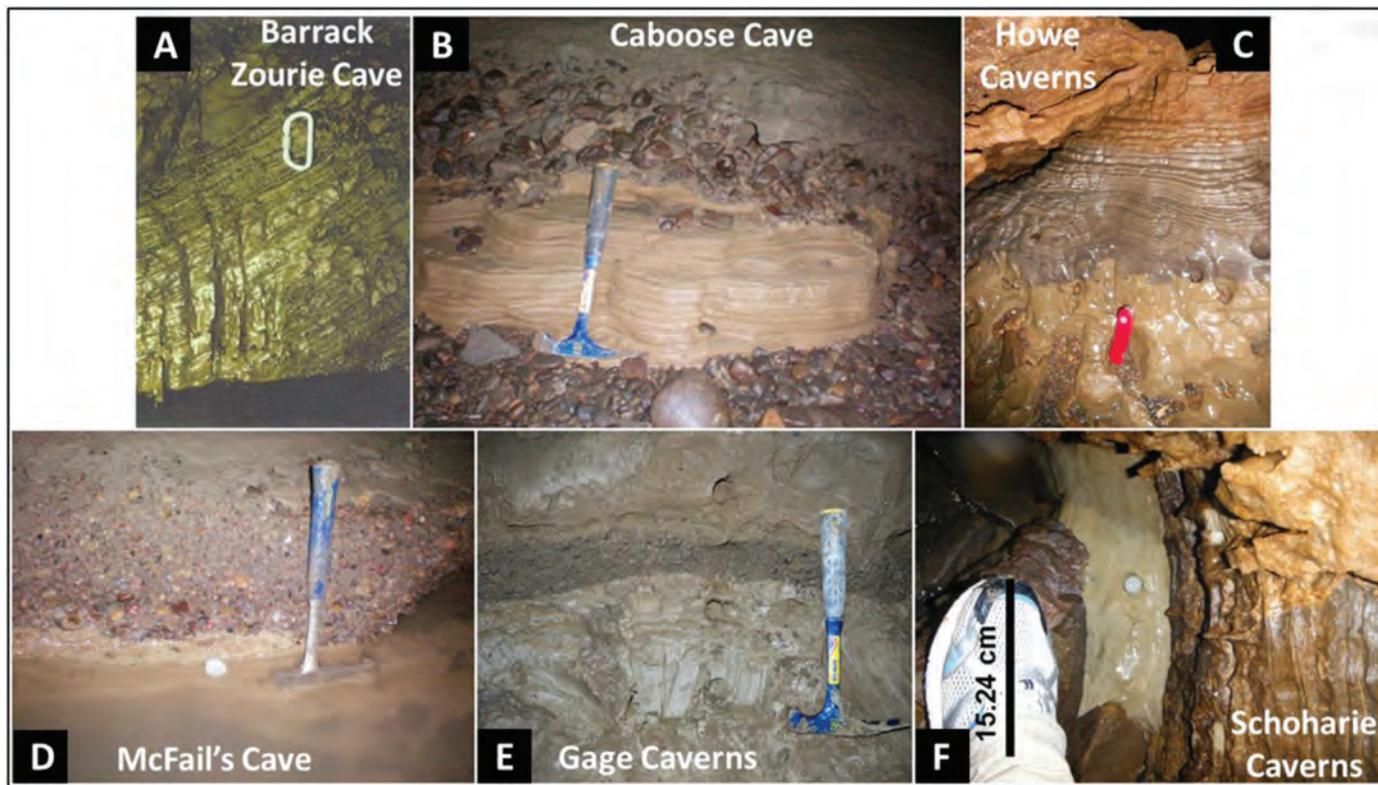


Figure 3. Distinct “white” clay was found to exist in multiple caves selected for this study. Note in B, D, and E the abrupt transition from the finely laminated light-colored material at the bottom of the section to the very coarse gravelly layer above. The darker colored fine-grained deposit that commonly caps the sequence is best seen in B.

this interpretation (e.g., Palmer et al., 2003), but it was recognized that caves in other areas of the state lacked these glacial sediments. The question became, what was unique about the caves in the Schoharie Valley. The presence of a glacial lake could create the same stagnant-water conditions in the underlying caves, and the lake’s footprint would explain the unique cluster of caves containing the glacial sediment.

CAVES OF THE HELDERBERG PLATEAU

The caves located in the Helderberg Plateau formed in the Upper Silurian and Lower Devonian limestones of the Helderberg Group. The major caves and cave systems within the plateau, including the caves mentioned in this study, primarily formed within the thick-bedded Coeymans Limestone and the thinly bedded Manlius Limestone (Fig. 5). There has also been some cavern development within the Rondout Dolomite, as at Knox Cave and Baryte’s Cave (Myroie, 1977; Palmer, 2009), but cavern development within this particular unit is usually limited to conduits with small cross-sectional areas.

The caves and karst features of the Helderberg Plateau were created by epigenic processes providing surface runoff water an alternative to over-land flow paths, allowing water to travel more directly. The karst features of the

Helderberg Plateau have been described as “one of the finest examples of glaciated karst in the country” (Palmer et al., 1991, p. 161).

There has been extensive published work regarding the caves located in the Cobleskill Plateau and adjoining areas, such as that of Dumont (1995), Kastning (1975), Myroie (1977), and Palmer et al. (2003). The glacial deposits within the caves were discussed by these authors, but the link of these sediments to a postulated glacial lake in this area had not been thoroughly investigated.

Westfall Spring Cave was included in this study because its geologic context suggested it was post-glacial in origin; and therefore, it should not have a glacial sediment signature. Knox Cave was included because it is outside the footprint of Glacial Lake Schoharie. These two caves acted as controls for the sediment study.

THE WISCONSIN GLACIATION IN THE HELDERBERG PLATEAU

The last major Pleistocene glaciation to occur in New York was the Late Wisconsin glaciation. The Helderberg Plateau was covered by three lobes of glacial ice, the Mohawk lobe, the Hudson lobe, and the Schoharie sub-lobe, during the onset of the Late Wisconsin glaciation (Dineen, 1986). The lobes that covered the plateau entered

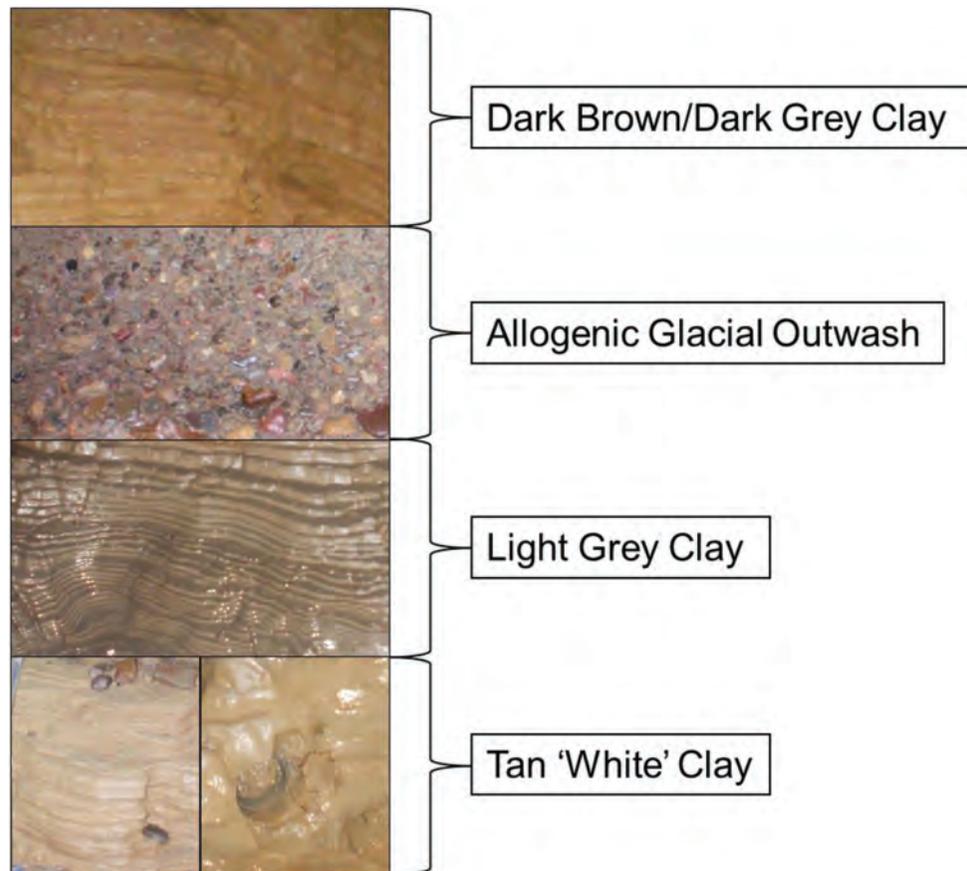


Figure 4. Examples of the sediment layers, in stratigraphic order, encountered within the caves in this study.

the region from the northeast, as shown by drumlins and bedrock striations found in the study area that have a clear northeast-southwest trend (Mylroie and Mylroie, 2004).

The glacial lobes deranged the landscape, altering it greatly. The landscape seen today is covered by drumlins, kames, glaciokarst, and buried glacial drainage basins, as well as other paleoglacial landforms. Dineen and Hanson (1985) proposed the Late Wisconsin glaciation ended in the region approximately 12,300 years ago, but the exact date is still highly debated. According to Muller and Calkin (1993), the Wisconsin is broken up into Early (~117.0–64.0 ka), Middle (~64.0–23.0 ka), and Late (~23.0–11.9 ka) episodes.

GLACIAL LAKE SCHOHARIE

A glacial lake is a body of fresh water that is confined partly or entirely by a glacier or a geomorphic feature produced by a glacier (LaFleur, 1976). As mentioned earlier, there were a number of advance, retreat, and readvance phases associated with the Late Wisconsin glaciation in New York, resulting in the formation of multiple glacial lakes.

The instability of glacial ice caused Glacial Lake Schoharie to have shorelines at varying elevations through-

out the Late Wisconsin glaciation. The Woodstock ice margin was established by a halt in ice retreat from 18.2–17.4 ka, according to Ridge (2004). Following the establishment of the ice margin, glacial meltwater began to flood the Schoharie Valley. As the stagnated glacial ice continued to melt and retreat toward the northeast, water levels continued to rise until a glacial lake was established with a shoreline at an elevation of 213 m (700 ft) above sea level (Dineen, 1986) (Fig. 6). The establishment of Glacial Lake Schoharie will be called *stage one* of three known stages of the glacial lake's development.

With the onset of the Middleburg readvancement at ~17.4 ka, based on Ridge (2004), advancing ice re-entered the Schoharie Valley and the greater Helderberg area until the ice reached the Catskill Front (Catskill Mountains). After reaching the Catskill Front, the glacier stagnated and once again began to retreat northward. While retreating, the glacier produced a vast amount of meltwater, resulting in the enlargement of several proglacial lakes (Dineen, 1986). Glacial Lake Schoharie enlarged considerably and established a shoreline between 354 and 366 m (1,160 and 1,200 ft) above sea level (Fig. 7), reaching *stage two*.

With the establishment of the Delmar ice margin at ~16.2 ka (Ridge, 2004), water from Glacial Lake Schoharie drained to the northeast, through what is known

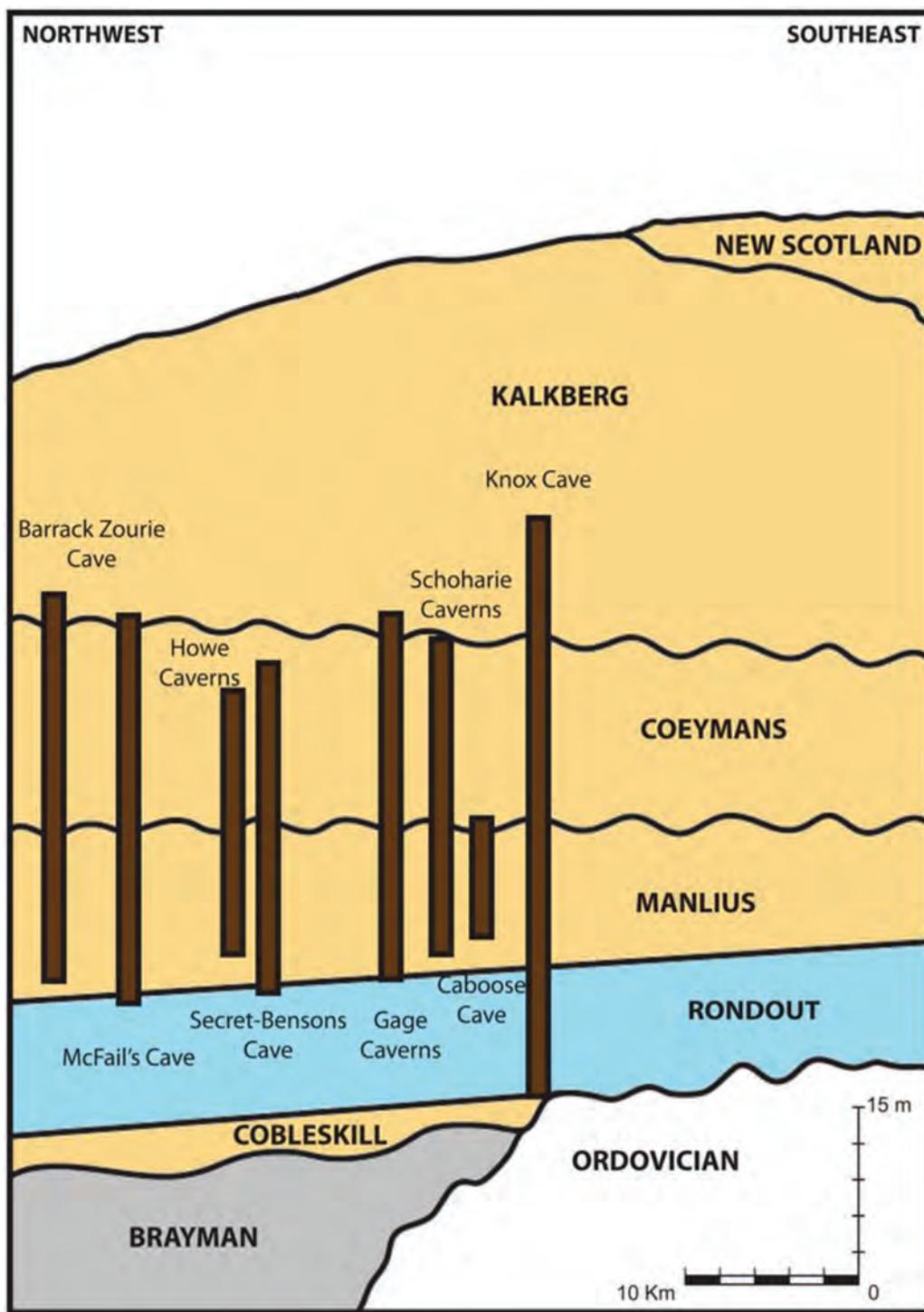


Figure 5. Generalized diagram depicting the Silurian and Devonian rocks in which the caves of this study formed. The grey unit is shale, blue unit is dolomite, and the tan units are limestone.

as the Delanson spillway (LaFleur, 1969). The spillway fed the Delanson River, which eventually emptied into Glacial Lake Albany (LaFleur, 1976). The *stage three* shoreline of Glacial Lake Schoharie was established at 256 to 213 m (840 to 700 ft) above sea level (LaFleur, 1969; Dineen and Hanson, 1985) (Fig. 8).

METHODS

A total of 63 samples were collected and stored in sterilized plastic 35 mm film canisters for this study; three additional samples were collected from Barrack Zourie Cave by Kevin Dumont in 1995. Each sample was labeled

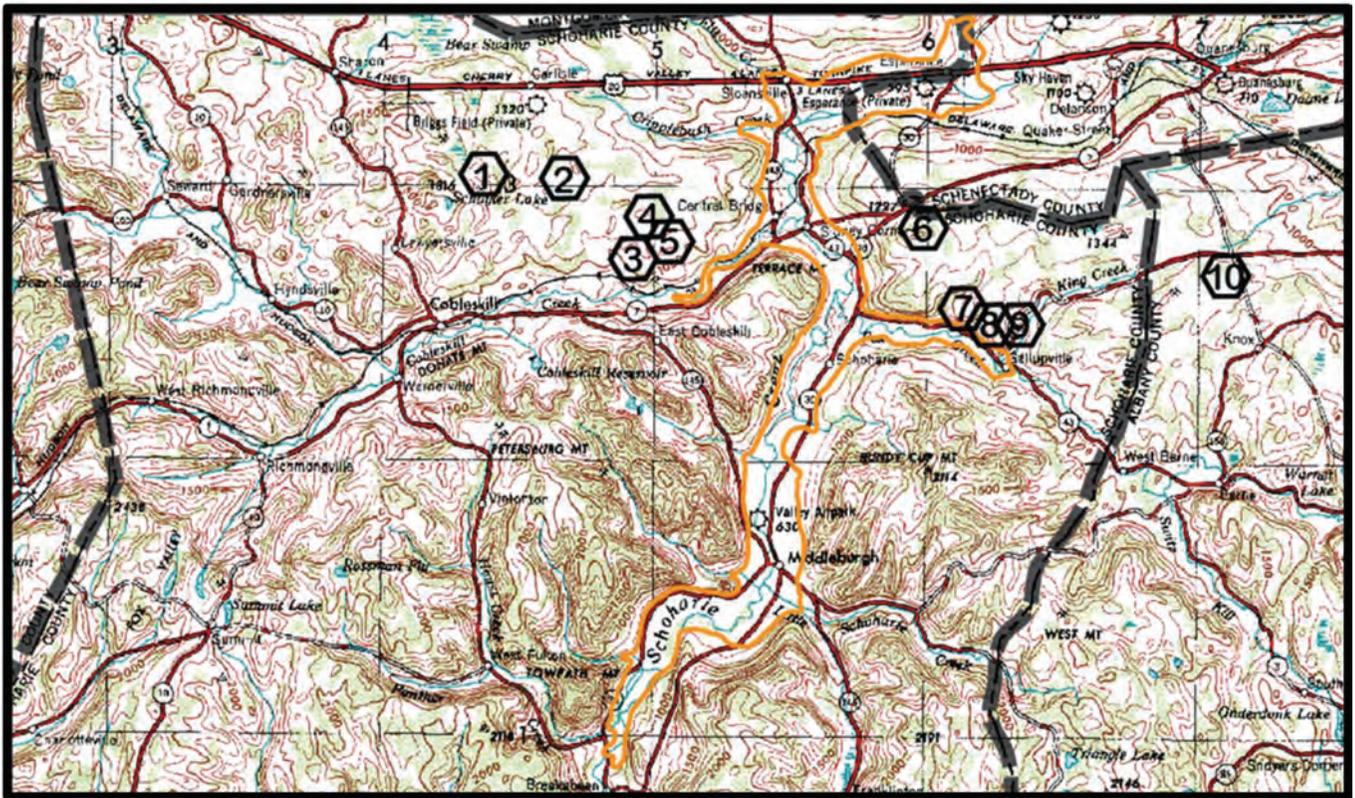


Figure 6. Topographic map showing the location of the caves in relation to the 213 m (700 ft or stage one) shoreline of Glacial Lake Schoharie outlined in orange, created using information provided by Dineen (1986). Caves are numbered as in Figure 1. The grid is 6.4 by 6.4 km (4 by 4 miles.)

with the cave, the location in the cave, and the stratum in the outcrop at that location.

The samples collected for this study come from a wider suite of caves than those used in Mylroie (1984), and more sophisticated analysis techniques were conducted to determine how reliable Mylroie's results were and how the samples compare to his data from Caboose Cave. The sample analyses were not intended to be diagnostic, but to provide a reconnaissance baseline to guide further research.

To determine a general mineralogical content of the samples collected, x-ray diffraction (XRD) was utilized because of its ability to provide qualitative results in a cost-effective and time-efficient manner. All XRD analyses of powdered samples were conducted using the Rigaku Ultima III X-ray diffractometer and were interpreted using the MDI Jade 8 program. The XRD pattern for each sample was obtained using $\text{CuK}\alpha$ radiation with a wavelength of 1.541867 Å. Scan speed was set for 2 degrees a minute with a scan step of 0.02 degrees, a scan axis of 2-theta/theta, and an effective scan range of 3.00–70.00 degrees.

RESULTS

The laboratory analyses of samples to determine the mass of water in each sample, the mass of carbonates, and

the mass of organics with the purpose of discerning a pattern among individual clastic units recovered from the ten caves in this study was inconclusive in terms of a recognizable pattern and can be seen in Weremeichik (2013).

Although the laboratory results were inconclusive, X-ray diffraction yielded more conclusive information. The XRD data were not used to determine actual amounts of materials in a given sample; it was an assay of presence or absence. Table 1 shows the frequency of mineral content found to exist in each type of sample. Figure 4 shows typical examples of the vertical sequence of the sediment types found in the caves and used in Table 1. For example, the dark-grey/dark-brown clay unit had calcite in 62% of the samples, and the allogenic outwash unit had calcite in 40% of the samples. Together, these post-glacial lake sediments had 56% calcite occurrence. The light-grey clay unit had calcite in 100% of the samples, and the tan "white" clay unit had calcite in 75% of the samples. Together, the supposed glacial lake sediments had calcite in 81% of the samples. The Knox Cave and Westfall Cave sediment control samples, because those cave did not lie under the lake or postdated it, had calcite in only 33% of the samples. Brushite shows a different trend, being more common in the post-glacial sediments.

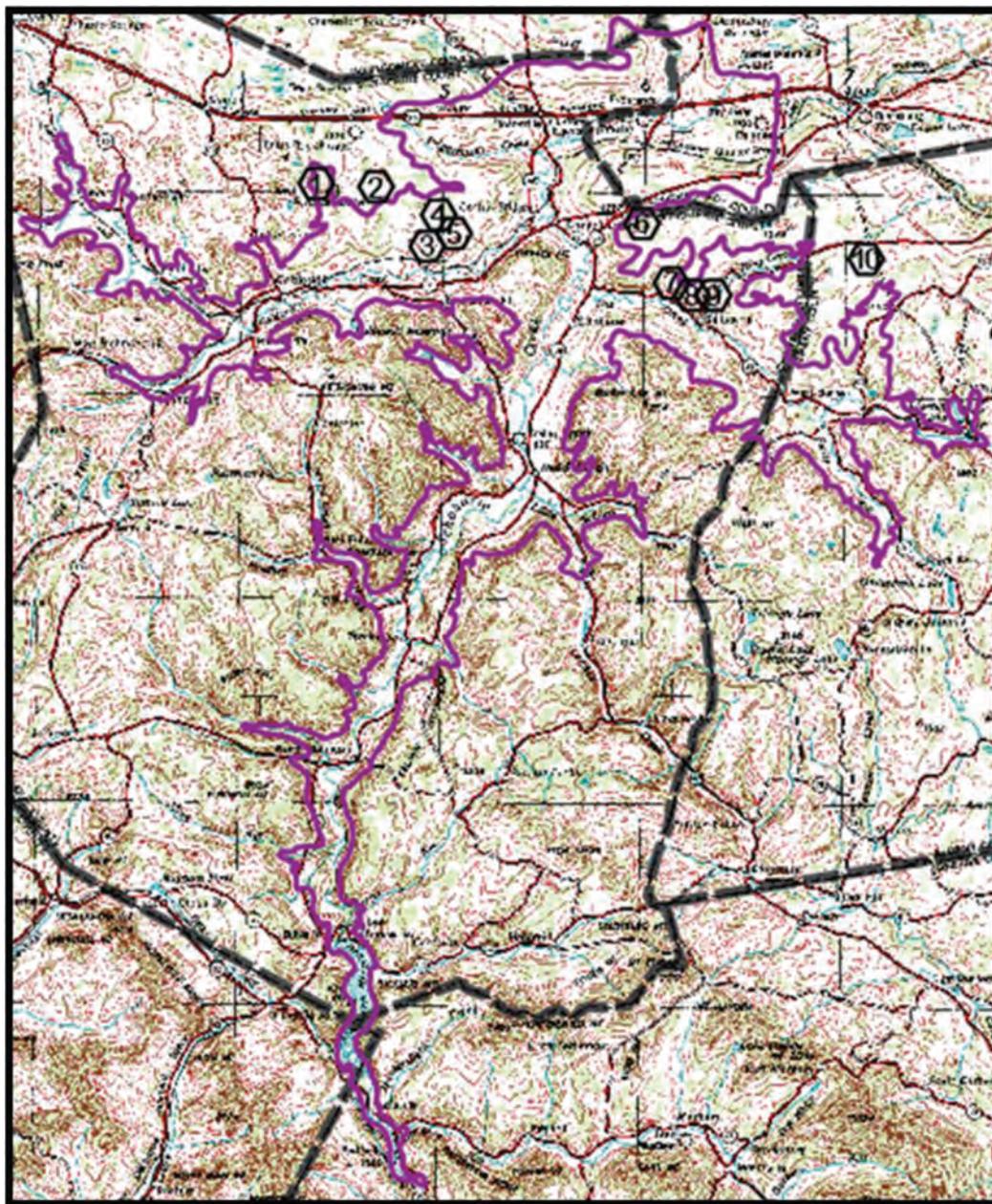


Figure 7. Glacial Lake Schoharie shoreline at 354–366 m (1,160–1,200 ft or stage two) above sea level outlined in purple. Note the reduction of scale to portray a much larger lake and the lake's extension eastward into Schenectady and Albany Counties. Caves are numbered as in Figure 1. The grid is 6.4 by 6.4 km (4 by 4 mi).

DISCUSSION

During *stage one* of Glacial Lake Schoharie's development, there would not have been any outlet for the water to escape by way of the Schoharie Valley. However, it would have been possible for the water in Glacial Lake Schoharie to drain north toward what is known today as the Mohawk Valley. But there is a problem with this idea, because during the Late Wisconsin the Mohawk Valley was occupied by the active Mohawk glacial lobe. The Mohawk glacial lobe, also referred to locally as the Mohawk Ice

Block, filled the area between the neighboring Cobleskill and Barton Hill plateaus and acted as a plug, trapping glacial meltwater in the Schoharie Valley (LaFleur, 1969). Near the close of the Wisconsin glaciation, at least 50% of Glacial Lake Schoharie would have been covered by active glacial ice belonging to the Schoharie glacial sub-lobe (Dineen, 1986). As seen in Figures 6 and 9, during *stage one* (213 m) there would not have been a sufficient amount of water in Glacial Lake Schoharie to even partially inundate the caves of the Cobleskill Plateau and Barton Hill included in this study.

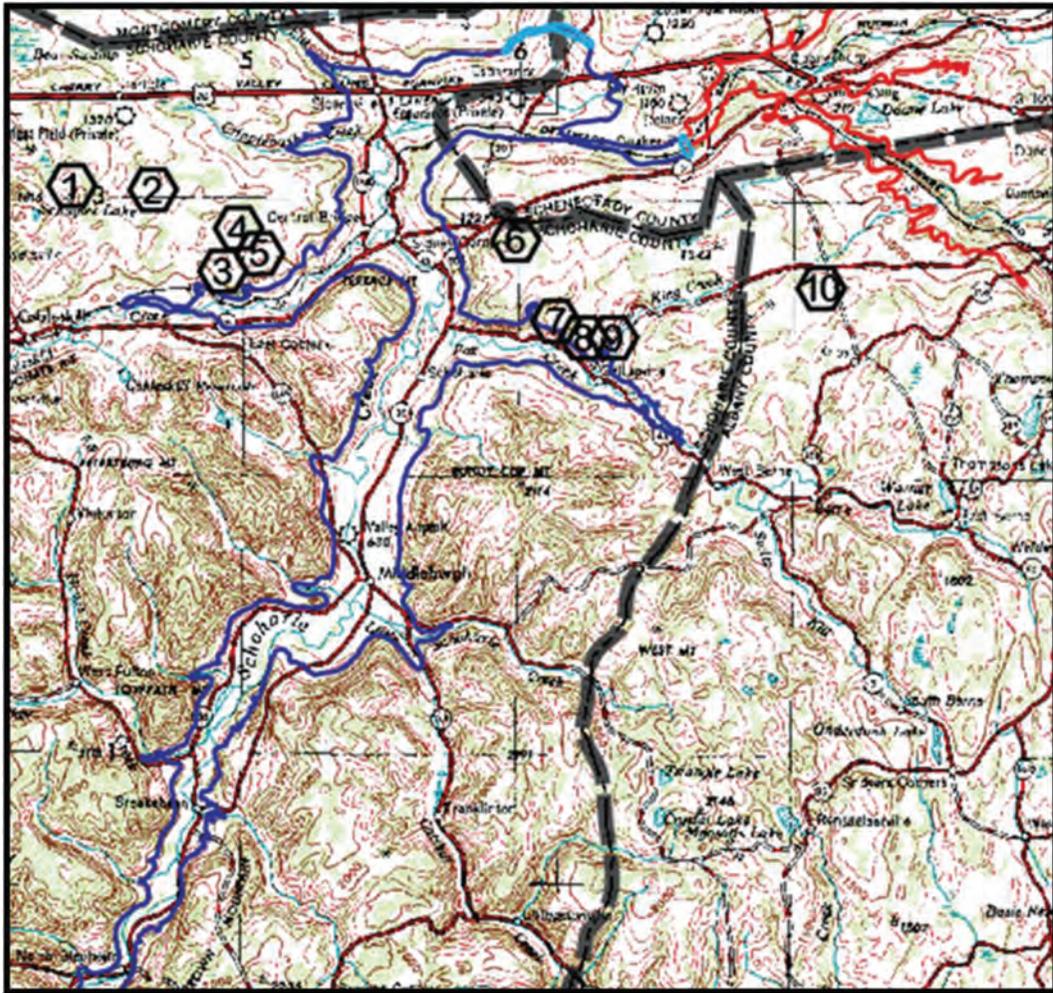


Figure 8. Glacial Lake Schoharie with a shoreline, outlined in dark blue, at 256 m (840 ft or stage three) above sea level, created using information provided by LaFleur (1969) and Dineen and Hanson (1985). The red lines indicate a spillway, and the light-blue lines indicate the boundary between glacial lake water and active glacial ice. Caves are numbered as in Figure 1. The grid is 6.4 by 6.4 km (4 by 4 mi).

In Figures 7 and 9 it can be seen that nearly all of the caves in the Cobleskill Plateau and Barton Hill are completely inundated by water from Glacial lake Schoharie during *stage two* (~360 m). Note that although the entrances to both McFail's Cave and Gage Caverns were not inundated, the majority of the cave passages are over 30 m below the surface and would have been inundated based on their elevation relative to sea level and the *stage two* lake level. This would include inundation of locations where samples were collected for the study. The upper passages where samples were collected in Knox Cave would not have been inundated by glacial lake water due to their elevation, even if the lake had extended that far eastward, and so these samples acted as a control. Westfall Spring Cave, being post-glacial in origin, is not included in Figure 9.

The clay sediments encountered in the caves fit the description of a varved sequence (Fig. 3). Varves are usually couplets of fine and coarse grained material

(Neuendorf et al., 2011). These sediments do not show the alternating coarse-to-fine sequencing; they appear to only contain the fine sediments. A possible reason the sediments that compose the units are so uniform is that the insurgences and resurgences of the caves were most likely choked with glacially transported material, so only the smallest of sediments would be able to slowly percolate through the debris. These deposits are consistent with a laminar-flow regime expected for deposition deep in cave passages below a glacial lake. The white to tan clay deposits have an abrupt contact with overlying sand and gravel deposits (Fig. 3). Mylroie (1984) interpreted these coarse-grained sediments to be the result of ice retreat and re-establishment of the epigenic turbulent flow system in these caves. The same thing would have occurred during the draining of Glacial Lake Schoharie. The dark-brown clay was hypothesized by Mylroie (1984) to represent a surge of incoming sediment associated with clear-cutting

Table 1. X-ray diffraction results. The figures are the percentages of samples of the given strata that showed qualitatively the presence of the mineral. The totals are not numerical averages of the values to their left because there were not equal numbers of samples of each type. The control samples were from caves not under Glacial Lake Schoharie.

Mineral, %	Glacial Lake Sediment, %			Post Glacial Sediment, %			Control Samples, %
	Light Grey Clay	Tan "White" Clay	Total	Dark Brown Clay	Allogenic Glacial Outwash	Total	
Calcite	100	75	81	62	40	56	33
Dolomite ?	0	0	0	4	0	3	0
Quartz	100	100	100	100	100	100	100
Muscovite	60	69	67	73	80	75	83
Phlogopite	40	19	24	31	40	33	67
Chlorite	0	0	0	0	0	0	0
Montmorillonite	0	0	0	0	0	0	0
Albite (low temp)	20	44	38	58	50	56	67
Enstatite ?	0	6	5	0	0	0	0
Brushite	40	31	33	65	40	58	83
Nacrite	20	0	5	15	0	11	17
Carbon	0	25	19	8	30	14	67

following European settlement in the 1700s. The results here can neither prove nor disprove that speculation, but the dark-brown clays do represent what is being deposited in the caves today during flood cycles. The sequence of

events that produced the sediment column of Figure 4 is presented in Figure 10.

The Howe Caverns sediment section is especially instructive and is the thickest of all such sequences. While

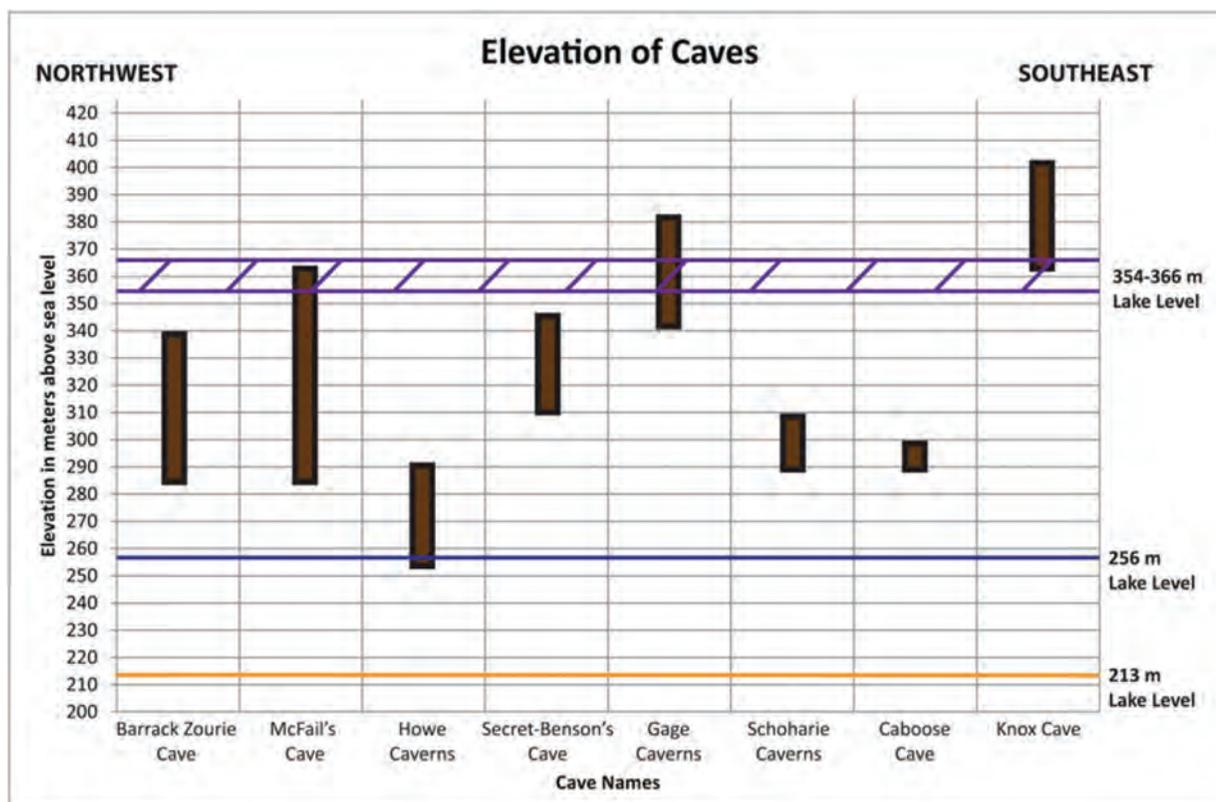


Figure 9. The elevations occupied by each cave in relation to the shoreline elevations of Glacial Lake Schoharie during stage one (213 m, Fig. 6), stage 2 (~360 m, Fig. 7), and stage 3 (256 m, Fig. 8).

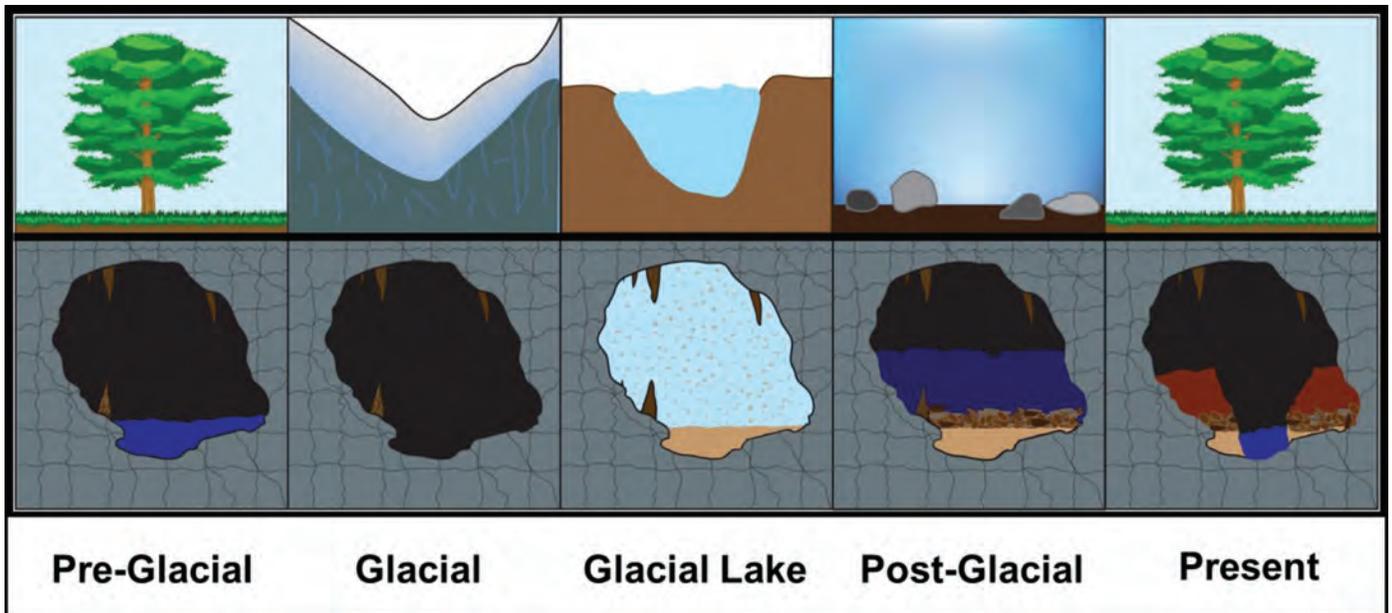


Figure 10. Cartoon depicting the caves' history during a glacial cycle, with time progressing from left to right.

most caves have less than or equal to 1 m of the light-grey and tan “white” clay, Howe Caverns has over 2 m of section. This greater thickness is the result of Howe Caverns' main stream passage being the lowest in elevation of all the cave passages studied, by approximately 30 meters (Fig. 9). Therefore, while lake surface elevations shifted vertically, Howe Caverns spent more time under Glacial Lake Schoharie than any other cave in the study, being inundated even during *stage three*. In addition, Figure 3 shows an interesting transition from a very amorphous white clay deposit at the base (next to the knife) to a progressively better layered light-grey clay in which the individual layers get thicker upwards to the contact with more ordinary cave sediments. This transition can be interpreted to indicate initial clay deposition *stage two*, when the Howe Caverns stream passage would have been ~100 m below the lake's surface at ~360 m. Sediment transport by laminar flow into the cave would have been slow and quite isolated from seasonal changes, indicated by the lack of rhythmical layering in the “white” clay deposit. As lake level lowered to the 256 m level during *stage three*, the Howe Caverns main stream passage would have been merely meters below the lake's surface and more likely to record the seasonal changes in water and sediment addition to the lake, as demonstrated by the light-grey clay. The upward thickening may record the final transition of Howe Caverns out of the lake footprint as the lake drained away.

The sediment analyses were for the most part inconclusive. Based on the X-ray diffraction results, the glacial sediments are more likely to have calcite in them, which is consistent with the stagnant water conditions proposed by Mylroie (1984). The mass-loss experiments were less convincing, with a great deal of variation within the data

and no consistent pattern. Mylroie (1984) had reported a very high solubles content for the Caboose Cave white clay, and while this study did replicate that result to an extent, the high solubles content was not consistent across the other caves in the study. It is useful to note that Knox Cave, acting as a pre-glacial control cave, has much less variation in its samples than the caves under the Glacial Lake Schoharie footprint. The sediment analysis was done as a reconnaissance, to determine if more work would be worthwhile in the future, and it was not central to the final interpretation of the sediment's glaciolacustrine origin.

CONCLUSIONS

The caves suspected to have been inundated by glacial lake water and, therefore, to have collected fine-grained lake sediment do not show any statistical correlation between samples collected (see Weremeichik, 2013). But, as seen in Figure 3, it is apparent that physical similarities between the samples collected exist. These physical similarities can be correlated with their mineral's color and grain size. It was originally hypothesized that the sediment in the caves may have been deposited during a retreat phase of glaciation resulting from stagnant ice-covered conditions (e.g., Mylroie, 1984). This hypothesis was thought to be true because it explains how the fine-grained sediment was deposited in the caves. This could not have happened if there had been turbid or even transitionally laminar flow through the caves. Ice cover would have created the necessary stagnant conditions. The glacial-lake hypothesis presented here also would create stagnant conditions, but in an environment where the associated fine-grained sediment could more easily enter the cave.

Glacial Lake Schoharie endured multiple retreats and readvances of glacial ice, in part, by being insulated and protected by a layer of stagnated glacial ice. During retreat phases of glacial activity, new glacial meltwater carrying glacial-derived sediment must have been delivered to the lake, which subsequently filtered into the caves below.

The analyses of the sediments themselves are consistent with the glacial-lake hypothesis. They are extremely fine-grained, very low in organics (Weremeichik, 2013), and with a measurable soluble content of calcite. They are visually striking when observed in the field and are easily recognized. They are, to date, known only from within the footprint of Glacial Lake Schoharie. This final aspect is important, as the deposits were originally considered by earlier workers (e.g., Mylroie, 1984) to be sub-ice deposits. The failure to find such deposits elsewhere in the Helderberg Plateau or in other glaciated karst regions was very problematic. Everyone who saw the deposits *in situ* agreed with their glacial rock-flour origin (e.g., Palmer et al., 2003). The use of the Glacial Lake Schoharie footprint to explain these deposits as not sub-ice, but sub-lake deposits, explains the failure to find such deposits in other glaciated karst locales in the region.

REFERENCES

- Dineen, R.J., 1986, Deglaciation of the Hudson Valley Between Hyde Park and Albany, New York, in Cadwell, D.H., ed., *The Wisconsin Stage of the First Geological District, Eastern New York*, Albany, New York State Museum Bulletin 455, p. 89–108.
- Dineen, R.J., and Hanson, E.L., 1985, Deglaciation of the Middle Mohawk and Sacandaga Valleys, or a tale of two tongues, in Lindemann, R.H., ed., *Field Trip Guidebook of the New York State Geological Association 57th Annual Meeting*, Saratoga Springs, New York, p. 250–256.
- Dumont, K.A., 1995, Karst Hydrology and Geomorphology of the Barrack Zourie Cave System, Schoharie County, New York [M.S. thesis]: Mississippi State, Miss., Mississippi State University, reprinted as New York Cave Survey Bulletin 5, 70 p., map plate.
- Kastning, E.H., 1975, Cavern Development in the Helderberg Plateau, East-Central New York [M.S. thesis]: Storrs, Conn., University of Connecticut, reprinted as New York Cave Survey Bulletin 1, 194 p. plus map plates.
- Lauritzen, S-E., and Mylroie, J.E., 2000, Results of a speleothem U/Th dating reconnaissance from the Helderberg Plateau, New York: *Journal of Cave and Karst Studies*, v. 62, p. 20–26.
- LaFleur, R.G., 1969, Glacial geology of the Schoharie Valley, in Bird, J.M., ed., 61st Annual Meeting of the New England Intercollegiate Geological Conference Guidebook for Field Trips in New York, Massachusetts, and Vermont, p. (5-1)–(5-20).
- LaFleur, R.G., 1976, Glacial Lake Albany, in Rittner, D., ed., *The Pine Bush Albany's Last Frontier: Albany, N.Y., Pine Bush Historic Preservation Project*, p. 1–10.
- Muller, E.H., and Calkin, P.E., 1993, Timing of Pleistocene glacial events in New York State: *Canadian Journal of Earth Sciences*, v. 30, p. 1829–1845. doi:10.1139/e93-161.
- Mylroie, J.E., 1977, Speleogenesis and Karst Geomorphology of the Helderberg Plateau, Schoharie County, New York [Ph.D. dissertation]: Troy, N.Y., Rensselaer Polytechnic Institute, reprinted as New York Cave Survey Bulletin 2, 336 p.
- Mylroie, J.E., 1984, Pleistocene climatic variation and cave development: *Norsk Geografisk Tidsskrift*, v. 38, p. 151–156. doi:10.1080/00291958408552119.
- Mylroie, J.E., and Mylroie, J.R., 2004, Glaciated karst: How the Helderberg Plateau revised the geologic perception: *Northeastern Geology and Environmental Sciences*, v. 26, no. 1–2, p. 82–92.
- Neuendorf, K.K.E., Mehl, J.P. Jr., and Jackson, J.A., 2011, ed., *Glossary of Geology*, 5th revised edition: Alexandria, Virginia, American Geosciences Institute, 800 p.
- Palmer, A.N., 2009, Cave exploration as a guide to geologic research in the Appalachians: *Journal of Cave and Karst Studies*, v. 71, no. 3, p. 180–192.
- Palmer, A.N., Rubin, P.A., and Palmer, M.V., 1991, Interaction between karst and glaciation in the Helderberg Plateau, Schoharie and Albany Counties, New York, in Ebert, J.R., ed., *New York State Geological Association Field Trip Guidebook 63rd Annual Meeting*, p. 161–190.
- Palmer, A.N., Rubin, P.A., Palmer, M.V., Engel, T.D., and Morgan, B., 2003, Karst of the Schoharie Valley and land use analysis, Schoharie County, New York State, in Johnson, E.L., ed., *New York State Geological Association Field Trip Guidebook 75th Annual Meeting*, p. 141–165.
- Ridge, J.C., 2004, The Quaternary glaciation of western New England with correlations to surrounding areas, in Ehlers, J., and Gibbard, P.L., eds., *Quaternary Glaciations—Extent and Chronology Part II: North America*: Amsterdam, Elsevier, *Developments in Quaternary Sciences series 2*, p. 169–199. doi:10.1016/S1571-0866(04)80196-9.
- Weremeichik, J.M., 2013, Paleoenvironmental reconstruction by identification of glacial cave deposits, Helderberg Plateau, Schoharie County, New York [M.S. thesis]: Mississippi State, MS, Mississippi State University, 191 p.