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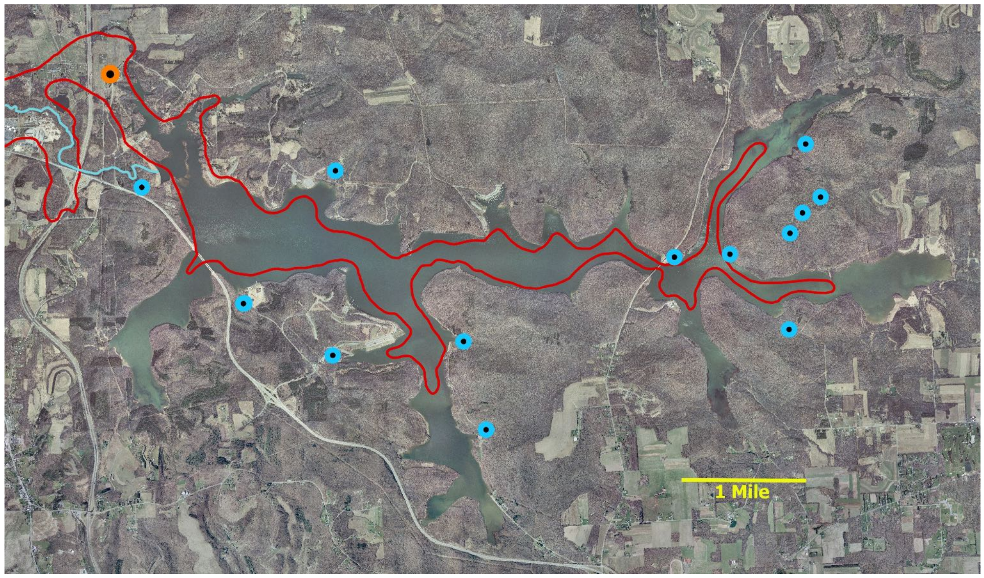

Aerial image (from PAMAP) of Lake Arthur in Moraine State Park. The red line is the 1,100-ft bedrock surface contour, which outlines the buried pre-glacial valley of Muddy Creek. The blue line marks the course of the post-glacial diversion of (present) Muddy Creek through a bedrock ridge. The blue dots are the locations of 14 water-supply wells drilled in the park between 1966 and 2011 (two of the dots are superimposed at this scale), none of which were drilled in the buried pre-glacial valley, and none of which provided an adequate quantity and/or quality for a water supply for all of the functions in the park. The orange dot indicates the location of the new water-supply well that now serves the park and is within the buried pre-glacial valley. It is far superior in both quantity and quality than any of the previously drilled wells (see article on page 3).

EDITORIAL

The Year 2021 at the Bureau

Gale C. Blackmer, State Geologist
Pennsylvania Geological Survey

A friend of mine recently shared an amusing t-shirt graphic: a haggard-looking flaming dumpster labeled 2020 is being approached by a cheery-looking dumpster labeled 2021 who asks the first dumpster if he's got a light. I think that sums it up. Still, the bureau has done well this year.

After a flurry of hiring that took most of the year, we are at full complement for the first time in several years. We welcomed six new employees this year (you will meet three of them later in this issue) and are looking forward to the arrival of two more in early January. We are privileged to have these new folks on our team. The management staff now gets a brief respite from interviewing until the wave of 2022 retirements hits!

Much of what we did this year was to integrate these new people into the staff and the work. Every new person brings their own special skills and abilities that enable us to think about our work in ways we hadn't before. Of course, much other work was accomplished as well. **(1)** We continued our participation in the U.S. Geological Survey (USGS) STATEMAP and Great Lakes Geologic Mapping Coalition grant programs that enable us to pursue geologic mapping beyond what we can do with our own resources. The USGS launched the U.S. GeoFramework Initiative (USGI) with the goal of constructing a multi-resolution seamless national 2D/3D geologic framework model for the nation. USGI funds provided through STATEMAP will help us move toward our own 3D geologic model of Pennsylvania. **(2)** Our work on carbon capture utilization and storage (CCUS) continues with participation in the Midwest Regional Carbon Initiative and the 21st Century Power Plants program. **(3)** Elevation-derived hydrography datasets are being released on Pennsylvania Spatial Data Access (PASDA) as individual watersheds are completed. **(4)** We ran a highly successful in-person Field Conference of Pennsylvania Geologists in the Ohiopyle area in October. **(5)** Our geologists respond to a steady stream of inquiries regarding sinkholes, landslides, core and library collections, and other geologic matters.

The bureau also provides leadership outside of our own work. **(1)** Kris Carter leads the CCUS Inter-Agency Work Group. Major accomplishments of the Work Group this year include Pennsylvania's collaboration with other signatory states on the CO_2 Transport Infrastructure Action Plan, which was released in October, as well as the convening of the initial meeting of the Work Group's Advisory Committee with public and private stakeholders throughout the Mid-Atlantic region. **(2)** I co-lead the Elevation Working Group under the State Geospatial Board. By encouraging communication among

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Chasing a Buried Valley—Moraine State Park Water Supply

Gary Fleeger
Pennsylvania Geological Survey, retired

INTRODUCTION

The year 2020 marked the 50th anniversary of the dedication of Moraine State Park in Butler County, Pa. (Figure 1). That dedication, on May 23, 1970, marked the culmination of more than a decade of park planning and development. Some of the major and difficult issues were the siting, design, and construction of the dam to create Lake Arthur, plugging of hundreds of oil and gas wells, sealing more than 100 deep-mine openings, reclaiming hundreds of acres of strip mines, and relocating two highways. While those issues were completed by the time of the dedication, one issue has continued to evolve in the 50 years since the dedication—the supply of potable water in the park.

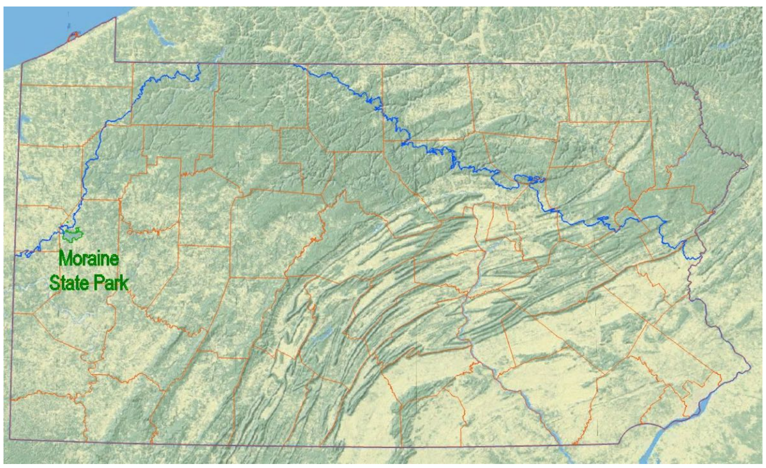

Figure 1. Location map of Moraine State Park. The park is outlined in green; the glacial border is in blue; county lines are orange; and the state border is red.

INITIAL PARK DEVELOPMENT

Initially, during the development of the park, existing home-supply wells were utilized to supply the offices and park employee homes (which were private, pre-park homes). In 1966, fourteen water wells were drilled to supply various planned facilities in the park (Figure 2). Some of the wells were never used because of quality or quantity issues, or because they were drilled for facilities that were never developed. Wells #3, 5, 6, 7, 8, 9, and 11 were drilled to supply various family, walk-in, canoe-in, and organized-group campgrounds. But the park did not build these planned campgrounds and never used those wells. Wells #7 and 9 were drilled twice, after the first of each of those wells proved to be insufficient in quantity. Well #1, near the park office, maintenance area, and beach in Pleasant Valley, was the deepest well drilled, but it was never used because of quantity issues (Pennsylvania Department of Environmental Resources, 1972). Well #2 supplied the Pleasant Valley Day Use area. Well #4 provided water to the regional park office and nearby park residences. Well #10 supplied the Davis Hollow marina, and was intended to supply future North Shore development. Well #12 supplied water to the sewage treatment plant.

Most of the initial 14 wells were bedrock wells drilled into or through the coal measures of the Allegheny Formation, some starting in the Glenshaw Formation, and others starting in the Allegheny and penetrating into the Pottsville Formation. Wells #2 and 10 had significant water-quality issues, being high in iron and manganese. The other wells had less of a problem with water quality, but all had some issue. The interval of the uncased portion of each well was largely responsible for the water quality (Figure 3).

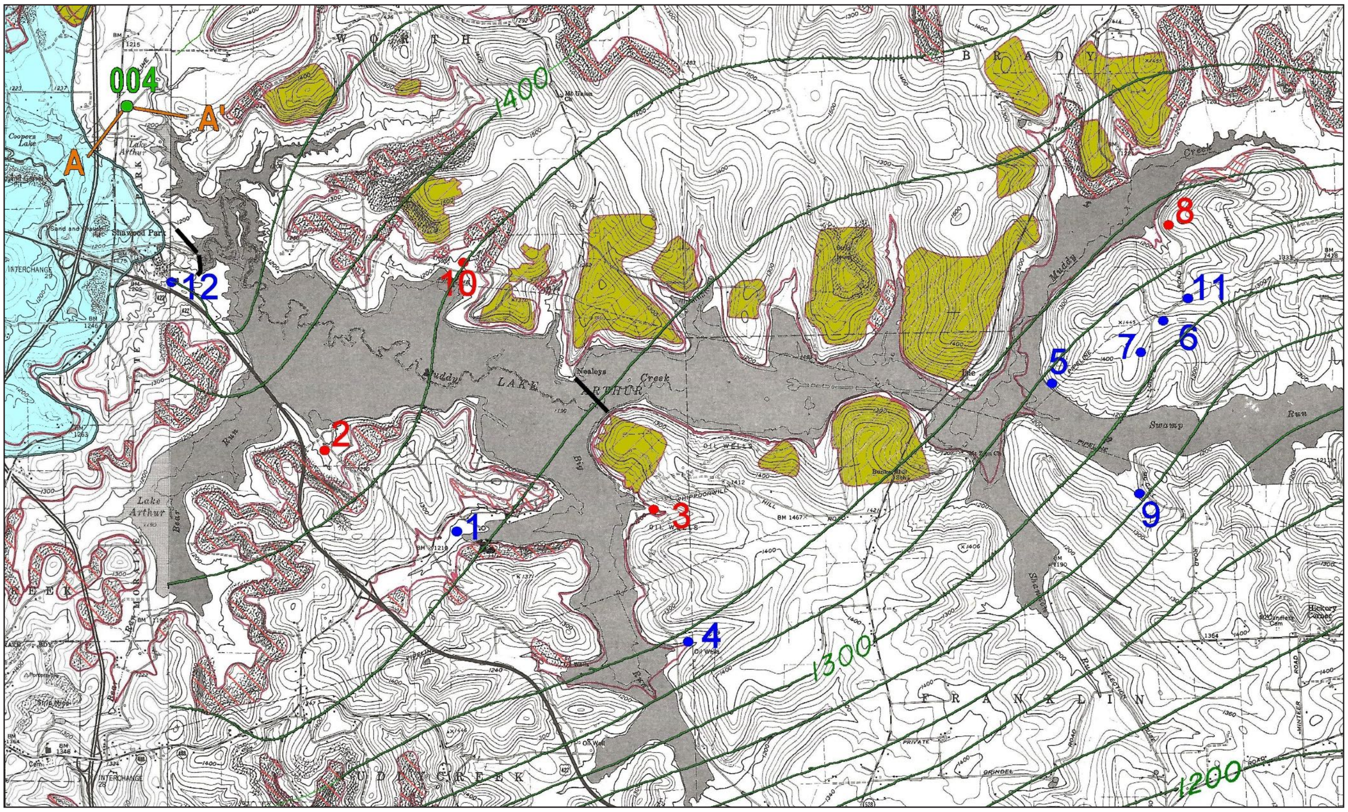

Figure 2. Locations of water wells; Middle Kittanning coal crop lines and mined-out areas, and structure contours (Dodge, 1985); early dam site (Pennsylvania Department of Forests and Waters, 1958); and glaciated area (Shepps and others, 1959). Well colors indicate relative water quality (red is Group A [see text for explanation], blue is Group B, and the green dot is the new 2017 water-supply well, designated Well #004). The red line is the Middle Kittanning coal crop line. Uncolored cross-hachured areas are Middle Kittanning coal surface-mined areas. Cross-hachured colored areas are Middle Kittanning coal deep-mined areas. Green lines are structure contours on the Upper Freeport coal. The black line near Well #12 is the existing dam; across the middle of the lake near Nealeys is an early proposed dam site. Cyan tint in the western part of the map is the glaciated area. The orange line in the northwestern corner is the line of cross section in Figure 9. Information on the surface-mined areas just northeast of Well #1 and just northeast of Well #8 is from Gwin Engineers (1968), U.S. Department of Agriculture aerial photography, and field observation.

The Allegheny Formation can be divided into two parts (Figure 3). The upper part, from the top of the Upper Freeport coal (or horizon) to the bottom of the Johnstown Limestone (or horizon), was deposited in predominantly freshwater environments. Below the Johnstown Limestone, marine deposition predominated (Williams, 1960; Edmunds and others, 1998). Groundwater quality associated with the marine environments is frequently high in iron and manganese, as evidenced in the common acid-mine-drainage issues from mines developed in the coals in the lower Allegheny Formation (Brady and others, 1998).

Figure 3 shows the interval of the stratigraphic column penetrated by each of the 1966 wells. Those that produced largely from the lower Allegheny Formation produced poor quality water. Those that produced from the Glenshaw and/or upper Allegheny Formations, or penetrated into the Pottsville Formation, had better quality water.

The regional bedrock structure through the park has a general dip to the southeast (Figure 2). Because of the regional dip, most wells in the eastern part of the park were drilled where the lower Allegheny Formation was deeper than the depth of the wells. Well #12, drilled in the western, updip part

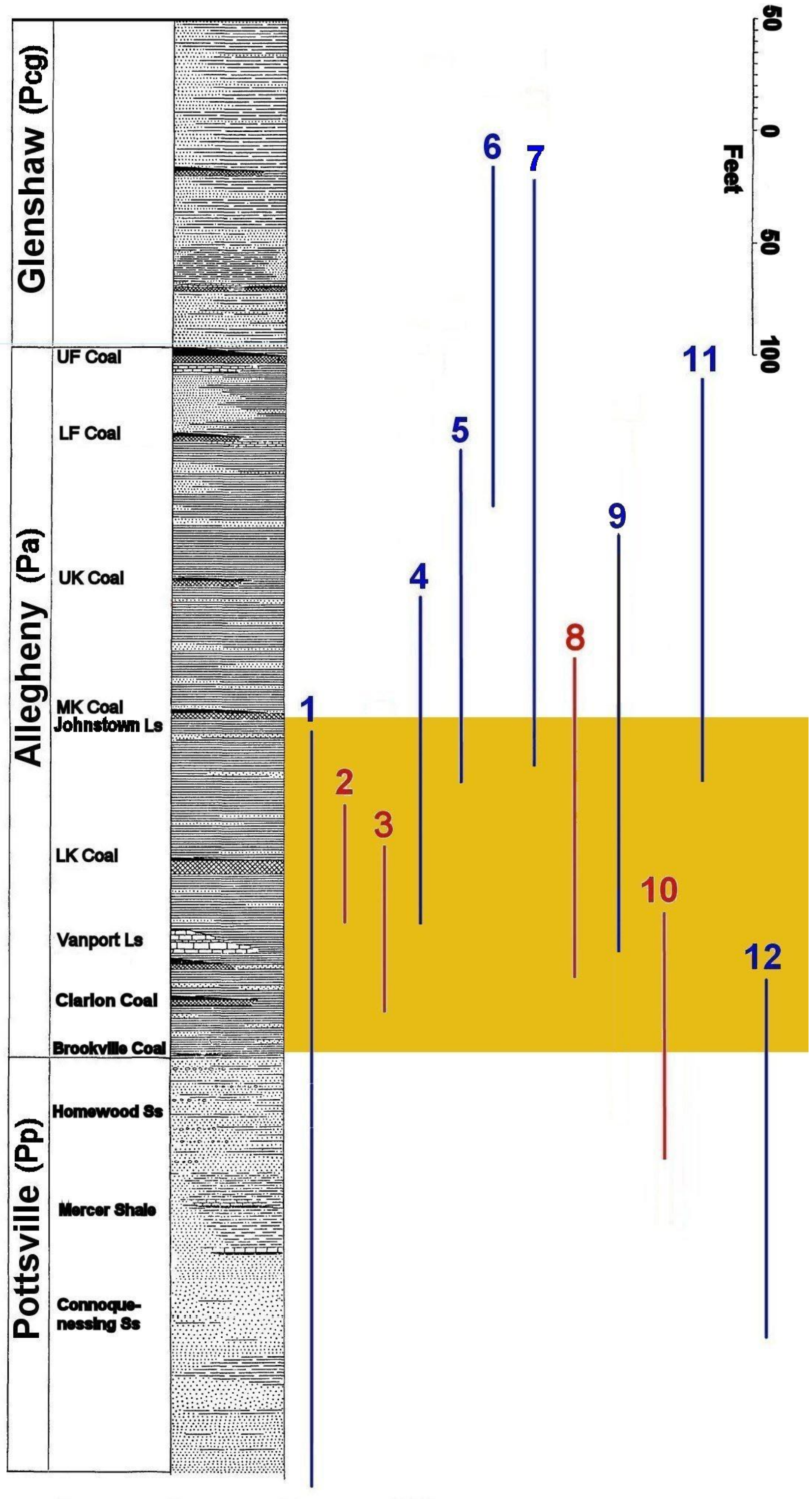

Figure 3. Profile of water wells by bedrock stratigraphic section penetrated. In some wells, glacio-lacustrine sediments overlie bedrock, which is not reflected in the line length representing the depth of wells. The shaded area indicates the lower Allegheny Formation, which generally produces poor-quality water (Brady and others, 1998). Stratigraphic column modified from Richardson (1936).

of the park, started in the lower Allegheny Formation and produced mostly from the Pottsville Formation. All of the wells with the worst quality (Group A—Wells #2, 3, 8, and 10) penetrated the lower Allegheny Formation (Figure 3) and were also in close proximity to surface and/or deep mines (Figure 2). The better quality wells (Group B—Wells #1, 4, 5, 6, 7, 9, 11, and 12) did not produce from the lower Allegheny Formation, or if they did (#4 and 9), were not proximal to previous mining. As a result, the two wells intended to supply most of the North (Well #10) and South (Well #2) Shores of the park were geologically in the least favorable locations. Nevertheless, initially, Wells #2 and 10 (Group A), and #4 and 12 (Group B) were placed into service to supply water to the park facilities and residences.

EVOLUTION OF WATER SUPPLIES

Shortly after the park was dedicated, the Boy Scouts of America decided to hold their upcoming 1973 National Jamboree on the North Shore of Moraine State Park (which they held there again in 1977). Well #10 (20 gpm [gallons per minute] yield), which supplied the North Shore, was incapable of supplying the 1.2 million gallons of water per day that would be required for 40,000 scouts (Pennsylvania Department of Environmental Resources, 1972). Well #10 was also high in iron, sulfates, solids, and hardness. Another supply would be required. As a result, in 1971, DER (Department of Environmental Resources, forerunner to today's Department of Conservation and Natural Resources) began a water-supply analysis (Pennsylvania Department of Environmental Resources, 1972) to determine the best way to supply the North Shore.

The 1971 analysis evaluated the geology and water quality of both surface and groundwater sources. It included a groundwater analysis conducted by geologists at the Pennsylvania Geological Survey. The Survey recommended that wells be drilled and cased through the Allegheny Formation and into the Pottsville Formation if a groundwater supply was chosen. Only 2 of the original 14 wells produced from the Pottsville (#1 and 12) (Figure 3). The Survey suggested two potential drilling sites (locations unknown). In addition, based on the success rates and yields of the 1966 wells, park engineers determined that, to get an adequate volume of groundwater, 16 successful wells with adequate yield would be required. The engineers estimated that 30 wells would have to be drilled in order to get 16 successful wells.

The main reason that the park developed groundwater sources in 1966 is because they feared that the water quality of Lake Arthur would be degraded due to acid drainage from the numerous abandoned coal mines in the watershed (Pennsylvania Department of Conservation and Natural Resources, 1998). However, the strip-mine reclamation and deep-mine sealing success resulted in lake-water quality that was excellent for a public water-supply source (Pennsylvania Department of Environmental Resources, 1972). As a result, a groundwater source was rejected, and the park elected to build a surface-water treatment plant and use Lake Arthur as the raw water source for the North Shore. Well #10 was abandoned and the treatment plant began to provide the North Shore water supply in 1972.

After the 1973 National Boy Scout Jamboree, the park began to connect separate water-supply systems together to reduce the number of separately sourced systems.

- In 1974, the Well #4 system (regional office area) was connected to the Well #2 system, and Well #4 was abandoned (Pennsylvania Department of Conservation and Natural Resources, 1998). The entire South Shore was supplied by Well #2.

- After a 1981 attempt to rehabilitate Wells #2 and 10 (to get better water) failed (Moody and Associates, Inc., 1981), a 2,000-foot water line was laid on the bottom of the lake from the North to the South Shore, and the Well #2 system was connected to the surface-water system. Well #2 was abandoned.

- In the early 2000s, the sewage-treatment plant was connected to the surface-water system, and Well #12 was abandoned (Dustin Drew, personal communication, 2019). The entire park was supplied by the surface-water treatment plant.

- In 2011, due to concerns about water-line breaks to the South Shore, and about DEP (Department of Environmental Protection) requiring upgrades to the surface-water treatment plant, DCNR (Department of Conservation and Natural Resources) again looked into groundwater sources. The park again asked the Pennsylvania Geological Survey for advice on attempting wells to supply water, and to recommend two sites. As in 1971, the Survey recommended two potential drilling sites and drilling through the Allegheny Formation and into the Pottsville Formation. Because of budget issues, Well #10 (North Shore) was cleaned out, and a new Well #2 (South Shore) was drilled beside and to about the same depth in the lower Allegheny Formation as the original Well #2. Not surprisingly, neither well was successful, because of water-quality issues.

THE YEAR 2016

By 2016, the surface-water treatment plant was showing its age. At 44 years old, it was reaching the end of its intended life and needed to be replaced if the park was to continue using Lake Arthur as a raw water source. In addition, because the treatment plant is run intermittently to fill the storage tanks and is idle while the tanks are drained by use, the treatment plant, which is designed to run continuously, is inefficient (John Jaskolka, regional DCNR engineer, personal communication, 2016). Therefore, DCNR decided to make another attempt to find an adequate groundwater source. One day in 2016, while I was in the park office, park manager Dustin Drew asked if I might have a recommendation for a potential drilling site.

GLACIAL GEOLOGY OF MORAINE STATE PARK—THE KEY TO SITING A WELL

Lake Arthur is a re-creation of a glacier-dammed lake from the Ice Age. Glacial Lake Arthur was about 6 miles longer and the water level was at least 70 feet higher than the current Lake Arthur. The glacier that dammed Muddy Creek to form glacial Lake Arthur stopped at the western edge of the park (Shepps and others, 1959), very near the current dam (Figure 2). As a result, almost none of the park was actually glaciated.

Prior to glaciation, drainage in western Pennsylvania was northwest into the Erie basin and out through the St. Lawrence River. As the glacier advanced into the area, the westward- and northwestward-flowing streams, including Muddy Creek, were dammed by the glacier, creating lakes in the valleys ahead of the glacier (Figure 4). Glacial Lake Watts formed in the Muddy Creek basin, where Lake Arthur currently exists. Sediment released by the melting glacier front was deposited in the lake. Coarse sediment (sand and gravel) settled out quickly near the ice front. Finer sediment (silt and clay) remained suspended longer and migrated farther out into the lake basin. More than 100 feet of fine lacustrine sediments was deposited on the lake bottom, so that today, the lake bottom is more than 100 feet above the preglacial bedrock floor of the Muddy Creek valley.

While the glacier was at or near its maximum extent, the front was very near the present location of Interstate Route 79 (Figure 2). Meltwater released from the glacier poured into Lake Watts and deposited the coarser sediment near the ice front, in the northwest corner of today's park, as a delta prograding into the glacial lake. Much of the shoreline of the northwest corner of present Lake Arthur is composed of this glacio-deltaic sediment. The coarser deltaic sediment overlies the earlier deposited fine-grained lacustrine clays (Figure 5) (see also Fleeger, 2020, cover photograph and fig. 3).

Lake Watts drained through the Slippery Rock Gorge at McConnells Mill State Park in several stages as low places in the divide were progressively uncovered when the glacier retreated (Figure 6). The final drainage path for glacial Lake Arthur was the current location of Muddy Creek. However, that is not the preglacial location of Muddy Creek.

Preglacial Muddy Creek flowed northwest from the northwest corner of the current lake and turned west toward Slippery Rock Creek (Figure 7). Preglacial Muddy Creek was buried by glacial sediment deposited on the lake bottom and in the delta that built into Lake Watts from the front of the glacier, preventing Muddy Creek from re-establishing its preglacial course. The current Muddy Creek flows west through a gorge at Portersville Station created by the drainage diversion, then turns northwest to rejoin the preglacial course (Figure 7).

Although the existence of a preglacial valley has been known for many years (Preston, 1950, 1977; Peck and Deere, 1964), I am not aware of any maps indicating its precise location. The published

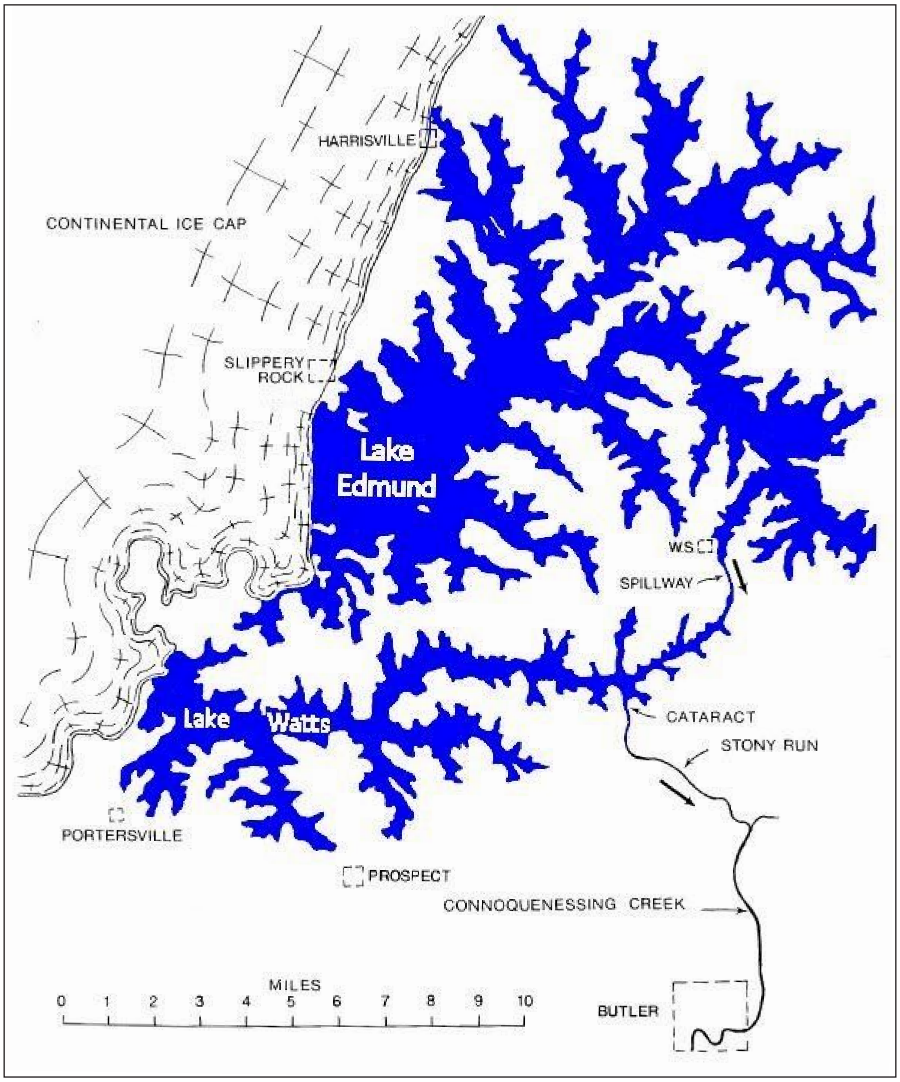

Figure 4. Lake distribution in Muddy Creek and Slippery Rock Creek valleys. Lake Arthur is a modern reduced reconstruction of glacial Lake Watts. WS, West Sunbury. Modified from Preston, 1977, Drainage changes in the late Pleistocene in central western Pennsylvania, *Pittsburgh, Pa., Carnegie Museum of Natural History, p. 46. Used with permission.*

geologic map of the area (Richardson, 1936) gives no indication that a buried preglacial valley exists. The mapped outcrop of the Pottsville Formation extends up the Muddy Creek valley only a very short distance from its confluence with Slippery Rock Creek. However, geotechnical exploratory drilling in the 1950s at several potential dam sites, and in the 1960s for the U.S. Route 422 and State Route 528 relocations, showed that the bedrock floor of Muddy Creek is buried beneath more than 100 feet of lacustrine sediments. It stands to reason that this deep bedrock valley must continue west behind the glacial border. However, no one siting any of the previous wells drilled in the park seems to have been aware of the existence of this preglacial Muddy Creek valley, because none of the wells were drilled there (see cover image).

SITING THE NEW WATER WELL

My goal for siting the new water well was to attempt to locate it at the axis of the buried preglacial Muddy Creek. Such a location could provide the following three benefits:

1. It would have the greatest thickness of the unconsolidated lake bottom and glacio-deltaic sediments. While some of these sediments may be fine grained, their intergranular porosity provides a significant storage reservoir for groundwater. A well drilled into these sediments may provide large quantities of water. If drilled into the underlying bedrock, the sediments would still provide much groundwater storage to resupply the underlying bedrock after water is withdrawn.

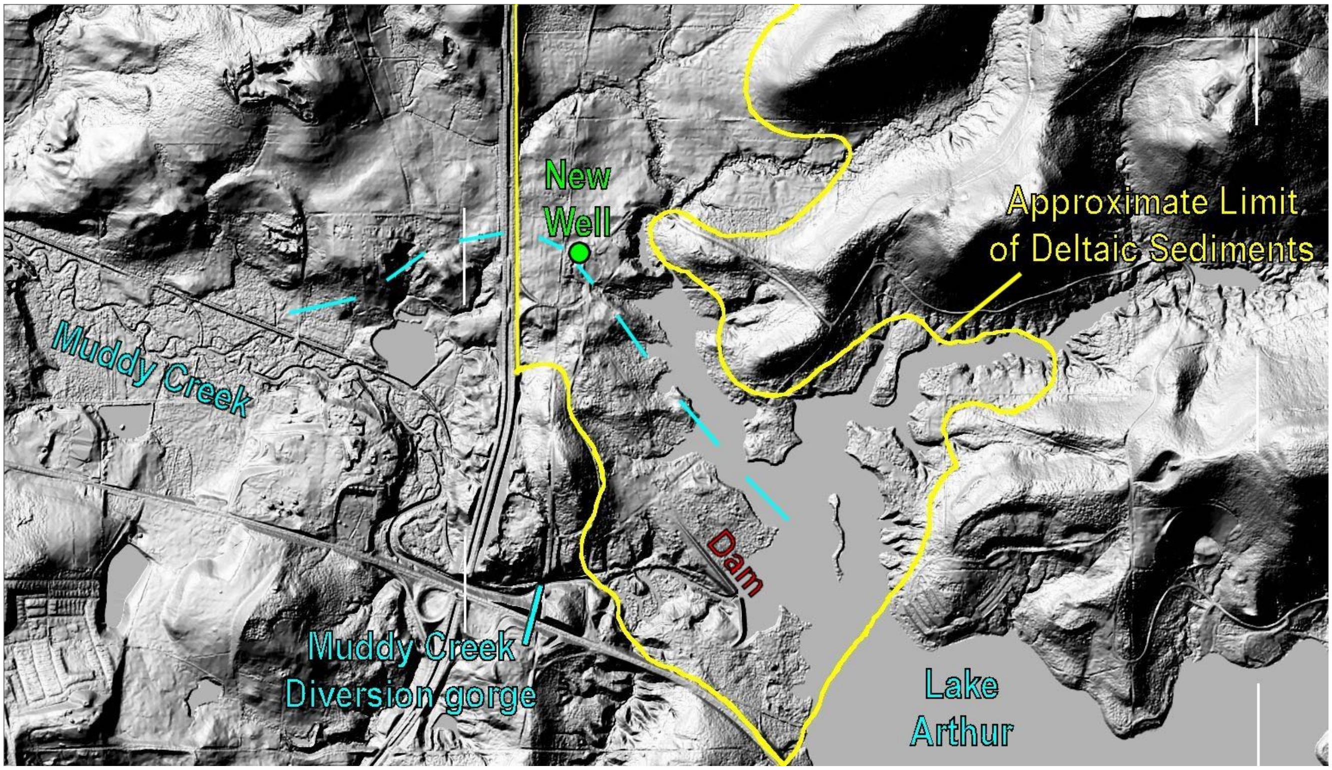

Figure 5. PAMAP hillshade image of the northwest corner of the park, showing the approximate extent of deltaic sediments (yellow). The blue dashed line shows the preglacial course of Muddy Creek. The location of the existing dam forming Lake Arthur is also shown.

2. The center of the buried valley would probably be below the Allegheny Formation; thus the associated poor water quality would be avoided.
3. If the well were drilled into the underlying bedrock, it might encounter more highly fractured bedrock. Valleys are eroded where the bedrock is more susceptible to erosion, and often it is more erodable because of fracturing. In addition, stress-relief fracturing often occurs in valleys because of the removal of supporting rock (Ferguson, 1967). Increased fracturing occurs beneath the valley and along the valley sides (Figure 8). Because fractures are pathways for groundwater in bedrock, valley stress-relief fractures are commonly the most transmissive part of an aquifer (Wyrick and Borchers, 1981).

To more precisely identify the location of the center of the buried valley, I first gathered all of the water-well records that were available in PaGWIS (Pennsylvania Groundwater Information System, online at https://www.dcnr.pa.gov/Conservation/Water/Groundwater/PAGroundwaterInformationSystem/Pages/default.aspx). With those data, I built a bedrock topographic map (Figure 7). While it did define the buried valley, the data density was insufficient to be able to determine if the valley was symmetric or asymmetric.

To try to better define the valley axis, I used a couple of geophysical methods. Because of the speed and ease of gathering data, I first attempted to use GPR (ground-penetrating radar). I realized that the GPR probably would not be able to penetrate to the maximum depth of the valley, but I hoped that penetration would be adequate to be able to determine the steepness of the valley sides in order to estimate valley depth and symmetry. I recruited Dr. Eric Straffin at EUP (Edinboro University of

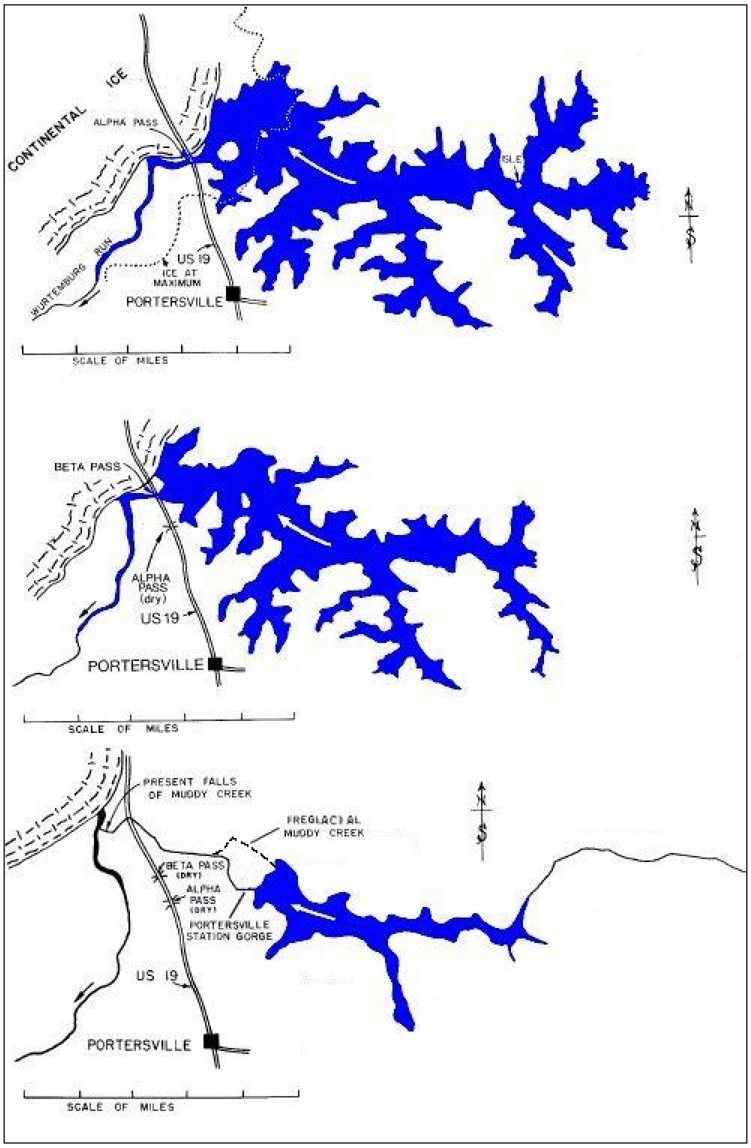

Figure 6. Lake Watts drainage through passes in phases as the glacier retreated (top to bottom). Modified from Preston, 1977, Drainage changes in the late Pleistocene in central western Pennsylvania, *Pittsburgh, Pa., Carnegie Museum of Natural History, p. 50. Used with permission.*

Pennsylvania) to bring their GPR unit, a Mala Geosciences 250 Mhz system, with data processed in RadExplorer software. He and some of his students ran several profiles across the buried valley. Unfortunately, the sediments were too clayey (electrically charged) for penetration to an adequate depth to provide much information.

I then invited Dr. Tamara Misner (EUP) to use their portable seismic array, a Geometrics shallow seismic system that collected refraction data. This was more successful but much more labor intensive and time consuming. The seismic data provided useful data on the unconsolidated sediment and the depth to bedrock along the valley margin (Morgan and others, 2017). However, we did not have time to complete the survey all the way across the buried valley, and we were still unable to precisely locate the valley axis.

By early 2017, DCNR had a contract in place to drill the well and needed a location in which to drill. I assumed that the center of the buried valley was most likely to be the deepest part, and I selected a location there.

The well was drilled in June 2017. An adequate quantity was obtained from within the glacial sediments, but the water was a little high in iron and manganese (John Jaskolka, personal communication, 2017). The DCNR regional engineer decided to drill deeper. The final well was 300 feet deep into highly fractured Pottsville Formation sandstone (Figure 9). The initial driller estimate was 4,000 gpm, the largest ever seen by the driller. A 48-hour pump test determined the yield to be 2,000 gpm. DEP applied a 75 percent safety factor for droughts, so the final yield determination is 1,500 gpm, or approximately 2 million gpd (gallons per day), more than enough to supply the park's maximum 50,000 gpd needs. It would have been adequate to supply the 1970s Boy Scout National Jamborees.

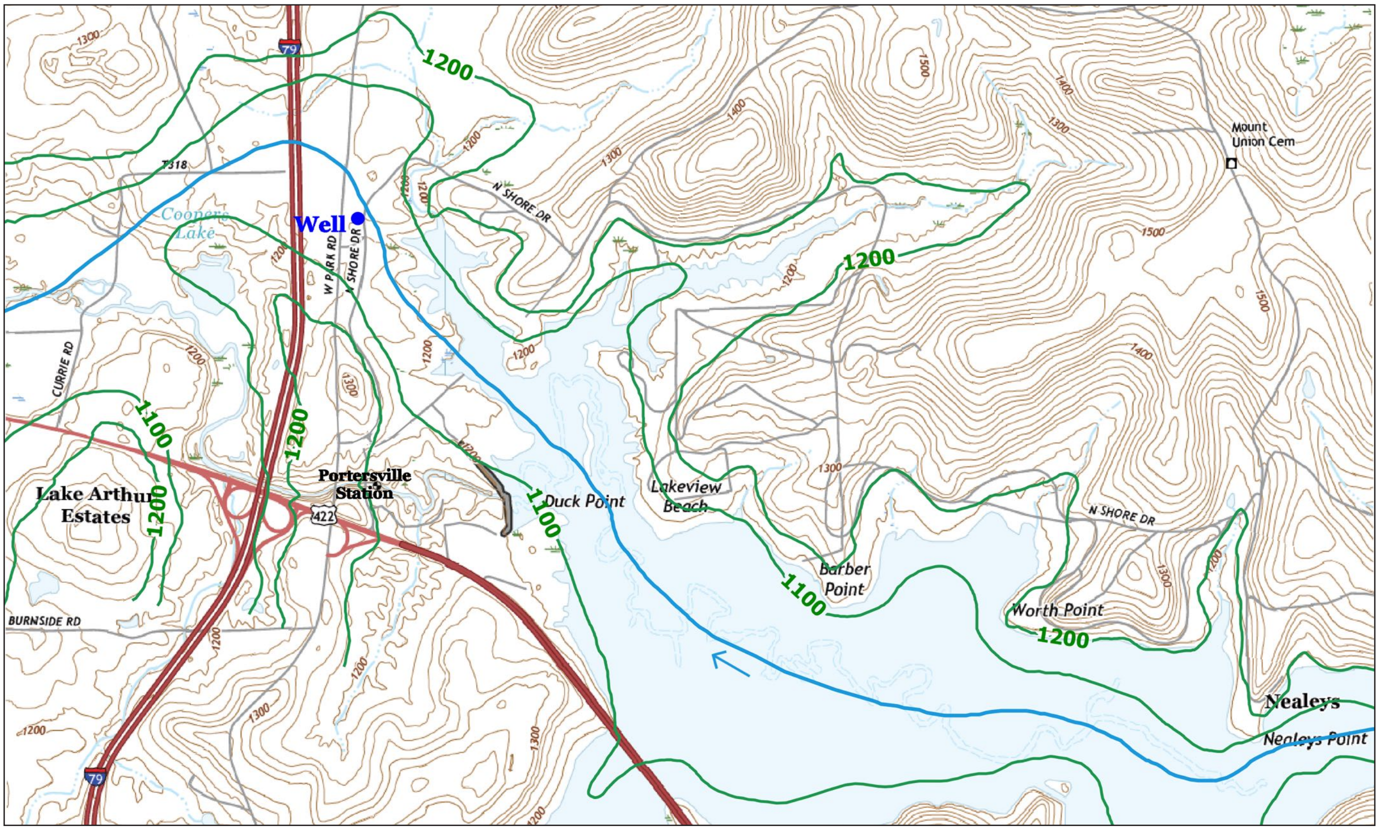

Figure 7. Bedrock topographic map of the area. The green contours on the top of the bedrock beneath surficial deposits indicate the approximate preglacial ground-surface configuration. The preglacial valley is now blocked by glacial sediment, and the current Muddy Creek flows through a small bedrock gorge at Portersville Station, not reflected by the preglacial bedrock contours. The blue line indicates the approximate course of preglacial Muddy Creek.

The water quality is exceptional. Because it is for a public water supply, it was analyzed for a complete suite of chemical parameters, a few of which are summarized below. Only manganese exceeded the EPA-established SMCL (secondary maximum contaminant level) of 0.05 mg/l and is not of any health concern.

- Iron, 0.25 mg/l **(SMCL = 0.3 mg/l)**
- pH, 7.4 **(SMCL = 6.5 to 8.5)**
- Hardness, 160 mg/l **(SMCL = 180 mg/l)**
- TDS (total dissolved solids), 280 mg/l **(SMCL = 500 mg/l)**
- Manganese, 0.113 mg/l **(SMCL = 0.05 mg/l)**
- Chloride, 33.0 mg/l **(SMCL = 250 mg/l)**
- Sulfate, 25.0 mg/l **(SMCL = 250 mg/l)**
- Fluoride, 0.252 mg/l **(MCL [maximum contaminant level] = 4.0 mg/l)**
- Total coliform, absent
- *E. coli,* absent

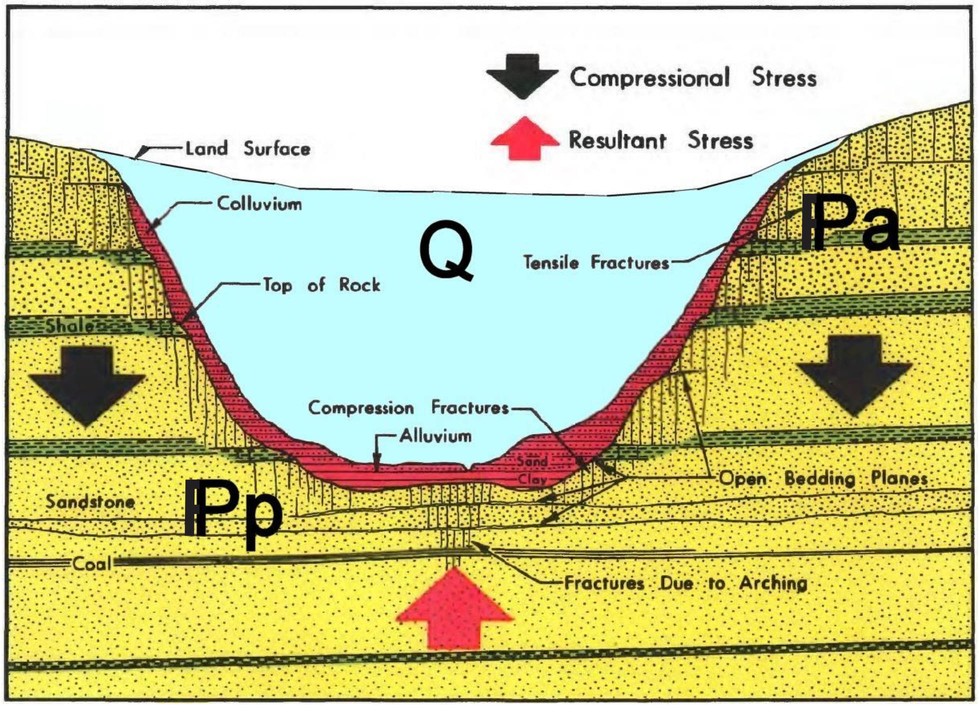

Figure 8. Theoretical stress-relief valley cross section. Modified from Wyrick and Borchers (1981) to reflect the local buried Muddy Creek valley. Q, Quaternary glacial valley fill; IPa, Pennsylvanian Allegheny Formation; IPp, Pennsylvanian Pottsville Formation.

The well penetrates 157 feet of glacial sediments over bedrock (Figure 9). The unconsolidated sediments in the well are a clayey sand over clay, interpreted as deltaic sediments over lake-bottom sediments.

Because of the success of the well, the park retired their surface-water treatment plant and connected the well, designated as Well #004, to the water-storage and distribution system in March 2021. In addition to saving the money that would have been used to build a new treatment plant, the well can efficiently be pumped intermittently as water is needed to refill the storage tanks throughout the park. The savings were applied to rehabilitating parts of the water-distribution system, which was also showing its age.

REVISING THE BEDROCK GEOLOGIC MAP

As noted previously, part of the reason that previous people siting water wells in the park failed to recognize the buried valley is because the bedrock geologic map (Richardson, 1936) was incorrect. The Pottsville Formation extends only a short distance up Muddy Creek from the Slippery Rock Gorge on Richardson's map. While Richardson did not have water-well data that are available today, he did recognize the lacustrine sediments in the Muddy Creek valley beyond the glacial border. It seems logical that those glacial sediments in the valley would also extend downstream on Muddy Creek within the glacial border. He probably had little information on the thickness of the valley fill and did not realize that the valley bottom extended into the Pottsville Formation.

When the park was being planned in the late 1950s, the state explored a number of potential dam sites (Pennsylvania Department of Forests and Waters [forerunner of DER and DCNR], 1958). Test borings for four dam sites (none of which were used; one is shown on Figure 2) often extended to bedrock. In addition, when the park was being built in the late 1960s, the relocations of U.S. Route 422

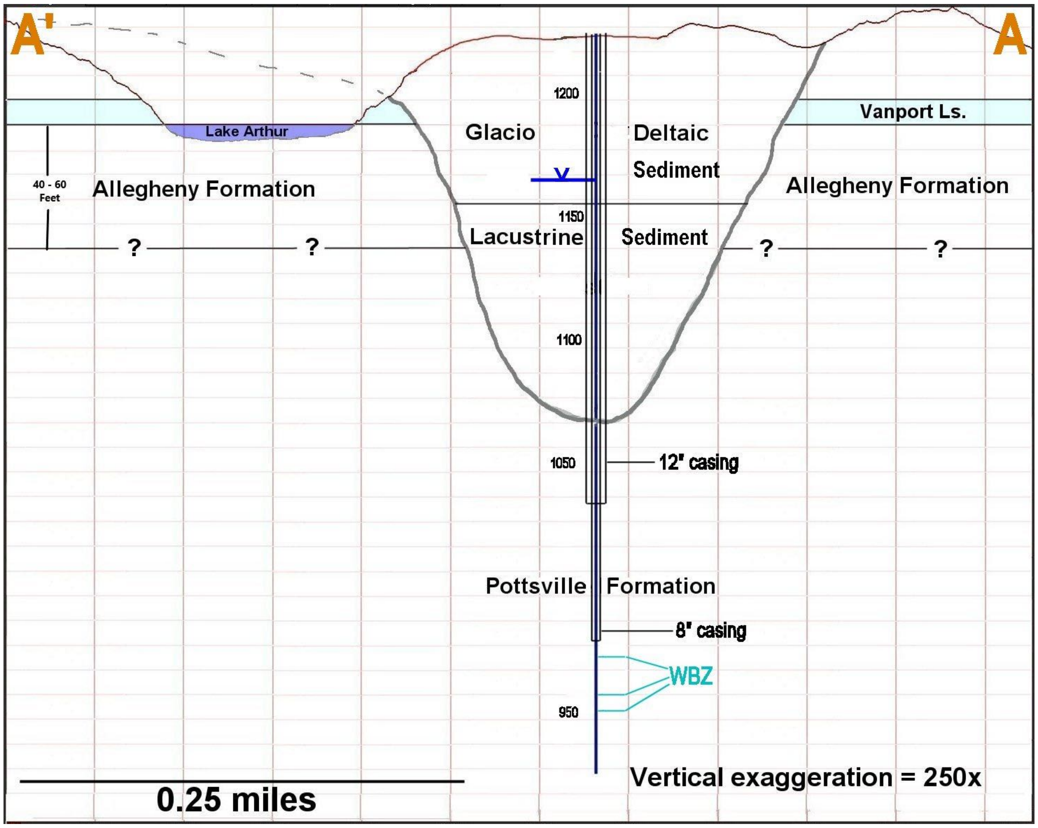

Figure 9. Cross section through the buried valley at the well, looking southeast. Well-construction information is shown on the well. WBZ, water-bearing zone; ⊻, static water level. Elevations are displayed beside the well. The line of section is shown on Figure 2.

and State Route 528 included bridges over the future lake. These also had geotechnical borings extending to bedrock (Pennsylvania Department of Transportation project files). In more recent years, bridge replacements over Muddy Creek and tributaries above and below the park have resulted in additional geotechnical boring data (Pennsylvania Department of Transportation project files).

Using these boring data, the bedrock surface contours, and the structure map for the area (Dodge, 1985), I have extended the contact between the Allegheny and Pottsville Formations in the Muddy Creek valley more than 5 miles to the east from Richardson's (1936) contact, to Nealeys Point (Figure 10). The contact defines the preglacial Muddy Creek valley. Had the contact been correctly mapped, previous workers might have recognized the buried valley, and a good water-supply well could have been developed when the park was built.

ACKNOWLEDGMENTS

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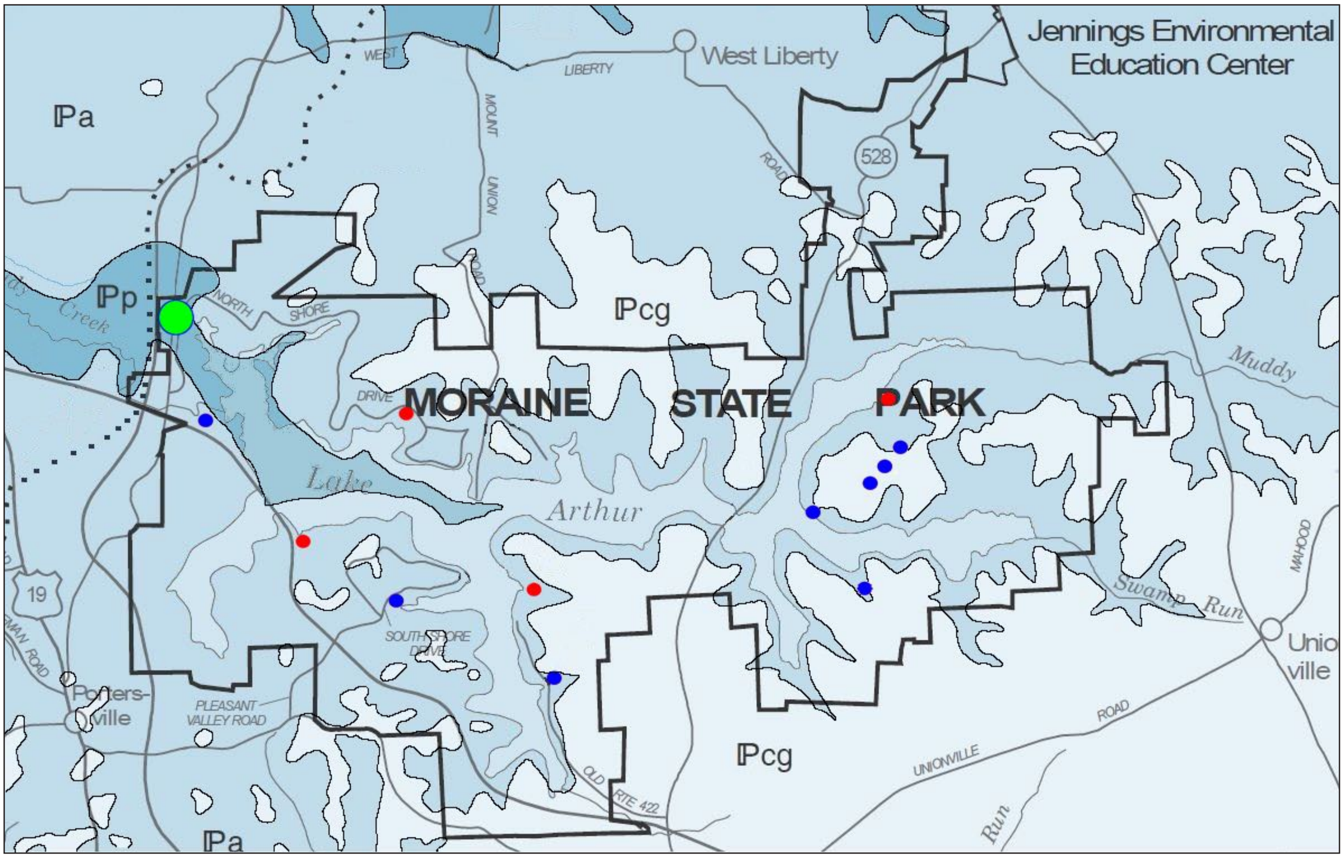

Figure 10. Revised geologic map showing extended Allegheny-Pottsville contact. Modified from Fleeger and others (2003). The 1966 wells are indicated by small red and blue dots reflecting relative water quality (red, Group A, poor water quality; blue, Group B, good water quality). The new 2017 well (Well #004) is indicated by the larger green dot in the northwestern corner of the park. ℙcg, Glenshaw Formation; ℙa, Allegheny Formation; ℙp, Pottsville Formation. The dotted line is the approximate glacial border.

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Editorial—Continued from page 2

state and federal partners, this group was instrumental in completing new QL2 (high-resolution) lidar coverage of the state. Data can be found on PASDA's website (https://www.pasda.psu.edu). **(3)** Kristen Hand is the Department of Conservation and Natural Resources (DCNR) lead for the Kittatinny Ridge Conservation Landscape. Her efforts on the Kittatinny and statewide help to promote how the geologic landscape is foundational to an area's "sense of place." Kittatinny Ridge won two national grant program awards this year: $10 million through the Regional Conservation Partnership Program of the Natural Resources Conservation Service to work with the Department of Agriculture on conservation easements along the ridge, and $15,000 from the Network for Landscape Preservation Catalyst Fund to further the strategic plan implementation and continue work with a new conservation plan for the ridge.

As I mentioned in the summer issue, our offices are open again. Although we are not encouraging large meetings, visitors are allowed. Most of the staff has taken advantage of the "permanent" telework agreements now offered by DCNR that allow us to telework up to 50 percent of the time. With a bit of adjusting to the technology, that arrangement seems to be working satisfactorily. I suggest that if you do plan an in-person visit, you should call or email ahead to ensure that the person you want to see will be in the office.

Best wishes to all for a happy and healthy new year!

Gale C. Blackmer

Gale C. Blackmer
State Geologist

Remembering the 2021 Annual Field Conference of Pennsylvania Geologists

Photographs and captions by Ellen Fehrs
Pennsylvania Geological Survey

Editor's note: The 85th Annual Field Conference of Pennsylvania Geologists was held on October 7–9, 2021. It focused on the geology of Ohiopyle State Park and surrounding areas in the Laurel Highlands, with a special emphasis on the geoheritage attributes of several sites. An example of the area's geoheritage includes the fact that during the last half of the eighteenth century, George Washington and other adventurers made some history when they ventured over the rock strata in this region. Another is that in 1877, J. J. Stevenson was the first person to notice that the Youghiogheny River at one time flowed across the narrow neck of what is known today as the Ferncliff Peninsula.

This is the third time that the Field Conference has featured Ohiopyle, but the last time was nearly 60 years ago. Since then, the area was made into a state park, and much has been learned about the geology and evolutionary history of its landscape. Topics discussed at the conference included

Aaron Bierly, a staff geologist at the Bureau of Geological Survey, is prepared for the caving expedition that served as one of the preconference field trips. Aaron is pictured here on the grounds of Laurel Caverns just prior to the four-hour private tour. Features of note in the cave included faulting, differential erosion due to phantomization, and extensive cross-stratification in the Loyalhanna Limestone.

Geologists beginning the first day of the field conference at Robinson Falls. The focus of this stop was the evolution of this waterfall as influenced by Glacial Lake Monongahela, and the stratigraphy and sedimentology of the Benwood Limestone Member. The first known geologic description of Robinson Falls was written by Thomas Hutchins 235 years ago! More information on the geologic history of the waterfall can be found in the Annual Field Conference of Pennsylvania Geologists (FCOPG) 2021 guidebook and road log, both of which are available to download for free from the FCOPG website (www.fcopg.org).

Pleistocene weathering and erosion rates related to Lake Monongahela and knickpoint migration in its Youghiogheny tributary (a knickpoint is part of a river or channel where there is a sharp change in channel slope); weathering rates of Homewood sandstone on Laurel Ridge related to the formation of Turtlehead Rock bog and the preserved ecological record; the complexity of groundwater movement in Mississippian Mauch Chunk and Burgoon strata to form caves (and its impact on underground mining and springs); the Paleozoic stratigraphy and structural geology of the area; and also some unique geologic and culturally historic aspects of Pennsylvanian and Mississippian strata exposed at quarries, waterfalls, rail trails, ridgelines, and caves.

There were also eight preconference trips: a GeoBike tour of the Lower Youghiogheny gorge; a hike to Meadow Run Cascades; a visit to Cucumber Falls; the Linn Run Loyalhanna Limestone quarry and PW and S Railroad; a private tour of Laurel Caverns; the Youghiogheny hydroelectric dam; thrust faulting in the Deer Valley Limestone; and the Quecreek coal mine “9 for 9” rescue site.

For another perspective concerning a visit to this area, see “Rocks and Water—The Conflict of a Typist in a Geologist’s World” by Renee Speicher in *Pennsylvania Geology,* v. 49, no. 1, 2019.

Geologists take in the view at the base of Robinson Falls. This feature is an upstream migrating knickpoint situated on Opossum Run—the ultimate result of the overflow of Glacial Lake Monongahela, which led to the formation of the Ohio River and the incision of the Youghiogheny River. The Benwood Limestone is a relatively resistant formation that concentrates the base level fall at this location.

Frank Pazzaglia, Professor of geology at Lehigh University, discusses the geologic and landscape evolution of the Laurel Highlands at the Baughman Rock overlook. This stop provided a remarkable view of the Youghiogheny River gorge. Readers interested in views from this outlook should take a look at the photography provided in the 2021 Annual Field Conference of Pennsylvania Geologists guidebook and road log.

Geologists diligently make their way toward Turtlehead Rock bog, named for the iconic formation that resembles a turtle head (pictured here at the center). Features of note include boulders (the Turtlehead Rock bog "rock city") comprised of the Homewood sandstone, the faces of which are joint controlled. Due to heavy vegetation, any accurate surveying of these boulders was difficult when using ground observation or drone photography. Examination of regional joint trends had to be performed using lidar data.

A geologist captures what are sure to be stunning photos of the Homewood sandstone "rock city" at the Turtlehead Rock bog stop. Due to the high value of this site, rock hammers were not permitted; in lieu of samples, many photographs were taken! Visitation of this Geoheritage Site requires pre-approval from the Ohiopyle State Park management.

Department of Environmental Protection geologists Mike Stefanic (left) and Steve Clark (right) enjoy the Homewood sandstone from different vantage points. The joint-controlled surfaces of these cross-bedded boulders are visible just behind (and on either side of) Mike.

Laurel Caverns Pen Shell Fossil

Katherine Schmid
Pennsylvania Geological Survey

One of the 2021 Field Conference of Pennsylvania Geologists stops was at Laurel Caverns, Pennsylvania's deepest cave, in Fayette County (Schmid, 2021). Due to my hobby of exploring caves and the fact that I have friends who have worked as tour guides at Laurel Caverns, I volunteered to run this stop and facilitate a tour of the cave. To guide 180 geologists through the cave, I ran three tours, one for each bus, and I planned various stops inside the cave. One of the stops was at a spot where a fossil that I had previously referred to as a marine fossil (Schmid and others, 2021) is exposed in the ceiling. I know my limits. I am not a paleontologist, and I knew that there would be some in attendance on this trip who might help with the identification of this fossil.

On the first tour, two geologists identified the fossil for me. John Harper and Steve Bill both identified it as a "pen shell," a member of the family Pinnidae, genus *Sulcatopina,* a clam that is found in shallow marine environments. Radenbaugh and McKinney (1998) compared Holocene and Mississippian assemblages that contained pen shells and noted that both occur in fine-grained, calcareous, siliciclastic sediments. This fits with a shallow marine interpretation of the depositional environment of the Loyalhanna Limestone. According to Christopher Swezey (2021), the Loyalhanna Limestone is an eolian (sand dune) strata preserved by a rise in sea level. This transgressive sea deposited the calcite cement (which allowed a cave to form in this sandy bedrock), as well as the few marine fossils found in the cavern.

A specimen of a pinnid bivalve (popularly called a pen shell) of the genus Sulcatopina *exposed on the roof of Laurel Caverns.*

ACKNOWLEDGMENTS

I would like to thank John Harper for identifying this fossil, sharing references about pen shell fossils with me, and making sure I used the correct terminology in this article. I would also like to thank Ryan Maurer. I would not have found this and other treasurers in Laurel Caverns without his help. Finally, I would like to thank Christopher Swezey for giving his talk on Mississippian eolian strata on April 22, 2021, at the geologic mapping forum hosted by the Minnesota Geological Survey.

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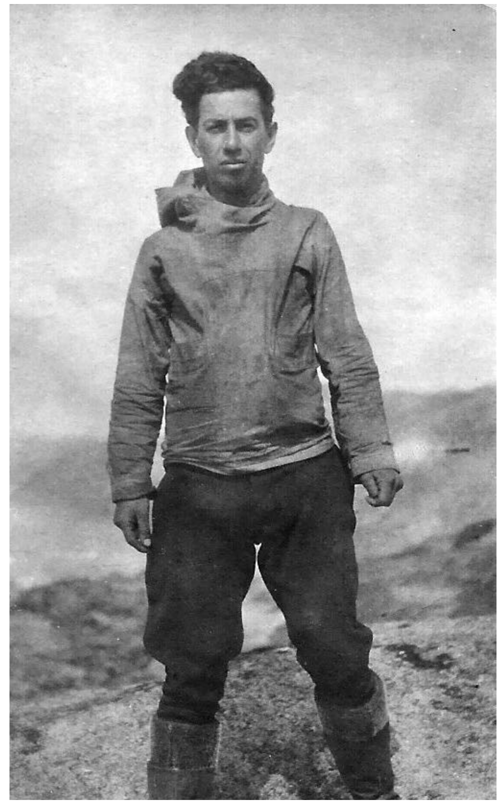
One Hundredth Anniversary of a Publishing Milestone

John H. Barnes
Pennsylvania Geological Survey, retired

The year 2022 marks the one hundredth anniversary of the publication of a book that is one of the staples of the literature for Pennsylvania mineralogists and mineral collectors, *The Mineralogy of Pennsylvania,* by Samuel G. Gordon, originally published by the Academy of Natural Sciences of Philadelphia as Special Publication 1 (Gordon, 1922). This book, which has been reprinted several times, is considered to be "the first and most complete listing, up to that time, of the location of some famous, and many obscure, Pennsylvania minerals" (according to D. M. Lapham in the foreword to the 4th printing [Gordon, 1973]). The compilation has two main sections. One section contains descriptions of minerals classified by their chemistry and accompanied by lists of localities where each mineral can be found. The other main section is a list of localities by county and township with information as to what minerals can be found at each. The emphasis is strongly on southeastern Pennsylvania, but Gordon documented occurrences throughout the state. Mineral collectors still refer to these localities as "Gordon localities." Many, perhaps the majority, of the occurrences are no longer accessible or are otherwise "lost" for various reasons, which makes this compilation especially valuable to those who work with collections and descriptions that are of historical interest, as well as modern researchers who wish to know what was previously found in an area where they are working. Some discussions toward the front of the book on general geology and the origin of minerals have long since been superseded by later work, but they still provide an interesting historical perspective.



Samuel G. Gordon on one of the two expeditions that he led to Greenland in 1923 and 1932. Photograph from the Pennsylvania Geological Survey archives.

One might suspect that a major compilation such as this would have come toward the end of a long and illustrious career, but that conclusion would be incorrect. *The Mineralogy of Pennsylvania* was published by the Academy in 1922, the year in which Gordon turned 25. The work drew mostly from earlier works, such as F. A. Genth's Second Pennsylvania Geological Survey Reports B and B2 on the mineralogy of Pennsylvania (Genth, 1875, 1876), and other compilations, such as the series of articles by Elmer Benge and Edgar T. Wherry that were published as the "Directory of Mineral Localities In and Around Philadelphia" in *Mineral Collector* (Benge and Wherry, 1905–08). Gordon included a lengthy "Bibliography of Pennsylvania Mineralogy" in his volume. But his compilation was more complete than any previous one. An important aspect of his book that set it apart was that he provided geological context for the occurrences by including information on the geological formations in which the minerals occurred, something that was not always done in previous compilations (Montgomery, 1973).

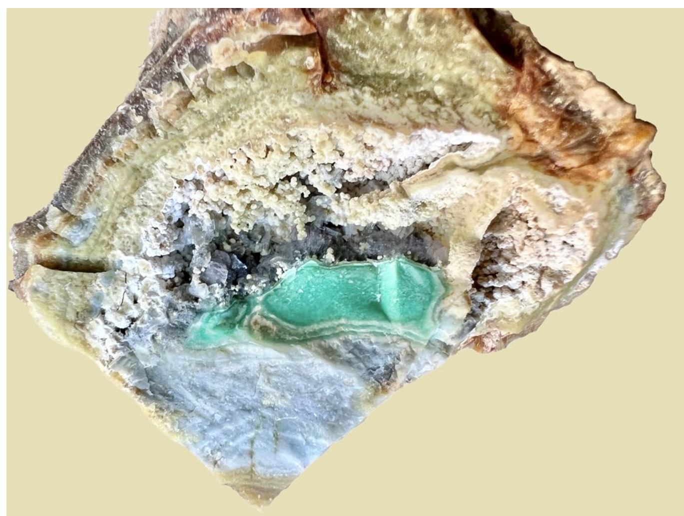
Gordon's formal training in mineralogy was limited to courses taken between the ages of 14 and 18 at the Wagner Free Institute of Science in Philadelphia, where he had an excellent teacher, Edgar T.

Wherry, who had recently received a Ph.D. in mineralogy from the University of Pennsylvania. Wherry played an important role in nurturing Gordon's interest and curiosity about mineral occurrences. At age 16, Gordon received a fellowship at the Academy of Natural Sciences, where he worked with a large private collection of 12,000 specimens that had been willed to the Academy by William S. Vaux. That work furthered Gordon's interest in minerals, including his interest in attempting to understand why particular minerals are found in certain places and not elsewhere (Montgomery, 1973).

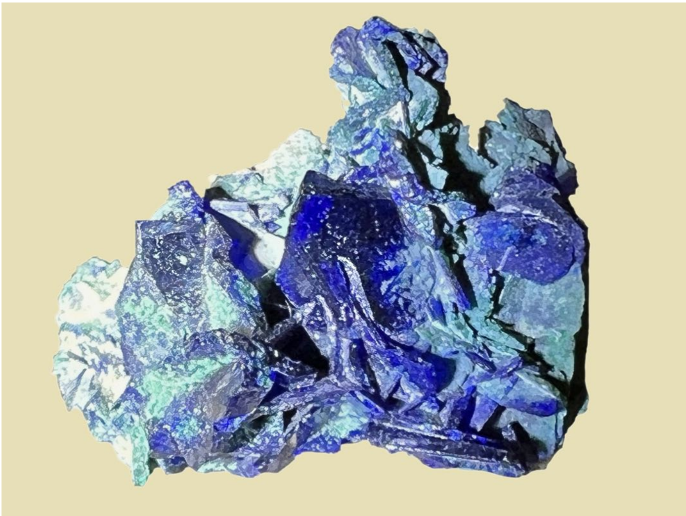
In addition to his studies with Wherry and his work at the Academy, Gordon had a strong interest in improving communication among mineralogists so that they could better share their research and their findings. One aspect of that was manifested by his enthusiasm as an active member of the Philadelphia Mineralogical Society. Another, which was to have national repercussions to this day, was his spending "much of 1915 contacting individuals and organizations and by early 1916 [assembling] a staff" of what was to eventually become an important new journal, *The American Mineralogist,* which later became the principal journal of the Mineralogical Society of America after it was organized in 1919. Gordon accomplished this when he was only 19 years old (Phair, 1969).

Rather than pursuing a college degree following his studies with Wherry, Gordon continued his work at the Academy, where he compiled a significant amount of data on Pennsylvania mineral occurrences. That work "grew out of his indefatigable field collecting and creative concern for the geological associations and origin of the minerals collected and studied. It led finally to the publication [in 1922] of one of his finest scholarly achievements, and the work by which he is perhaps best remembered," *The Mineralogy of Pennsylvania* (Montgomery, 1973, p. 260).

Founding *The American Mineralogist* and publishing *The Mineralogy of Pennsylvania* were only the opening acts of a long career. Gordon went on from there to many additional accomplishments. He continued his work on the Vaux collection at the Academy into the early 1930s, by which time "12,000 specimens of exceptional caliber had been rearranged, catalogued, and securely housed . . . Several thousand of the finest Vaux minerals had been exhibited in display cases . . . The older pre-Vaux Academy collection of 7,000 specimens, mostly mediocre in quality but of much historic and regional value, had been cleaned up and put in better scientific order" (Montgomery, 1975a, p. 7). He performed this work with a minimum of laboratory equipment, his main tools being a two-circle reflecting goniometer, which he used



Specimen from Clay Canyon, Oquirrh Mountains, Utah, containing gordonite, $MgAl_2(PO_4)_2(OH)_2{\cdot}8H_2O$. The name ***gordonite,*** *in honor of Samuel Gordon, was proposed by Esper S. Larsen of Harvard University and Earl V. Shannon of the U.S. National Museum, who first described it (Larsen and Shannon, 1930). They recognized its relation to the mineral paravauxite, $Fe^{2+}Al_2(PO_4)_2(OH)_2{\cdot}8H_2O$, which was first described by Gordon. The gordonite is present as the relatively large, dark crystals in the cavity near the center of the specimen. The bright green mineral just below them is variscite, $AlPO_4{\cdot}2H_2O$. The bluish-gray material below that is probably wardite, $NaAl_3(PO_4)_2(OH)_4{\cdot}2H_2O$. The small, lighter colored crystals in the cavity are possibly crandallite, $CaAl_3(PO_4)(PO_3OH)(OH)_6$. The specimen is approximately 5.5 cm in width. This specimen was in the personal collection of Arthur Montgomery, who considered it to be the best specimen of gordonite not in a museum.*



Specimen of azurite, $Cu_3(CO_3)_2(OH)_2$, with malachite, $Cu_2(CO_3)(OH)_2$, collected by Samuel Gordon from Tsumeb, Oshikoto Region, Namibia. Specimen is approximately 2.5 cm in width.

expertly, and an old petrographic microscope. With these minimal facilities, he described and named nine new minerals, eight of which are still recognized today. (The ninth was later determined to be a mineral that had previously been described and named.) He was also a pioneer in museum display techniques, placing minerals in attractive, artistic displays rather than cramming as many as possible in tight rows of cabinets, as had been the practice at many museums up to that time (Montgomery, 1975a; Parrish, 1953).

Gordon did not confine his work to the thousands of specimens that the Academy already had in its collection. He undertook several major collecting expeditions for the Academy to significant mineral locales in the Andes of Bolivia, Peru, and Chile; to Greenland; and to what was then called South West Africa, today's Namibia, returning from each expedition with 25 to 30 cases of outstanding minerals (Parrish, 1953). He wrote and published numerous papers describing those expeditions and his research.

From 1942 to 1944, Gordon took a leave of absence from the Academy to assist with the nation's war effort by working with others to meet a pressing need to manufacture large quantities of high-quality quartz oscillator-plates, which were required to control the frequency of radio transmissions and reception. According to the crystallographer William Parrish, who collaborated with him in this work, Gordon "showed unusual perception in piecing together the procedures used from the noncrystallographic crude descriptions given by the workers" at various plants where oscillator-plates were being manufactured in small quantities and "developed various rule-of-thumb procedures for quickly evaluating the efficiency of a plant, which were valuable in predicting production rates" (Parrish, 1953, p. 304).

Gordon returned to work at the Academy after the war and tried to move things forward there, introducing new technologies, such as X-ray diffraction, into his laboratory. He accomplished that with little institutional support by using a secondhand X-ray generator and a homemade X-ray camera that he and a friend designed. He remained at the Academy until 1949, when he resigned because of the Academy's lack of continued support for his work and the institution's shifting priorities. After leaving the Academy, he worked for several years in major research labs where his previous experience with crystallography during the war could be of value, first at Oak Ridge, Tenn., and then at Los Alamos, N.M. (Montgomery, 1975b; Parrish, 1953).

Samuel G. Gordon died in 1952 at the age of 55, just as he was about to embark on a new career with the Air Nuclear Propulsion Division of the General Electric Company, but his legacy lives on, especially with the continued relevance and usefulness of his landmark 1922 publication and the two publications that it inspired: *The Mineralogy of Pennsylvania, 1922–1965* (Montgomery, 1969) and *The Mineralogy of Pennsylvania, 1966–1975* (Smith, 1978). In his introduction, Montgomery stated that a primary aim of his book was "to continue the major purpose of Gordon's publication: to record, describe and clarify all mineral occurrences in Pennsylvania” (Montgomery, 1969, p. 1). In the preface to his book, Smith said, “It is hoped that this book will enhance collectors’ awareness of the treasure of minerals available in Pennsylvania and will increase appreciation of the complex series of geochemical and geological events that interacted to form the irreplaceable crystals that we now observe” (Smith, 1978, p. iii). That seems to be very much in the spirit of what Sam Gordon was striving to achieve throughout his career, and he probably could not have put it any better.

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BUREAU NEWS

Fall 2021 Volunteer and Intern Spotlight

Rose-Anna Behr
Pennsylvania Geological Survey

Conservation volunteers Anne Muren and Robin Smith assist with sorting water-well files donated by the Germania Well Drilling Company.

Tim Garner and Abbey Atkinson, fall interns in the Groundwater and Environmental Geology Section of the Pennsylvania Geological Survey, examine a sinkhole on Marticville Road.

Staff Retirement

Renee Speicher. During my eight years working at the Pittsburgh office of the bureau, Lynn Levino and I (along with our Information Technology staff member, Dave Fletcher) worked as a team to clean up gaps in the Exploration and Development Well Information Network (EDWIN) system (which provides users access to the state's 180,000-plus oil and gas wells of record) that could not be automatically transferred from the old Pennsylvania Internet Record Imaging System (PA*IRIS). We transformed the paper filing system into an electronic system in EDWIN and worked with the Department of Environmental Protection (DEP) to accept electronic transfers of oil and gas records, thus eliminating receiving bulk mailings from DEP offices and sorting through stacks of papers. These activities were part of a *Lean management approach* (which supports the concept of continuous improvement) and were critically necessary during the mandatory COVID office closures in 2020.

Some long-anticipated clerical process improvements are being led by Kristin Carter, Geoscience Manager of the Geologic Resources Division in Pittsburgh. These advancements to capture most drilling data through the use of a hybrid Artificial Intelligence (AI) method will be a vast improvement over having to type all the data by hand.

The most exciting part of my clerk position was the hunt to locate an old well in spite of having little information, and being able to find it! I have lasting memories of meeting our external customers and helping so many who truly appreciated all the well information found in EDWIN, in donated historic papers, and in the library repository. There were a few land/mineral owners who walked through our doors or called and who did not have computer access at home; they found our friendly assistance to be invaluable.

I miss working alongside the other office staff, retired volunteers, and interns; learning about other kinds of specialized geology from our Middletown office staff; and being exposed to the science of geology and how it helps the world around us.

As my husband, Kurt, and I are finding free time to travel more throughout Pennsylvania and beyond, I will continue exploring my passion for rocks, promoting the Pennsylvania Geological Survey, and spreading the word of what Pennsylvania has to offer to all!

New Staff Members

The Pennsylvania Geological Survey welcomed two new employees to the Economic and Subsurface Geology Division in the Pittsburgh office this October.

Gail Fireman

Gail Fireman. Gail (a Clerk Typist) has worked as a librarian and archivist, including many years at the Carnegie Library of Pittsburgh. Gail holds a B.A. degree in history from the University of Massachusetts, Amherst, and a Master's degree in library science from the University of Pittsburgh. She enjoys walking the hills of Pittsburgh, travel, rooting for Pittsburgh sports teams, and spending time with her husband and two daughters.

Michele Cooney. You may remember Michele as a former intern and contractor for the bureau. She has returned to serve as the Geoscience Supervisor in the Petroleum and Subsurface Geology Section in the Pittsburgh office. Michele holds a B.S. degree in geology from Allegheny College and an M.S. degree in safety science from Indiana University of Pennsylvania. She is also a licensed Professional Geologist. Michele enjoys running, watching the Great British Baking Show, and spending time with her boyfriend and three cats (Oliver, Beau, and Gemma).

Michele Cooney

Both of these women are proud Pittsburghers, born and raised!

The bureau also welcomed one new employee to the Geologic and Geographic Information Services Division in the Middletown office.

Alfred C. Guiseppe. With more than 20 years of professional experience working at the intersection of geologic sciences and GIS (Geographic Information Systems) technology, Al Guiseppe joined the bureau as Geoscience Manager of the Geologic and Geographic Information Services Division in November 2021. Although this position is his first formal employment with the commonwealth, Al has spent the last 15 years as technical lead on the Pennsylvania Department of Environmental Protection Source Water Protection Technical Assistance Program while at Spotts, Stevens and McCoy (SSM), an engineering consulting firm based in Reading, Pa. Prior to joining the bureau, Al was the director of water resources and GIS manager at SSM. Overseeing a staff of environmental specialists and geologists, he managed various water-resources-related projects, including groundwater supply development, watershed management, and source-water protection. In addition, he was responsible for the management and development of geologic and hydrogeologic modeling capabilities, including

Alfred Guiseppe

regional groundwater flow and contaminant fate and transport modeling.

Before his return to Pennsylvania, Al began his professional career in the West Texas oil fields, working for three years as a production geologist for Burlington Resources Oil and Gas Company in Midland, Tex. He is experienced at reservoir characterization and geologic modeling in the Permian Basin. While at Burlington Resources, he acted as project manager of an Enhanced Oil Recovery Project, which involved extensive field-data collection leading to rock-core descriptions and well-log analysis of mature oil fields.

A rock hound at an early age, Al quickly embraced a passion for geology in academics, earning a B.S. in geology from Millersville University of Pennsylvania in 1995 and an M.S. in sedimentary geology from the University of Wyoming in 1997. Hailing from a family of educators, Al shares a passion for public outreach and education. In his new role, Al plans to leverage technology to bring the great work of the bureau to all Pennsylvanians.

A Look Back in Time

Dr. Benjamin LeRoy Miller at the microphone during the Fifth Annual Field Conference of Pennsylvania Geologists, which was held in the Philadelphia area of southeastern Pennsylvania in 1935. Dr. Miller was a Professor of geology at Lehigh University and was a "cooperating geologist" with the Pennsylvania Geological Survey from 1919 until his death in 1944. He authored or coauthored many reports for the bureau. This photograph was taken by bureau geologist Dr. Bradford Willard on June 2, 1935. Dr. Miller was the trip leader and led four stops on that day.

To learn more about the life and contributions of Dr. Benjamin LeRoy Miller, please see the following:

Stewart, Duncan, Jr., 1945, Memorial of Benjamin LeRoy Miller: American Mineralogist, v. 30, p. 142–147, online at http://www.minsocam.org/ammin/AM30/AM30_142.pdf, accessed November 10, 2021.

To see more photographs from the bureau's archives, please visit the library's Historical Photographs collection page.

—Jody Smale, Librarian

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Articles pertaining to the geology of Pennsylvania are enthusiastically invited.

Pennsylvania Geology is a journal intended for a wide audience, primarily within Pennsylvania, but including many out-of-state readers interested in Pennsylvania's geology, topography, and associated earth science topics. Authors should keep this type of audience in mind when preparing articles.

Feature Articles: All feature articles should be timely, lively, interesting, and well illustrated. The length of a feature article is ideally 5 to 7 pages, including illustrations. Line drawings should be submitted as jpg files. Ensure that black and white drawings are not saved as color images.

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Earth Science Teachers' Corner: Articles pertaining to available educational materials, classroom exercises, book reviews, and other geologic topics of interest to earth science educators should be 1 to 2 pages in length and should include illustrations where possible.

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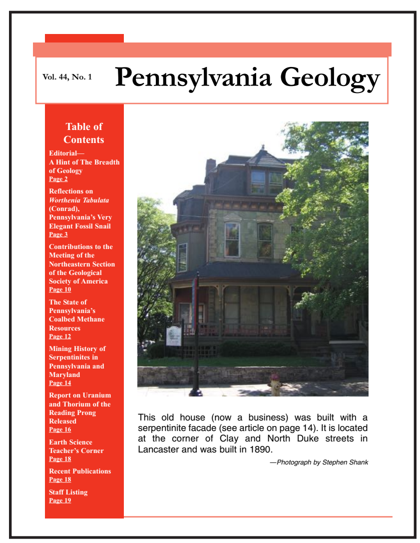
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This old house (now a business) was built with a serpentinite facade (see article on page 14). It is located at the corner of Clay and North Duke streets in Lancaster and was built in 1890.

—Photograph by Stephen Shank

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