Vol. 50, No. 1

Pennsylvania Geology

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Aerial view of the almost-completed dam (lower right) in 1968 that would create Lake Arthur in Moraine State Park, Butler County. View is to the southeast. The future lake bottom had been cleared of vegetation, making features visible. Preglacial Muddy Creek continued beyond the lower left of this photograph. Modern Muddy Creek passed in a large meander loop, at the lower left, to the dam. The core of that meander is now Snake Island in Lake Arthur. The light area behind the dam (lower right center) was the location of an abandoned Vanport Limestone quarry. The surface of a delta built into glacial Lake Arthur, segmented by erosion by modern Muddy Creek, is visible in most of the bottom half of the photograph. It is most obvious where the Western Allegheny Railroad cut passes through it, near the center of the photograph. The delta surface is lighter in color than the lake bottom beyond it. All of these features played a role in determining the location of the dam. Seven of the fifteen potential dam sites are located in this photograph. Old and new (to bypass the future lake) U.S. Route 422, respectively, cross the center and right side of the photograph. From Moraine State Park's historical photograph collection. (See article on page 3.)

EDITORIAL

The Year That Was

Gale C. Blackmer, State Geologist
Pennsylvania Geological Survey

Back in January, my intuition told me that 2020 would bring big changes. Still, none of us anticipated the events of this year. For the Bureau, it started slowly with the cancellation of some spring conferences and restrictions on state employees participating in large meetings. Then came the order that abruptly put us all on temporary telework on March 16. By the end of that day, we had laptops distributed and people out the door. The rest is history. It's been a bumpy ride, but our staff has given it their best.

We have all been touched by COVID, experiencing sacrifice, loss, and changes in our work and in our lives. I am so proud of the way Bureau staff have responded. They have been flexible, adaptive, and have found ways to keep the work going. Even with the uncertainty and changes, we have had great successes this year. The Bureau is leading state government efforts in carbon capture, utilization, and storage (CCUS) and is participating in several research programs and pilot projects funded by the Department of Energy. We are participating in a new U.S. Geological Survey (USGS) program called Earth MRI that focuses on locating potential sources of critical minerals. Despite some unexpected staff departures that necessitated shifting personnel and adjusting project goals, we are on track with the annual mapping projects funded through the USGS STATEMAP program. Our new elevation-derived hydrography program is advancing; expect to see data from several example watersheds on our website in January. Our administrative services have continued during remote work, as has progress on our databases. We are all now old hands at Skype, Zoom, Teams, and whatever other virtual platforms our partners dig up. Although in-person conferences are not happening, a proliferation of webinars and virtual conferences are providing new opportunities for learning, training, and interaction with colleagues across the country and around the world that might not have been available without these unusual circumstances.

As of this writing, the temporary telework order for state employees extends through June 30, 2021. Our offices will remain closed to visitors during that time as we work hard to keep you and our staff safe (see page 22 of this issue for information on accessing Bureau library materials). We are very much open for business remotely and can be reached by telephone and email. Due to the wonders of technology, calls and messages left on our office phones will reach us while we are on telework. You can still find our publications, water-well data, and other geologic information through our website. As always, if you need something that you can't find on the website, please contact us.

As 2020 draws to a close (thank goodness!) and you reflect on this most unusual of years, I hope that you and your loved ones can find moments of light and grace among all the weirdness. I am thankful for the Bureau staff and for the support we have received from the administration and from you in the geologic community. Next year will surely bring its own challenges, but I am confident that we will get through them together.

Happy Holidays and stay safe!

Gale C. Blackmer

Dam That Muddy Creek!—
Siting the Moraine State Park Dam

Gary Fleeger
Pennsylvania Geological Survey, retired

The year 2020 marks the 50th anniversary of Moraine State Park (including Lake Arthur) in Butler County. When it was dedicated in 1970, it was the culmination of a decade of planning and construction, which involved sealing dozens of deep mines, reclaiming hundreds of acres of strip mines, plugging hundreds of oil wells, relocating two highways (including two bridges over the new lake), and building infrastructure for the new park (beaches, roads, marinas, and water and sewer systems), and of course, building the dam to create the 3,225-acre Lake Arthur.

The main focus of the park is Lake Arthur, the re-creation of a Pleistocene glacier-dammed lake. The dam site selected was the 15th dam site considered. Why was this location preferred over the other 14 investigated locations?

There are two parts to this story. One is how geology determined the location of the dam, its design, and its construction. The other is how I found this information, a story in itself.

THE NORWEGIAN CONNECTION

Having grown up two miles from the park while it was being built, I have always had an interest in the history of the park, and it was an early impetus for my interest in geology. As a result, over the years, I accumulated many papers concerning the planning of the park. Some were those of Frank Preston, the Father of Moraine State Park. He was an internationally known glass engineer, amateur naturalist, and geologist, who, along with Edmund Watts Arthur (namesake of Lake Arthur), interpreted the glacial lake (Preston, 1950, 1977). Preston was the driving force behind the creation of Moraine State Park and began considering re-creating the lake as early as the late 1940s. The Western Pennsylvania Conservancy, of which Preston was on the Board of Directors, took over the park project until various people convinced the state of its merits as a state park. Dr. Maurice Goddard, then Secretary of the Department of Forests and Waters (created in 1923 and absorbed into the Department of Environmental Resources in 1971; this department was later split into the Department of Environmental Protection and the Department of Conservation and Natural Resources), had a goal at that time of creating a state park within 25 miles of every Pennsylvania resident. Timing is everything.

Some of the papers I had accumulated were 1956 Western Pennsylvania Conservancy and 1958 state engineering investigations of potential dam sites for the future lake. Although a letter from Dr. Goddard to the Pennsylvania Department of Highways (precursor to the Pennsylvania Department of Transportation) on December 29, 1958, indicated that “we are planning to construct a recreation dam on Muddy Creek at Site A–A,” one of the sites initially investigated, the resulting dam was not built at any of those sites. I had my own ideas as to the reasons why they were rejected, but I could find no documentation that explained why. I was curious as to why none of those sites was used and how the final site was determined.

In 2017, I asked the Moraine park manager if they had any information in their files. They did not. I asked the engineer at the regional park office, which happens to be in Moraine State Park. He had only a brief 1971 report (Peck and Ireland, 1971), entitled “Summary Report, Moraine State Park Dam, Project no. GSA 192–1, Butler County, Pennsylvania,” by Dr. Ralph Peck and Dr. H. O. Ireland of the

University of Illinois, my alma mater. The summary did not give much information, but it referred to a more detailed 1964 report explaining the dam-site selection. So I decided to try to track down the 1964 report.

The 1964 report (Peck and Deere, 1964), entitled “Report on Proposed Muddy Creek Reservoir, Butler County, Pennsylvania,” was authored by Dr. Peck and Dr. Don U. Deere, also of the University of Illinois. I thought that I would attempt to locate the authors to see if they could provide a copy.

Dr. Peck was a world-renowned geotechnical engineer, well known for his work on the Chicago subway and the Trans-Alaska Pipeline, among more than 1,000 consulting projects around the world, and a colleague of Dr. Karl Terzaghi, father of soil mechanics and geotechnical engineering (DiBiagio and Flaate, 2000). Unfortunately, Dr. Peck had passed away in 2008. I contacted both the engineering department and the University of Illinois library to see if they had any of Dr. Peck’s papers on file, but without success.

Dr. Peck’s former student and co-author, Dr. Deere, also a world-famous consulting engineer, had also worked on many famous projects, including the World Trade Center, the Chunnel, and the Cheyenne Mountain North American Aerospace Defense Command (NORAD) site. He invented the Rock Quality Designation, or RQD, used extensively today to contrast competent rock vs. weathered rock. He received the “Outstanding Contribution to Rock Mechanics Award” from the American Rock Mechanics Association in 2012, so I contacted the organization to see if they had any contact information. They sent me an address. I sent a letter to Dr. Deere asking if he might have a copy of the 1964 report. Several weeks later, I received a response from Dr. Deere’s daughter, explaining that the address I was given was hers. Her parents, in their 90s, were in assisted living. She took my letter to her father. He explained that when he moved into a retirement community, he disposed of all of his files, including any he might have had concerning the dam in Moraine State Park. However, he suggested that I contact the Norwegian Geotechnical Institute in Oslo, Norway, where the Ralph Peck Library had been established shortly after Peck’s death. Dr. Peck had done much work in Norway and had a close working relationship with the Institute. Dr. Deere passed away 6 months later, in January 2018. Once again, timing is everything.

I emailed the Norwegian Geotechnical Institute. The next morning, I had a copy of the 1964 report, part of a more complete file on that consulting job. I then asked for the complete file and received extensive correspondence between Dr. Peck and various state officials, the engineering contractor siting and designing the dam (Michael Baker Jr., Inc.), and the dam building contractor (John G. Ruhlin Co.) through the siting, design, and building phases of the dam. The park and the engineering office now have copies of all of this information regarding the dam. This project was one of nine projects that Dr. Peck consulted on in Pennsylvania (DiBiagio and Flaate, 2000) during his career.

The 1964 report proved to be very informative. But it did assume that the reader could refer to two other reports, both titled “Report of Preliminary Subsurface Investigations at Proposed Dam Site, Moraine State Park, Butler County, Pennsylvania,” prepared by Michael Baker Jr, Inc., in February 1962 and September 1963. After finding the Peck-Deere report in Oslo, Norway, I was confident that getting a copy of the 1962 and 1963 Baker reports would be no problem. Michael Baker Jr., Inc., is a still-operating international engineering company headquartered in Pittsburgh. It should have been relatively easy for them to access a copy of the reports from their archives. Surprisingly, Baker no longer has a copy of those reports in their files.

THE GEOLOGY OF LAKE ARTHUR

Details of the glacial history of the glacial lake in the Muddy Creek valley, named Lake Watts, are described in Preston (1950, 1977), Peck and Deere (1964), and Fleeger and others (2003). Below are several geological points pertinent to the various sites considered for the dam.

1. The advance of the Illinoian Titusville glacier, 140,000 years ago, dammed the west-flowing Muddy Creek to form glacial Lake Watts in the Muddy Creek basin.

2. During the glacial maximum, the glacier front was positioned approximately at the present position of Interstate 79 (I 79) (Figure 1). The ramp from U.S. Route 422 eastbound to I 79 southbound, on the west side of I 79, is cut into glacial sediments partially filling a small ice-marginal channel. The ramp from I 79 northbound to U.S. Route 422, on the east side of I 79, is cut into bedrock.

3. During the existence of the glacier-dammed Lake Watts, up to 100 feet of lacustrine silt and clay was deposited on the lake bottom over much of the lake (Figure 2). The lacustrine sediment is plastic, weak, and had been unable to support substantial structures, such as the Western Allegheny

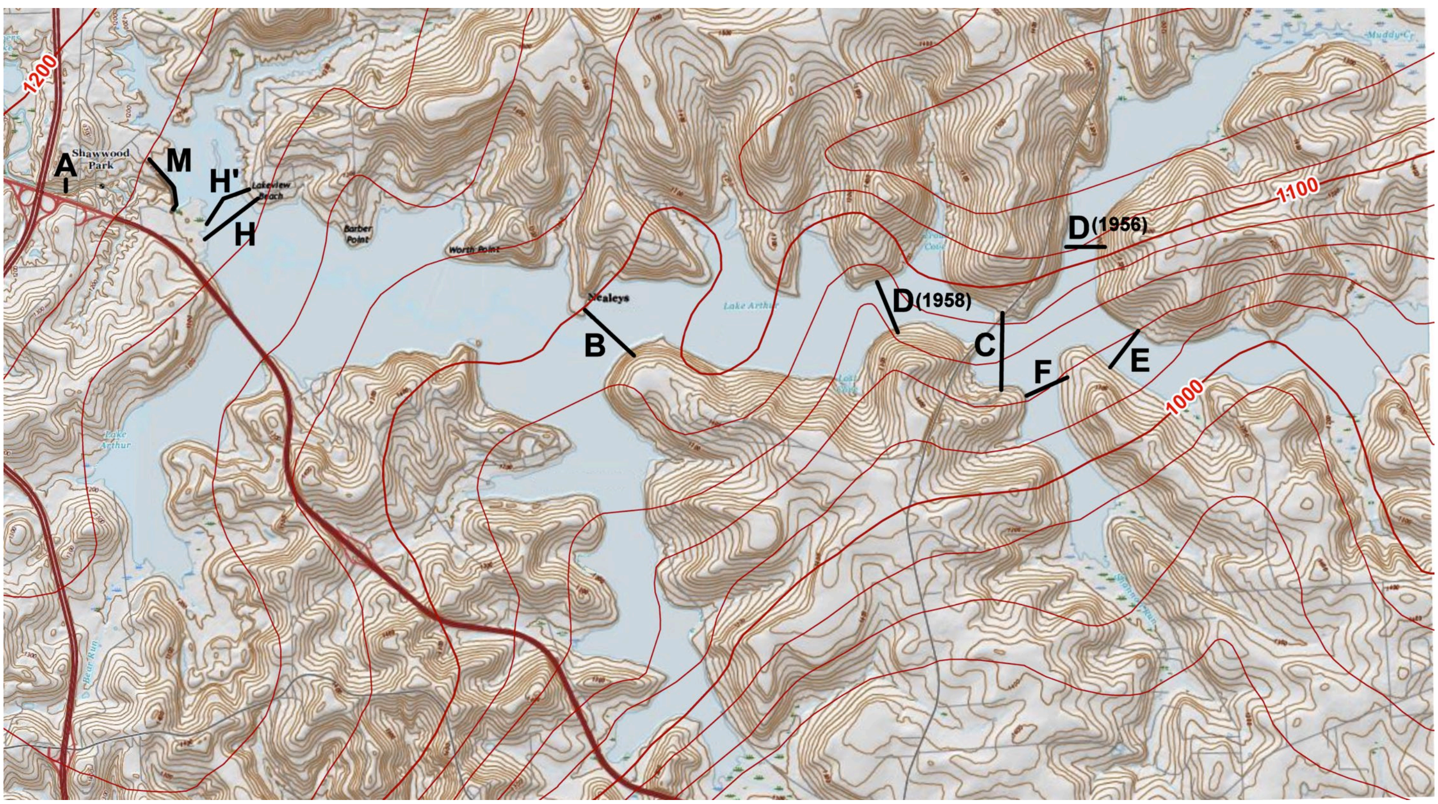

Figure 1. Some of the various dam sites considered for Lake Arthur. A, B, C, D (1956), E, and F were the sites mentioned in a 1956 letter. A, B, C, and D (1958) were drilled by the Commonwealth of Pennsylvania in 1958. Note that there are two sites labeled as D. The locations of G and I are not known. A, H, H', and J (approximately at M) were the finalists in 1964. K and L were minor realignments of J. M is the final realignment of J and is the location of today's dam. Structure contours on top of the Vanport Limestone (lightweight red lines) are from Wagner and others (1975). The Vanport contour interval is 20 feet. U.S. Geological Survey 2019 Portersville and Prospect 7.5-minute topographic map base.

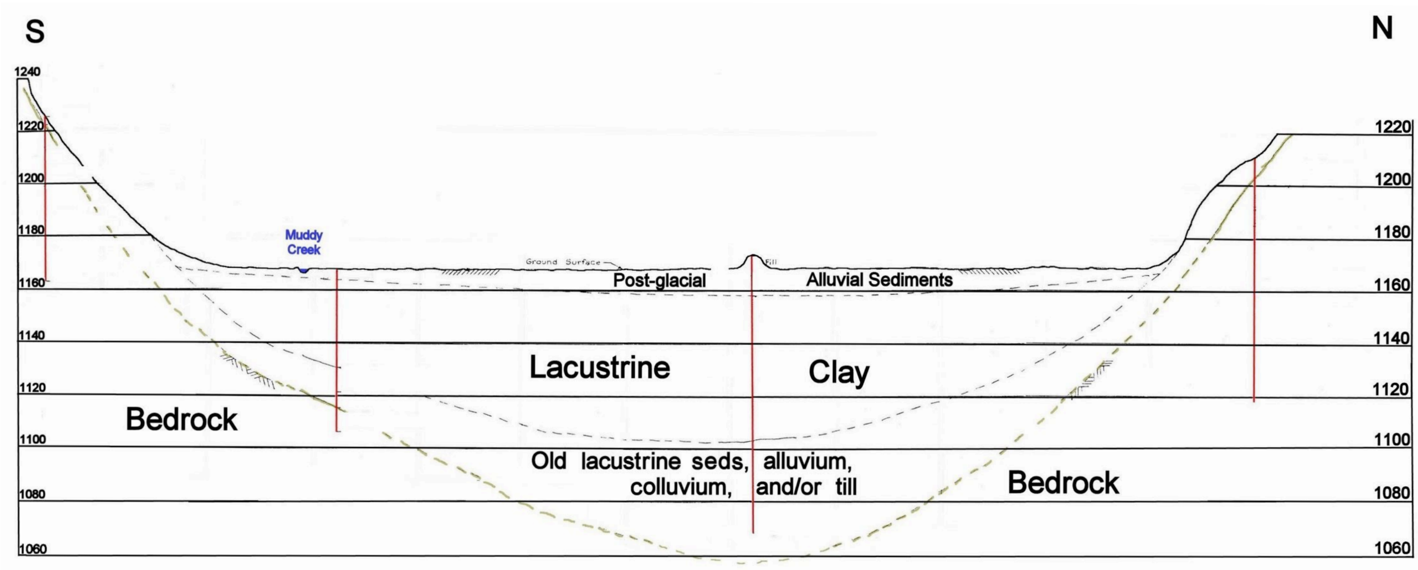

Figure 2. Cross section and dam site B (see Figure 1). This illustrates the typical problem of dam sites B, C, D, E, F, and H. All had a considerable thickness of soft, plastic, deformable lacustrine clays, many tens of feet thick, that would not provide a stable foundation for the dam. Vertical exaggeration is 5x; elevation is in feet; vertical red lines indicate the locations of exploratory boreholes drilled in 1958. Modified from Pennsylvania Department of Forests and Waters (1958).

Railroad, which would continually subside and have to be reballasted (draft letter from Dr. Frank Preston to Dr. Maurice Goddard, 1958).

4. While the glacier sat at or near its terminus, a delta built into Lake Watts to the east deposited sediment over the fine-grained lacustrine lake-bottom sediments (see photograph on page 1). Much of the shoreline of the northwestern corner of modern Lake Arthur is composed of these glacio-deltaic sediments, including Snyder Point, Mt. Union Point, Snake Island, and Duck Point, as well as the shoal between Snake Island and Duck Point, and the area around the dam (Figure 3). The shoal, which forms the delta front, is generally less than 5 feet deep at full pool and is visible on aerial photography (Figure 3).

5. The preglacial course of Muddy Creek, near the bicycle rental building, is buried to a depth of 150 feet by lake-bottom and deltaic sediments. It passes to the north of the present course of Muddy Creek, at the western end of Lake Arthur (Figure 3).

6. After the glacier retreated and most of Lake Watts drained through the newly eroded Slippery Rock Gorge, a remnant remained in the Muddy Creek valley, blocked by the 150-foot-thick sediment dam filling the preglacial outlet of Muddy Creek. The lake remnant drained through a low spot in a north-south bedrock ridge, gradually eroding a small gorge at Portersville Station, draining the remainder of the lake. The present course of Muddy Creek downstream of Lake Arthur flows through the gorge (from the dam through Site A) (Figures 1 and 3).

7. The park is on the southeast limb of the Homewood anticline. The Vanport Limestone is found at depth at the eastern end of the park but is at or near the surface at the western end (Figure 1).

EVOLUTION OF THE SITING OF THE DAM

A number of factors affected the siting of the dam to create Lake Arthur. In addition to the geological conditions of the site and shoreline, the need to relocate highways and other infrastructure,

Figure 3. An aerial image from PAMap (from the 2006 flights) of the northwestern corner of Lake Arthur, showing the rough outline, in yellow, of the extent of the glacio-deltaic sediments built into glacial Lake Watts. Snake Island, and Duck, Snyder, and Mt. Union Points (Pt=Point) are all erosional remnants of the delta. The shoal connecting the southern end of Snake Island and Duck Point is a remnant of the surface and front of the delta sloping into the deeper water of Lake Arthur. The gap in the shoal was a railroad cut of the Western Allegheny Railroad. The locations of dam sites A, H, H', and J are shown in blue. The current dam is Site M (not labeled; adjacent to Site J). The dashed blue line in the upper left indicates the preglacial channel of Muddy Creek. North is toward the top.

the size of the lake, the cost of the dam, the availability of material for dam construction, and the intended uses of the lake were other considerations affecting the placement of the dam. The geological conditions turned out to be the overriding factor and had a significant effect on some of the other factors.

Two general geologic questions affected the siting of the dam.

1. Will the geology of the basin to be flooded by a dam at that site allow it to hold water?
2. Will the geology at the specific dam site allow support of the dam and prevent leakage around the dam?

BASIN GEOLOGIC EVALUATION

The Vanport Limestone contains extensive solutional features, including nearby Harlansburg Cave, the longest cave known in the state (Fawley and Long, 1997). Depending on where the dam would be sited, the area to be flooded might include an area where the Vanport would form the shoreline, and/or be found in the very shallow subsurface. Potential conduit flow through solutional features in the Vanport could make leakage an issue, even if the dam site itself was stable.

Although the vast majority of the proposed reservoir sites would have clastic bedrock overlain by thin lacustrine sediments along their shorelines, a dam at sites A or J would flood areas where the Vanport forms part of the shoreline or is in the shallow subsurface (Geology point no. 7). If leakage occurred from the areas where the Vanport would form the shoreline, sites A and J would be eliminated from consideration regardless of the specific dam-site geology. So the structure of the Vanport was crucial to determining if the dam could be built at either of those sites. The correspondence that I received from the Norwegian Geotechnical Institute is apparently not complete, because there is nothing indicating a final decision showing that there would be minimal or no leakage. What I have suggests that detailed structural mapping of the Vanport determined that the Vanport increases in elevation to the west sufficiently to rise above the planned lake level, and/or a groundwater divide probably existed to prevent significant leakage to the west from the shore of the lake. So in 1964, if either site A or J was determined to be the best dam site, the valley could be flooded to hold a lake. The lake that has now existed for 50 years flooded an area known as Hidden River, where the Vanport forms the shoreline (Figure 4).

EARLY SPECIFIC DAM-SITE CONSIDERATION

Frank Preston talked about re-creating Lake Watts with a dam at Portersville Station Gorge as early as the late 1940s (Preston, unpublished notes dated February 2, 1950). However, in 1950, U.S. Route 422 was rerouted into the Muddy Creek valley, and a dam at Portersville Station (Site A) would flood the new road. For the first time, other potential sites were considered. A letter from Shailer S. Philbrick of Foundation Associates, Inc., of Pittsburgh to the Western Pennsylvania Conservancy, dated November

Figure 4. Vanport Limestone at Hidden River, exposed along the shoreline in the northwest corner of Lake Arthur. Note the solution-enlarged jointing and bedding planes. The limestone cliff is about 12 feet high.

19, 1956, mentions six potential sites, designated as sites A (Portersville Station), B (Nealeys), C, D, E, and F (all near Isle) (Figure 1). There is no map, but a written description of each site is provided.

Four potential dam sites investigated by the Pennsylvania Department of Forests and Waters in 1958 were at Portersville Station gorge (A), Nealeys (B), and two sites near Isle (C and D) (Figure 1). Sites A, B, and C were the same as described in 1956, but Site D was in a different location. Each of the sites had its own advantages and disadvantages in terms of dam length, dam height, lake size, and foundation conditions (Table 1).

The foundation conditions at all except for Portersville Station were similar. All had tens of feet of plastic lacustrine clays (Geology point no. 3, above) overlain by floodplain sediments. None would have been very good foundation material for supporting the weight of a gravity dam, although a dam could have been designed to account for those conditions. In fact, location C is approximately at the current location of the Pa. State Route 528 bridge over Lake Arthur. There had been a considerable amount of difficulty with the bridge pilings during this bridge's construction, because of the soft, plastic lacustrine clays, and there had to be some redesign during its construction as a result (Latham, 1969). Fractured bedrock at the abutments also caused concern for leakage around the dam at sites B, C, and D (1958). Projected dam costs because of the foundation geology resulted in the elimination of sites B and C.

The favored location at the time was Portersville Station (Site A). The Portersville Station location was in the narrow gorge eroded post-glacially by the draining of a remnant of the glacial lake after the glacier retreated (Geology point no. 6) because the preglacial course was buried (Geology point no. 5). This was the only one of the four sites where the dam foundation would be in bedrock, and the dam length of about 250 feet would be only a fraction of the length of the other 3 sites. Unfortunately, the bedrock in the gorge includes the Vanport Limestone. A dam in the gorge could involve risk of leakage around the dam through the karstic limestone.

At this point is a gap and some confusion in the story. We have the information on the first 7 potential dam sites (A, B, C, D [1956], D [1958], E, and F). Now we jump to the last 6 potential dam sites (H, H', J, K, L, and M). We have little or no information on the intervening 2 dam sites that were considered (G and I). These other sites were likely discussed in the missing 1962 and 1963 Michael Baker Jr., Inc., engineering reports referred to in Peck and Deere (1964). Peck and Deere (1964) indicated that Sites E, F, and G were considered to be inferior to Site J for reasons explained in the report of September, 1963, but did not mention those reasons. The report disclosed an abandoned Vanport quarry at Site E, which possibly is a small, abandoned quarry just downstream from Site J. If so, then it is not the same Site E mentioned in the 1956 letter, where the Vanport is about 140 feet below the surface (Figure 1). Perhaps Site F is also not the same as the site mentioned in 1956, and there are actually more than 15 sites that were considered. But without access to the two missing Baker reports, that is not known for certain. Site I is never mentioned in Peck and Deere (1964), nor in any other discovered document concerning dam siting.

Site A was still being considered in Peck and Deere (1964). In addition, three additional sites were introduced—sites H, H', and J (Figures 1 and 3). Probably H and J were initially discussed in the missing Baker reports.

DAM-SITE EVALUATION (PECK AND DEERE, 1964, AND PECK FILES FROM THE NORWEGIAN GEOTECHNICAL INSTITUTE)

Site A was obviously the best location being considered for foundation stability, since it would be built on bedrock. But, with the Vanport exposed in both abutments, a dam at this location would make for potential significant leakage.

Table 1. The 15 Sites Evaluated for the Location of the Dam to Create Lake Arthur

Designation	Site	Identified[1]	Rejection reason
A	Portersville Station	1958 DFW report	Karst development in Vanport Limestone in both abutments
B	Nealeys	1958 DFW report	Thick weak lacustrine clay dam foundation, small lake area
C	Isle	1958 DFW report	Thick weak lacustrine clay dam foundation, small lake area
D (1958)	West of Isle	1958 DFW report	Thick weak lacustrine clay dam foundation, small lake area
D (1956)	North of Isle	1956 letter from Foundation Association to WPC	Unknown
E	East of Isle	1956 letter from Foundation Association to WPC	Unknown
F	South of Isle	1956 letter from Foundation Association to WPC	Unknown
G	Unknown	Presumably 1962 or 1963 MBJ report	Unknown
H	Lakeview	1964 Peck-Deere report	Excessive dam length, thick weak lacustrine clay dam foundation, small lake area
H'	Downstream of Lakeview on delta surface	1964 Peck-Deere report	No advantage over Site J
I	Unknown	Presumably 1962 or 1963 MBJ report	Unknown
J	Near present dam	1964 Peck-Deere report	Slight adjustment, based on boreholes, to maintain best balance of shallow foundation, minimum embankment, and reasonable depth of lake beds blanketing pervious bedrock, resulting in site K
K	50 feet downstream of J	May 15, 1964, MBJ correspondence	Slight adjustment, based on boreholes, to maintain best balance of shallow foundation, minimum embankment, and reasonable depth of lake beds blanketing pervious bedrock, resulting in site L
L	Near M	August 14, 1964, MBJ correspondence	Slight adjustment, based on boreholes, to maintain best balance of shallow foundation, minimum embankment, and reasonable depth of lake beds blanketing pervious bedrock, resulting in site M
M	Present dam	August 14, 1964, MBJ correspondence	Site selected has shallow bedrock covered by a thin layer of lacustrine sediment capable of blanketing the pervious bedrock

[1]DFW, Department of Forests and Waters; WPC, Western Pennsylvania Conservancy; MBJ, Michael Baker, Jr., Inc.

Site H crossed the Muddy Creek valley just beyond the front of the delta remnant (Geology point no. 4). The subsurface would be similar to that shown in Figure 2, with tens of feet of soft lacustrine clay as a foundation for the dam. The weak foundation would require very flat embankment slopes for stability, resulting in a large amount of fill. The site was deemed undesirable because of the resulting excessive embankment volume, and a reduced reservoir area, compared to Sites A and J. To attempt to alleviate the embankment volume and stability issues, Site H' was considered, a short distance downstream from Site H. Site H' would place much of the dam on the surface of the delta. The somewhat more stable foundation would allow for more steeply sloping dam faces, and therefore, less fill than Site H.

Site J was located at a site that was geologically a transition between Sites A and H, avoiding the worst problems of those sites. Relatively thin lacustrine and deltaic sediments blanketed permeable bedrock. A few hundred feet upstream would have found thick lacustrine sediments and their associated foundation stability issues. A few hundred feet downstream would have encountered porous Vanport Limestone with solution channels and its leakage issues at the abandoned limestone quarry (see photograph on page 1). However, Site J was not without issues, as was to be discovered during exploratory drilling and during construction.

Peck and Deere (1964) suggested a Phase 1 drilling program, where a number of exploratory holes would be drilled to test the materials at dam sites J and H'; it would provide a better understanding of the structure of the Vanport Limestone in the vicinity of the dam sites.

A site meeting on May 5, 1964, attended by Dr. Peck, representatives of the Department of Forests and Waters, and Michael Baker, Jr., Inc., eliminated Site A from consideration because subsurface conditions would not be suitable for economic construction of a dam there. Nothing more specific was stated in the meeting minutes, but presumably, it was due to potential leakage caused by karstic development in the Vanport. Test results from the Phase 1 drilling program indicated that site H' had no advantages over site J. The main benefit of site H' was that it would not flood areas where the Vanport would form the shoreline, but the concern for leakage out of the watershed through the Vanport had been eliminated. Thus, Site J, with modifications, was selected as the dam site. However, Phase 2 exploratory drilling would be moved about 100 feet downstream from site J, referred to as site K, to a point where the thickness of weak soft material underlying the future dam would be less. The drilling program for Site K was laid out in a wide band to allow for further refining the precise final location of the dam.

During Phase 2 drilling, the dam site was revised two more times in order to maintain the "best balance between shallow foundation, minimum embankment, a reasonable depth of lake beds upstream of the core and to keep the south end of the embankment immediately upstream of the limestone quarry" (Michael Baker Jr, Inc., correspondence to Pennsylvania Department of Forests and Waters, August 14, 1964). These dam sites were designated as Sites L and M, with M being the final agreed-upon site, where the dam is today (Michael Baker Jr., Inc., meeting minutes, August 28, 1964). Site M is within the zone of Site K Phase 2 drilling, so the precise locations of Sites K and L are not specified.

The final Site M had sands and silts of the deltaic sediments (Figure 5) underlain by relatively thin lacustrine clay over bedrock. The bedrock in the center of the valley was weathered sandstone stratigraphically below the Vanport Limestone, which cropped out on the northern end of a small bedrock ridge just downstream of the dam site. The abandoned quarry mentioned previously had been developed in the ridge. Vanport is present in the valley wall under the southern embankment of the dam (Figure 6).

ISSUES WITH SITE M AFFECTING DESIGN AND CONSTRUCTION.

The site geology had a significant effect on the placement of the dam. But it also had some effect on both the design and the construction of the dam.

In general, the dam design called for a core of impervious material and an outer shell of pervious material. Ideally, a trench to bedrock would be excavated, and the impervious core would be placed

Figure 5. Photograph of fine sand and silt of the deltaic sediments, probably similar to those encountered during dam construction. This photograph was taken at an excavation for the sewage-treatment plant about 1/10 mile west of the south end of the dam. Pocket knife in upper right corner for scale.

there. However, the depth to bedrock in the northern embankment, as well as the stability of the lacustrine material, precluded such a deep trench. So the design called for a trench essentially to lacustrine material, or a short depth into it. Below the trench, Wakefield pilings would be driven to bedrock, or where bedrock was too deep, to a sufficient depth to stop underflow beneath the dam. Wakefield pilings are interlocking wooden pilings that are watertight and permanent.

In addition, in the embankment south of the spillway, where Wakefield pilings would reach near bedrock, an impervious blanket on the upstream dam face would be placed to reduce infiltration that could seep through sand and silt beds within the lacustrine sediments, and along the contact between the lacustrine sediments and bedrock. It would also reduce any seepage that might enter solutional pathways in the limestone and through to the abandoned quarry in the ridge behind the dam.

In the center of the length of the dam, where the concrete spillway would be located, and for a short distance on either side, where sandstone was shallow, jointing in the bedrock would provide a pathway for water leakage beneath the dam. The design called for a grout curtain to be emplaced through this section to reduce the water flow through the joints.

As Dr. Peck pointed out in correspondence to the Director of Construction of the General State Authority (August 10, 1966), the design of a dam is not complete until the construction is complete. Conditions were discovered that were not predicted by the predesign drilling program. During the driving of the Wakefield pilings, rebound was experienced because of an increase in pore pressure in the lacustrine sediments, caused by their inability to dewater rapidly enough. After altering the emplacement procedure, without success, this resulted in the inability to drive the pilings to the desired depth. To

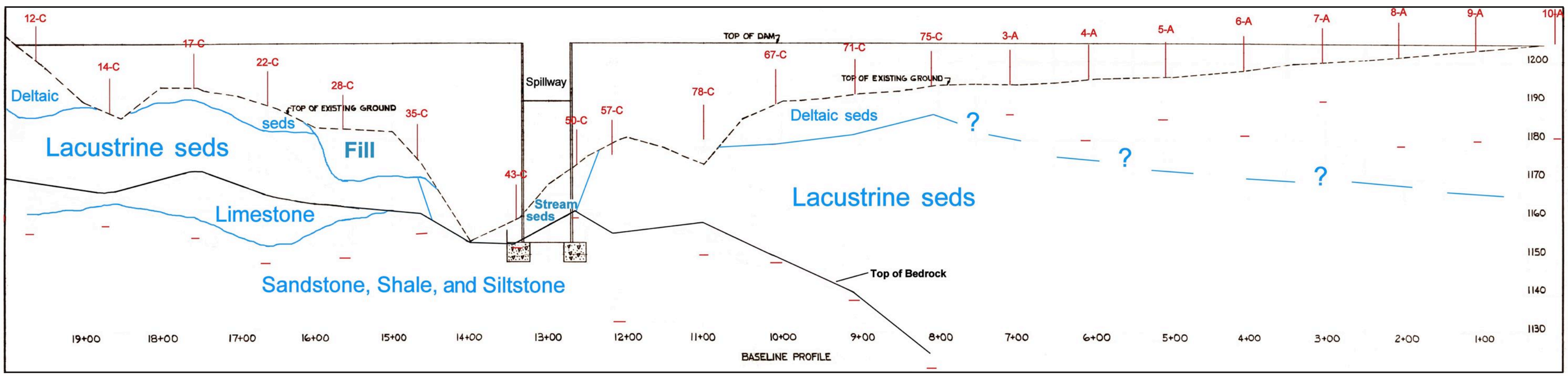

Figure 6. Geologic section along the baseline of the dam, looking downstream on Muddy Creek (seds=sediments). The short red horizontal lines indicate the bottom of each test borehole. Some boreholes were projected to the line of section. The bedrock surface dips into the preglacial valley of Muddy Creek to the north. The greatest depth to bedrock in the boreholes that reached bedrock was about 70 feet (not shown on section). The Vanport Limestone is present in the left (south) valley wall but is covered by deltaic sediments, and it does not crop out in the stream-valley wall. The fill in the left bank was from the abandoned limestone quarry just downstream from the dam. Excavation removed the fill and some of the geologic sediments during dam construction. Dam profile, original ground-surface profile, and top of bedrock profile are from original dam-design documents. Vertical exaggeration is 5x.

compensate for that, an impervious blanket was placed on the upstream face of the northern embankment of the dam to an adequate elevation to further reduce infiltration into the dam and reduce water flow through the dam.

While the dam that created Lake Arthur is a relatively small dam, it is notable for the complexity of its geology that affected the siting, as well as the design and construction of the dam. But all of the difficulties were overcome, and after 8 years of detailed study and the rejection of at least 14 sites, an acceptable site was finally selected. The dam was built from 1965–68, overcoming additional geological complexities. The gates of the dam were closed on May 15, 1969, and the lake overtopped the spillway for the first time 50 years ago this year, on April 3, 1970. Lake Arthur's existence for those 50 years shows that careful analysis of the geology will end with a successful result.

ACKNOWLEDGMENTS

This article benefitted from the reviews of Stuart Reese and Dustin Drew (Moraine State Park Manager).

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An Example of the Usefulness of Drill Cuttings (Harry Dewey #1 Mud Log)

Katherine W. Schmid
Pennsylvania Geological Survey
Steven D. Clark
Pennsylvania Department of Environmental Protection

In 2016, while working as a geologist for Inflection Energy LLC, Steve Clark created a pictorial mud log using cuttings samples (part of the Bureau's holdings) from an exploratory oil and gas well drilled in western Tioga County in 1974. This well, the Harry Dewey #1 (API # 37–117–20057), is a deep well that penetrates both the Marcellus and Utica shale formations, which are organic-rich shales that oil and gas operators are currently drilling. Steve's mud log is a great example of a nondestructive use of drill cuttings, and it is available as Pennsylvania Geological Survey Open-File Report OFOG 18–01.0 (Clark and Schmid, 2018).

Drill cuttings are rock fragments returned to the surface while a well is being drilled. Cuttings are typically caught over a defined interval, such as 10 to 100 feet (ft). In this case, the interval was 10 ft. Despite this rather large interval, the cuttings are useful for showing lithologic changes in a well. For example, Figure 1 shows the following units that were encountered as drilling progressed downward: medium-gray shales of the Hamilton Group, dark-gray shales of the Marcellus Formation, both light-gray limestone and dark-gray shale in the tray containing mixed Onondaga limestone and Needmore shale, and finally, white- to light-gray Oriskany Sandstone.

Examining these changes may help identify formation boundaries. For example, both the Juniata and Bald Eagle Formations are sandstones that can be difficult to distinguish using geophysical logs. However, the change from the red sandstone of the Juniata Formation to the light-gray sandstone of the Bald Eagle Formation is easy to see in cuttings. Figure 2 shows this change, and Figure 3 allows a closer view of these two sandstones.

To aid in cuttings identification, Steve used solutions of 10 percent hydrochloric acid and Alizarin Red S according to standard mud-logging protocols (e.g., Swanson, 1981). Alizarin Red S is used on cuttings that react strongly with hydrochloric acid to help distinguish the different carbonate minerals. It is an acid-base indicator that turns red in a basic (high pH) environment and is colorless in neutral or acidic (low pH) environments. In this case, the color of the calcite cement in the Oriskany Sandstone (Figure 4) became red. This test also highlights how rocks can differ in the subsurface compared to those in nearby outcrops. The Oriskany Sandstone is commonly calcareous when it is encountered in the subsurface due to the presence of the cement but is commonly only slightly calcareous in outcrop due to exposure to slightly acidic shallow groundwater and rain that dissolves the cement.

Careful visual inspection of cuttings can reveal formation details. For example, Figure 5 shows a crystal of gypsum (variety selenite) among mostly shale and anhydrite in the Silurian Salina Group (6,710 ft measured depth). Gypsum and anhydrite are both evaporites (minerals deposited from aqueous solution after evaporation).

Figure 6 is a photograph of cuttings from the top of the Silurian Rose Hill Formation (8,200 ft measured depth). Although this formation is mostly shale that had been deposited in a near offshore stagnant pool environment (Folk, 1960), this sample includes two oolitic limestone cuttings that may

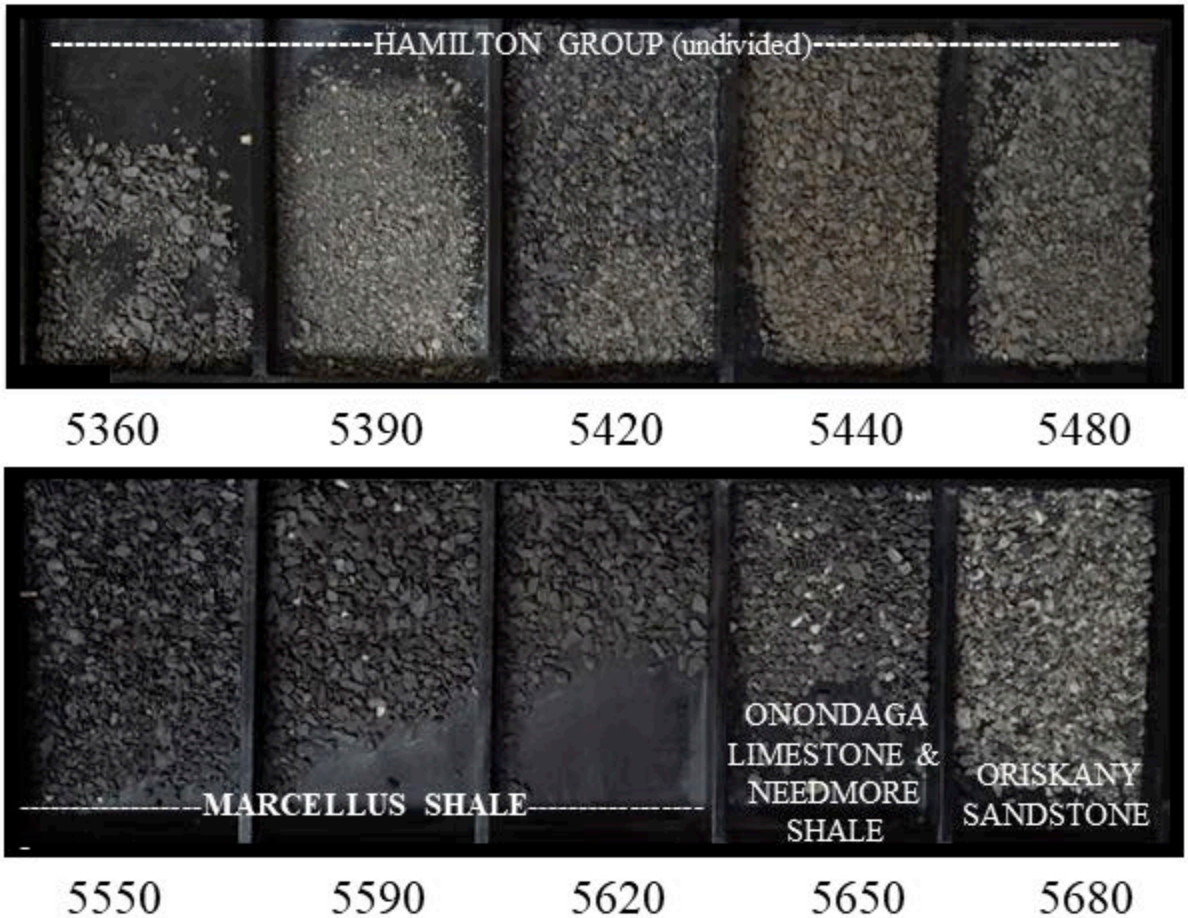

Figure 1. Drill cuttings from the Devonian Hamilton Group (Hamilton shale) down to the Devonian Oriskany Sandstone. Numbers below the sample trays are the approximate measured depths of the samples in feet.

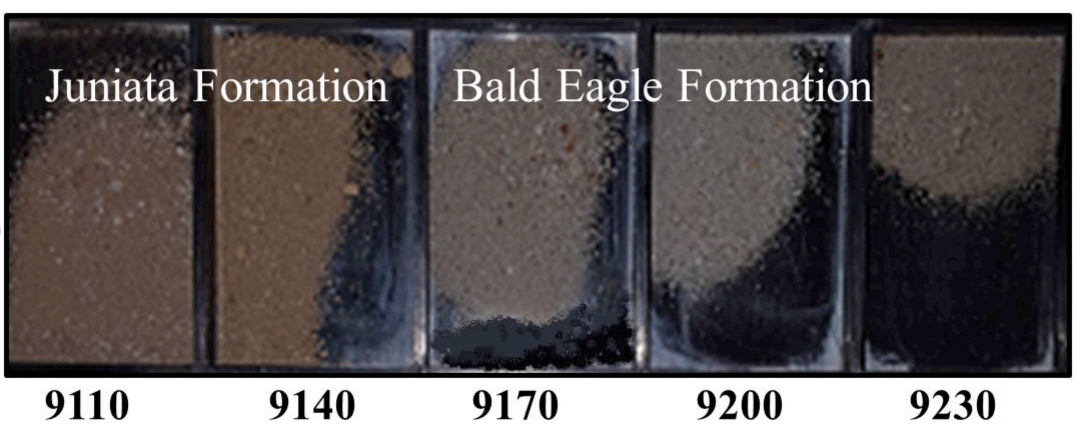

Figure 2. Cuttings trays showing the color change from the Juniata Formation to the Bald Eagle Formation. See Figure 3 for close-up views of these two sandstones.

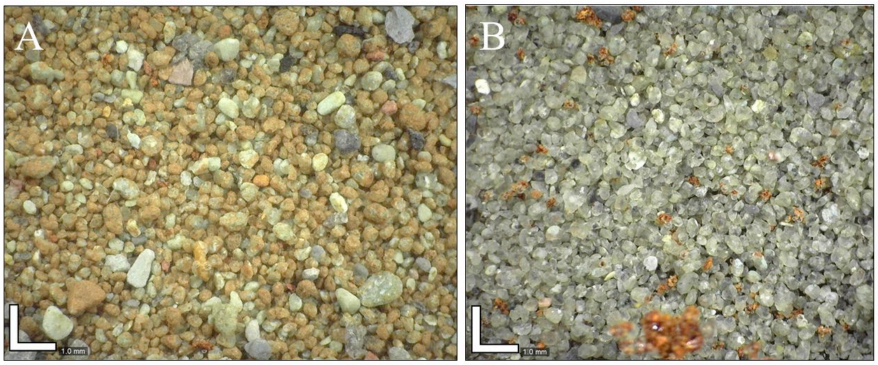

Figure 3. Drill cuttings from the Juniata and Bald Eagle Formations. A. The red sandstone of the Juniata Formation (9,110 ft measured depth). B. The light-gray sandstone of the Bald Eagle Formation (9,920 ft measured depth).

have originated from a very thin Irondequoit Dolomite unit identified in this well (Pennsylvania Geological Survey, 2016). The Irondequoit Dolomite was identified from geophysical logs about 30 ft above this sample depth. These oolitic limestone fragments are evidence of a shallow marine, wave-dominated depositional setting, which fits with the Middle Silurian paleoenvironment marginal shelf model proposed by Laughrey (1999).

Trenton Limestone cuttings at 12,110 ft measured depth are shown in Figure 7 after treatment with Alizarin Red S. The cutting sample in the inset photograph has a small red star-shaped echinoderm fossil. The fossil contained much more calcium carbonate than the rest of the cutting. Echinoderms are marine animals that exhibit fivefold radial symmetry such as that shown by this tiny star.

Figure 4. Oriskany Sandstone cuttings (5,680 ft measured depth) from the Harry Dewey #1 well after treatment with Alizarin Red S solution. Abundant calcite cement (red staining) is apparent between the sandstone clasts.

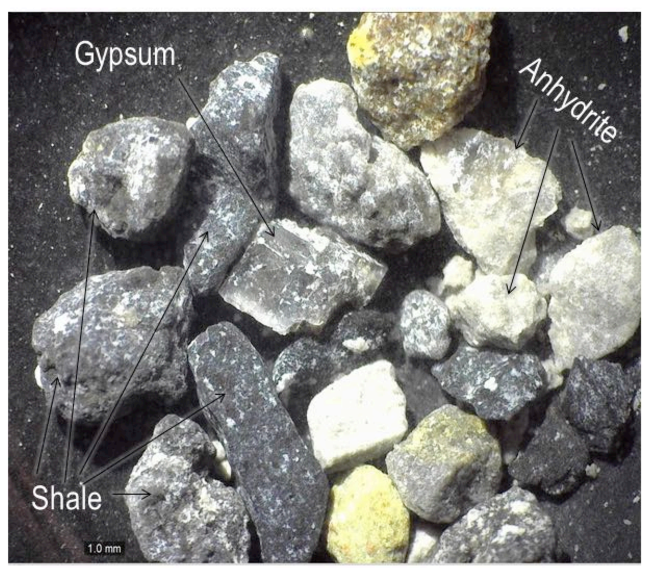

Figure 5. Anhydrite, shale, and trace gypsum (variety selenite) in the Salina Formation (6,710 ft measured depth).

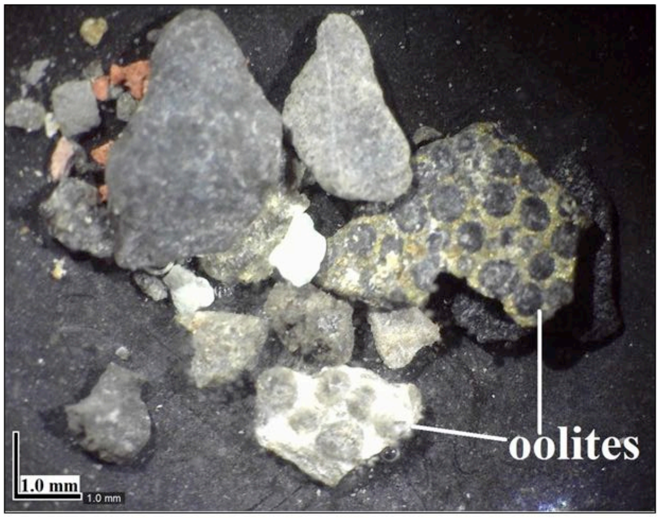

Figure 6. Shale from the Rose Hill Formation (8,200 ft measured depth), and also two oolitic limestone cavings in the right of the photograph. These cavings are possibly from the Irondequoit Dolomite.

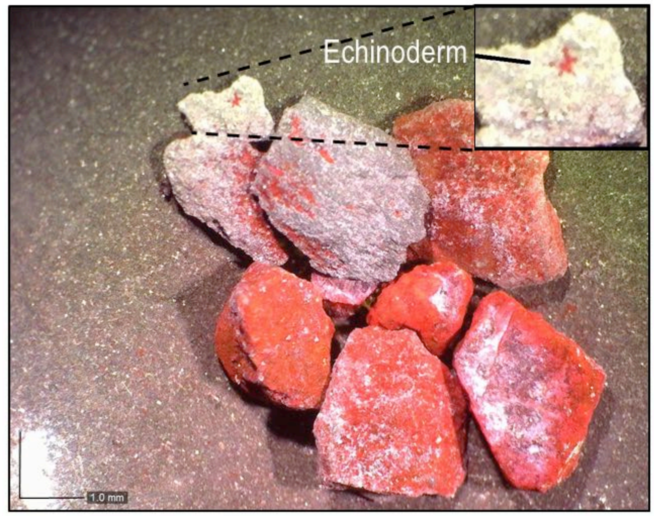

Figure 7. Trenton Limestone (12,110 ft measured depth) after treatment with Alizarin Red S. Likely echinoderm fossil (red-stained star) in the upper left cutting (enlargement of cutting shown in upper right).

The pictorial mud log created by Steve Clark is a great example of nondestructive work that can be done with samples from the Pennsylvania Geological Survey's sample library. The mud log shows the color change in the Middle Devonian shales from medium gray in the Hamilton Group to the dark-gray shales of the organic-rich Marcellus Formation. Deeper in the well, the color change from red to gray sandstone helped geologists refine the Bald Eagle Formation lithologic boundary in the Bureau's database. Further, visual inspection of the cuttings revealed some interesting specimens, including a gypsum crystal, oolites, and a small echinoderm fossil.

The drill cuttings, photographs, and geophysical logs from this well may be accessed by request from the Pennsylvania Geological Survey. The open-file report (Clark and Schmid, 2018) is available through the Department of Conservation and Natural Resources website given in the reference list.

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BUREAU NEWS

Bureau Staff Volunteer Judging at Pre-COVID-19 Area Science Events

PENNSYLVANIA JUNIOR ACADEMY OF SCIENCE REGION 4 COMPETITION

Staff geologist Antonette Markowski judged eight junior and senior botany projects and two senior earth-science projects with 53 other judges for the Pennsylvania Junior Academy of Science (PJAS) Region 4 Competition on Saturday, February 22, at Carlisle High School. Students presented their projects using PowerPoint slides. According to PJAS Director Emilie Tekely (email communication, 2020), a total of 135 students (56 in the junior division and 79 in the senior division) participated from 16 schools in Region 4 (Figure 1). Overall, 3 projects scored perfect, 68 placed as first-award winners, and various organizations sponsored 31 special awards. The next level of state competition at The Pennsylvania State University this year was canceled due to the pandemic.

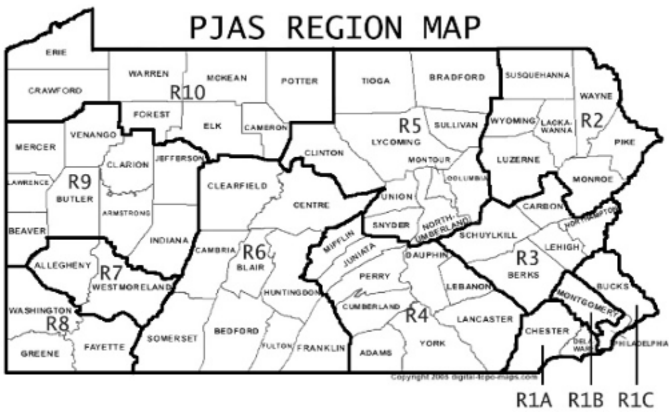


Figure 1. Map showing the location of Region 4 (R4), from https://www.pjas.net/find-your-region. Used with permission from the Pennsylvania Junior Academy of Science.

Four out of seven botany projects won first-place awards. Two earth-science projects also won first place. They respectively covered the impact of water temperature on the strength of hurricanes and on tornadoes.

Anyone interested in volunteering at the 2021 PJAS Regional Competition should contact Emilie Tekely at pjasr4director@gmail.com. For further information and the status of next year's event, see the PJAS website.

CAPITAL AREA SCIENCE AND ENGINEERING FAIR

Staff geologists Victoria Neboga and Antonette Markowski also engaged in category judging of traditional project panel presentations with 105 other judges and 47 special-award judges at the 63rd Capital Area Science and Engineering Fair (CASEF) (Figure 2) held March 9–12. This was the third year that Harrisburg Area Community College at Blocker Hall has hosted the scholastic event. The fair provided an opportunity for 244 aspiring young scientists from 41 schools in 12 counties to showcase 217 independent and 27 team projects, according to CASEF Director Valerie Knowles (email communication, 2020).

Figure 2. The Capital Area Science and Engineering Fair logo.

Neboga judged seven senior chemistry projects. Students demonstrated their creativity and knowledge in areas such as the study of microplastic release from tea bags and coffee pods, the effect of conditioners on hair strength, the effectiveness of quenching liquids on steel hardness, and the impact of water temperature on tornado intensity.

"Microplastics in Beverages" was recommended for the Dr. George Hayward Love Sr. Judges' Award. The student studied microplastic levels released from brewing coffee and tea beverages using paper tea bags, single-use plastic pods, and coffee filters. This project and two others, "Cell Phone Radiation: Effectiveness of a Mesh Barrier" and "Hotter Stuff," won the above award among other senior division special awards.

Markowski judged eight junior physical science projects, from meteorological crickets to which materials can catch a bubble. Four projects exhibiting strong creativity and critical thinking were nominated as grand champions. One of the nominees determined a model equation to confirm how adjusting the angle of a rotating ultrasonic module from a revolving servo relative to a material (water) affects wave measurements. The ultrasonic module contains a transmitter, receiver, and control circuit; the servo is a highly efficient and precise electrical device used in process automation. Two of the five Dr. George Hayward Love Sr. Judges' Award candidates were also recommended for regional International Science and Engineering Fair (ISEF) special awards. (Local special-award and regional ISEF special-award sponsors are on page 6 of the 2020 CASEF Awards Ceremony program booklet.) "How Does Global Warming Affect Sea Level Rise" won the American Society of Civil Engineers local special award. Two regional ISEF special awards and grand-champion recommendations went to "Influence of Material Density on Sound Absorption," which also won a first-place award, two other junior division special awards, a Broadcom MASTERS (Math, Applied Science, Technology and Engineering for Rising Stars) award, and a CASEF Category Award.

POST-CASEF COMPETITION OPPORTUNITIES

CASEF selected Hershey Middle School's Alexander Petula as a national semifinalist among 11 other students for the virtual 2020 Broadcom MASTERS (normally held in Washington, D.C., in October). This national science competition is affiliated with the Society for Science and the Public (SSP) and features the top 10 percent of United States middle-school students. SSP has been dedicated to the achievement of young scientists in independent research and to public engagement in science since 1921. SSP is committed to inform, educate, and inspire through world-class competitions such as the Regeneron Science Talent Search, Regeneron International Science and Engineering Fair (RISEF), Broadcom MASTERS, and its award-winning magazines, *Science News* and *Science News for Students*.

Junior grand champion finalist Annabel Hathaway received a cash award from Sheetz and a scholarship to attend one of the summer camps offered at the Oakes Museum of Messiah College. Senior grand champion finalists are eligible for the virtual 2020 RISEF (originally scheduled for Anaheim, Calif., in May). The finalists were Danielle Miller (East Pennsboro High School), Taylor Koda (Hershey High School), and Dev Lochan (Cumberland Valley High School). Dev Lochan also won at Whitaker Center's first Virtual Science Fair in June. All grand champions, division special awardees, and category awardees are listed in the junior division and senior division online postings.

CASEF students received 143 special awards overall. Eighty students received $4,800,000 ($60,000 each) in partnership scholarship offers to Harrisburg University. Other local and regional scientific, professional, industrial, educational, and governmental organizations also sponsored $78,400 in prizes and scholarships (Valerie Knowles, email communication, 2020).

New judges, special awards, and sponsorships are always welcome—a sponsor is especially needed for the judging portion of the fair. Please consider joining Bureau of Geological Survey staff at next year's virtual CASEF category and grand champion judging March 16 and 17, respectively, by registering at CASEF Judge Registration. For further information, contact Valerie Knowles (CASEF Director) at director@casef.org or 717–580–3812.

The future of science and engineering is becoming apparent through students' increasing desire and ability to think creatively, critically, and constructively to generate solutions for a sustainable future. As testimony to this, 1973 CASEF senior grand champion Deborah Birx of Carlisle High School is now a global health official and physician Ambassador to the Office of the Vice President as the Coronavirus Response Coordinator.

RECENT PUBLICATIONS

Trail of Geology (May 2020)

- Outstanding geologic feature of Pennsylvania—Cornwall mines, Lebanon County
- Outstanding geologic feature of Pennsylvania—Baughman Rock, Fayette County
- Outstanding geologic feature of Pennsylvania—Jumonville Glen Rocks, Fayette County

The Bureau Library offers a variety of geologic resources, both in print and online.

FROM THE STACKS . . .

Jody Smale, Librarian
Pennsylvania Geological Survey

Although the Bureau's library was closed for several months in the spring of 2020 because of the pandemic, we were able to continue library services due to the automation of library processes and the internet. During this time, the librarian was still able to respond to requests for information over the telephone and through email, and information was exchanged electronically. Work also continued to make the library's resources more searchable and available online. Thus, even though the library was not physically open during this time, work was being done to ensure that individuals got the information they needed and that more of the Bureau's resources would be accessible online.

During the pandemic, people are still working, researching, and needing information. Requests for research materials are still being received from Bureau geologists, other state agencies, consultants, and the general public. There is often a misconception that "everything" is available online, but that is not the case. On many occasions, the Bureau librarian retrieved resources from the library's shelves that were not available online (or that were not *freely* available online). If the Bureau library did not own the sought-after resources, interlibrary loan requests were made to other libraries to obtain the materials, and most of those requests were filled electronically.

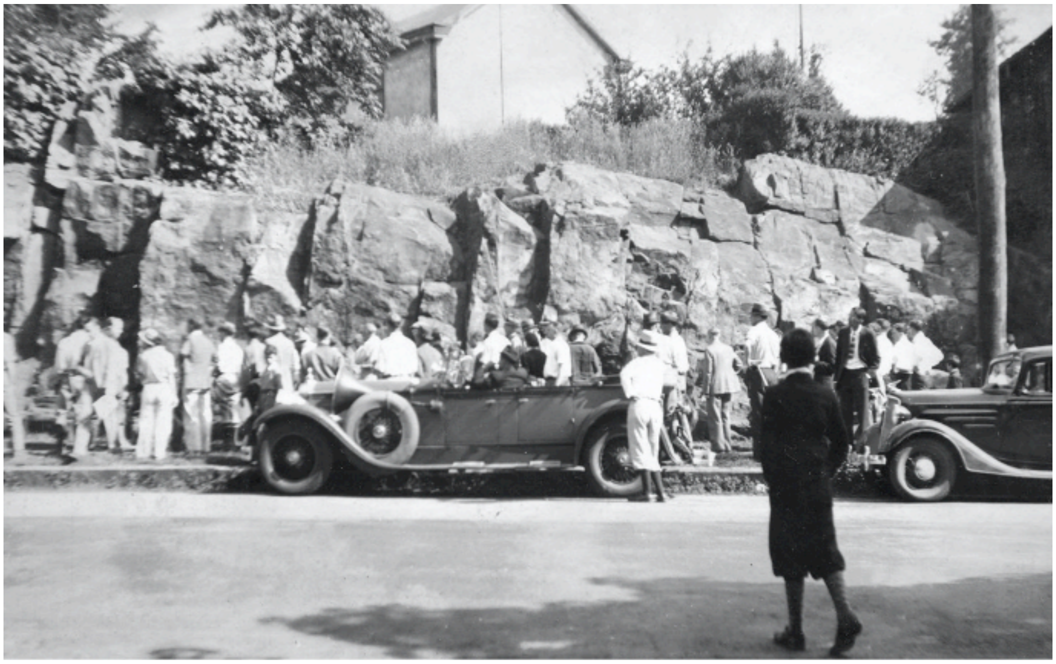
Work also continued on updating the Bureau's records in the online catalog of the State Library of Pennsylvania. (Click in the "Search Anything" box or perform an "Advanced Search" of the "State Library Catalog," and enter your search criteria.) Several hundred new records for the Bureau's reports were added to the online catalog, which makes them more searchable and easier to find. The links to these publications were also updated, so that once the desired title is found, the report will be available at the user's fingertips. Now all the Bureau's reports can be found in the online catalog and users can search for these by title, author, subject, and/or keywords. The online catalog is a powerful resource that provides greater searching capability so that users can more easily find the Bureau's reports, and other publications owned by the Bureau library, online.

More than 1,000 photographs from the Bureau's archival photograph collection were also scanned during this time. Previously scanned photographs are available on the library's Historical Photographs Collection page, and the newly scanned photographs are in the process of being added to this online collection. Many of the photographs in the collection date back to the 1920s. Providing the photographs online gives individuals a glimpse back at the state's quarrying, mining, and oil and gas drilling industries as well as historic images of Pennsylvania's geologic features. Making these photographs available through this online platform gives users the ability to browse and search the Bureau's historical photograph collection from their homes and offices.

The last several months have been busy ones for the Bureau library. Work will continue in order to make more of the library's resources available online, and requests for information from library users will continue to be filled. If you need help finding or using any of the library's resources, either in print or online, please contact the librarian, Jody Smale, for assistance.

BUREAU NEWS

A Look Back in Time



During the Fifth Field Conference of Pennsylvania Geologists, Dr. Edgar T. Wherry of the University of Pennsylvania led a stop at this Triassic diabase dike located in Conshohocken, Montgomery County. The dike is 75 feet wide and "shows a complex system of joints," according to Wherry, 1935, page 36. Note the loudspeaker car. This photograph was taken on June 2, 1935, by Charles K. Graeber.

To read more about this stop, please see the following:

Wherry, E. T., 1935, Stop D-2—Conshohocken Triassic diabase dike, *in* Field Conference of Pennsylvania Geologists in the Philadelphia area of southeastern Pennsylvania: Philadelphia, Field Conference of Pennsylvania Geologists, 5th, Guidebook, p. 36–37.

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

—Jody Smale, Librarian

Calling All Authors

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.

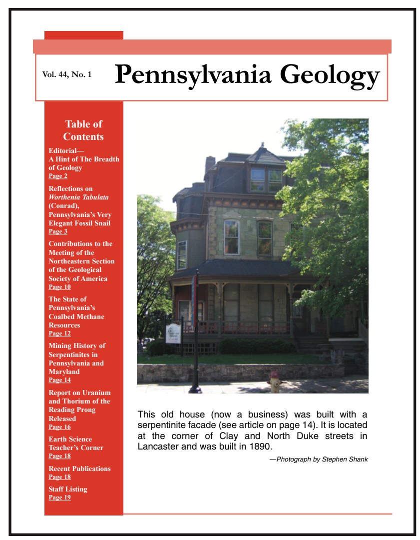
Feature Articles: All feature articles should be timely, lively, interesting, and well illustrated. The length of a feature article is ideally 5 to 7 pages, including illustrations. Line drawings should be submitted as CorelDraw (v. 9 or above) files if possible. Line drawings may also be submitted as jpg files. Ensure that black and white drawings are not saved as color images.

Articles should be submitted as Microsoft Word files. Feature articles will be reviewed by at least one Bureau staff member. It is the author's responsibility to obtain approval for use of any illustrations that are copyrighted, including those taken from the Internet.

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.

Announcements: Announcements of major meetings and conferences pertaining to the geology of Pennsylvania, significant awards received by Pennsylvania geologists, and other pertinent news items may be published in each issue. These announcements should be as brief as possible.

Photographs: Photographs should be submitted as separate files and not embedded in the text of the article. Please ensure that photographs as submitted are less than 10 inches wide in Photoshop or equivalent. Also ensure that black and white photographs are not saved as color images.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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*

Submittal: Authors may send their article and illustrations as email attachments to RA-pageology@state.pa.us if the file sizes are less than 6 MB. For larger sizes, please submit the files on CD–ROM to the address given below. All submittals should include the author's name, mailing address, telephone number, email address, and the date of submittal.

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Bureau of Geological Survey
Department of Conservation and Natural Resources
3240 Schoolhouse Road, Middletown, PA 17057–3534.

This edition's editor: Anne Lutz, Ph.D., P.G.

Links to websites were valid as of the date of release of this issue.

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