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Pinola spring (an unofficial name), located west of Shippensburg in Franklin County, issues from the Ordovician St. Paul Group. This is an excellent example of a limestone-fracture spring, and it produces 620 gallons/minute. See article on page 3.

EDITORIAL

Out of Sight . . .

Gale C. Blackmer, State Geologist
Pennsylvania Geological Survey

Considering its importance to our existence, you would think we would pay close attention to our water supply. Instead, most of us expect clean water to appear whenever we open the tap, without thinking much about where it comes from. We can be lulled into a false sense of security because many “contaminants” are invisible. Certainly turbidity—mud, clay, or other solids suspended in the water—is immediately obvious. It’s icky to drink, but it usually won’t make you sick. Iron is also easily detected, usually by taste or color. The well water for a house I once rented outside of West Chester had so much iron that all the bathroom fixtures were stained orange, iron “fuzz” grew on every surface inside the toilet tank, and the foam on boiling pasta water had an orange tinge. The water tasted awful, but it damaged only the fixtures, not the consumers. Same with sulfur—you can smell it immediately when you turn on the tap. No one wants to feel like they are showering at the gates of hell, but it won’t hurt you. No, the stuff that will really make you sick, such as bacteria, organic compounds, and trace metals like arsenic, is colorless and typically tasteless. It can only be detected by testing, or when symptoms develop in a consumer after sufficient exposure.

Pennsylvania is blessed with abundant water. Surface water in our lakes, rivers, and streams is easier to see and, therefore, to protect. Most people can understand the connection between a contaminant source on the surface and a nearby stream. Groundwater is trickier. It is out of sight, and the paths that water and contaminants take through rock and soil can be difficult to follow. It’s hard to tell what might make its way to your well. People also have a tendency to think that the sparkling-clear water that comes out of a well or spring is clean because it comes from a “natural” source. They don’t think about the metals that the water might have picked up as it passed through rock underground, or about the road salt, industrial chemicals, or fertilizer that might have leached into the groundwater. Victoria Neboga’s article on springs in this issue reminds us that these groundwater sources are not always as clean as they look. They require monitoring and active protection as much as surface-water sources.

Commercial and community water systems are required to test their water regularly to ensure that it meets state and federal quality standards. I receive an annual report from my water company that summarizes the test results and details any corrective actions they were required to take. Private-well owners, and those who collect their domestic water from a spring or cistern, are on their own. They aren’t required to test their water, and most people don’t. That might not be such a good plan. Those with their own water supplies should be aware of adjacent land uses and potential sources of contaminants. It might even be a good idea to think about a personal wellhead protection plan to help protect your water supply. Keeping track of surface activities in the area that might contribute to your water source and testing your water can help keep your family healthy. In the case of water, what you can’t see can hurt you.

Gale C. Blackmer

Monitoring the Springs of Pennsylvania

Victoria V. Neboga
Pennsylvania Geological Survey

"The bank was dense with magnolia and loblolly bay, sweet gum and gray-barked ash. He went down to the spring in the cool darkness of their shadows. A sharp pleasure came over him. This was a secret and a lovely place."

—Marjorie Kinnan Rawlings, The Yearling, *1938*

INTRODUCTION

Water is an essential resource for everyone, and Pennsylvania is home to many springs that have played a key role in the settlement of people and the development of the state. A spring is defined as a place where groundwater meets the land surface or a body of surface water. Each spring occurrence depends on the nature and relationship of the rocks, the position of the water table, and the topography. Most springs emerge at topographic low spots because of gravity, but some springs occur at higher elevations when the groundwater is forced to the surface by artesian pressure.

Springs are part of the continuous water cycle between atmospheric, surface, and subsurface water. Because springs are simply intersecting points of groundwater and the earth's surface, any changes to the groundwater will affect a spring's water quality or quantity. Most spring systems are relatively shallow; thus, they are more susceptible to contamination from the surface.

Some springs have long been used as a source of drinking water. In north-central Pennsylvania, for example, many domestic and public groundwater supplies are obtained from springs. Springs also become important components of ecosystems and habitats for both common and rare animal and plant species. For example, dusky salamanders can be observed near the heads of springs that have cool temperatures ranging from 43° to 54°F (6° to 12°C) in north-central Pennsylvania (Aaron Bierly, personal communication, 2016).

The names of various springs have provided names to numerous towns across the state, such as Three Springs, Chester Springs, Buffalo Springs, Beaver Springs, Arch Spring, and many others.

HISTORICAL AND CURRENT USAGE OF SPRINGS

Long before the first European immigrants settled in Pennsylvania, Native Americans valued clear spring water. Old Indian trails ran along direct routes from spring to spring, similar to the Great Trail, also known as Warriers Path, a part of which stretches from the Susquehanna River to Big Spring in Cumberland County. In the 1740s, there were small settlements of immigrants near Big Spring and Boiling Springs (Cumberland County, Pennsylvania, 2011).

Some springs, such as Schantz Spring in Allentown, Lehigh County, have been used as a main source of water for decades. Schantz Spring has been used as the main water supply for the city since 1898 and is considered one of the state's largest springs. The city of Allentown has estimated its flow at about 10 million gallons per day (mgd) (Mangan, 1945).

With the discovery of mineral springs in the late eighteenth to mid-nineteenth century, it was inevitable that they would attract many people who wanted to taste the mineral water. The widespread belief in the curative properties of mineralized water led to the establishment of resorts, hotels, and baths at many mineral springs. Bedford Springs resort was one of the first such places; this spring's medicinal values were discovered in 1796 by a local resident. It soon became a leading resort visited by numerous prominent citizens, including Presidents Polk, Taylor, and Buchanan. Buchanan used the resort (and its spring water) as his summer White House during his presidency.

Many of these mineral-spring resorts developed into complete recreational facilities without an emphasis on the "curative" powers of their water. One example is Doubling Gap White Sulphur Springs Hotel, which was built in the beginning of the nineteenth century around two mineral springs. Later, it became home to a summer camp and retreat center for all ages (Historical Doubling Gap Center, 2017). Many springs have also been described in *Guide to the Appalachian Trail in Pennsylvania* (Forrester, 1991) as a source of water for hikers. Unfortunately, many of these springs are no longer potable (drinkable) because of pollution.

Public water companies use springs to supply many Pennsylvania households with at least part of their water. One of these springs is Findley Spring in Somerset County, used by the Salisbury Borough Water Commission. It supplies 130,000 gallons per day (gpd), which flows to Salisbury by gravity. The water quality is reportedly good, and there is little seasonal variation (Flint, 1965). It discharges from the Loyalhanna Member (a limestone) of the Mauch Chunk Formation, which crops out on the hillside at this locality. As of 2016, about 2,800,000 people rely on more than 8,000 public water systems supplied with groundwater from wells and springs, whereas 11 percent of the Pennsylvania population rely on their own wells as their main water source (Pennsylvania Department of Environmental Protection, 2016).

There are plenty of opportunities to observe springs along roadcuts that intersect shallow natural locations, allowing the groundwater to flow into drainage ditches and sometimes onto road surfaces. These springs are generally located within public rights-of-way along state or local roads, and (to assist in accessing the water) there may be stone or concrete structures having metal or PVC pipes that were built many years ago (Figure 1). Some of them continue to be popular sources of drinking water; however, research conducted by the Pennsylvania State University from 2013 to 2015 on several dozen roadside springs found that nearly all of these failed health-based drinking-water standards. These results suggest that untreated roadside springs are unsuitable as a drinking-water source (Swistock and others, 2016).

Figure 1. Roadside spring in Perry County, Pa. Its water has been determined to be unfit for drinking.

In many cases, vegetation can provide a significant clue to the presence of a spring. Water-loving plants, such as willow, poplar, saltgrass, and many more, are called phreatophytes. They can live with their roots below the water table, and they extract their moisture directly from the saturated zone. In addition, wetlands are commonly associated with springs.

SPRING OCCURRENCES AND MAGNITUDE

Springs occur in every principal rock type in Pennsylvania, but the largest springs are recorded in the central and southeastern parts of the commonwealth (Figure 2), where they

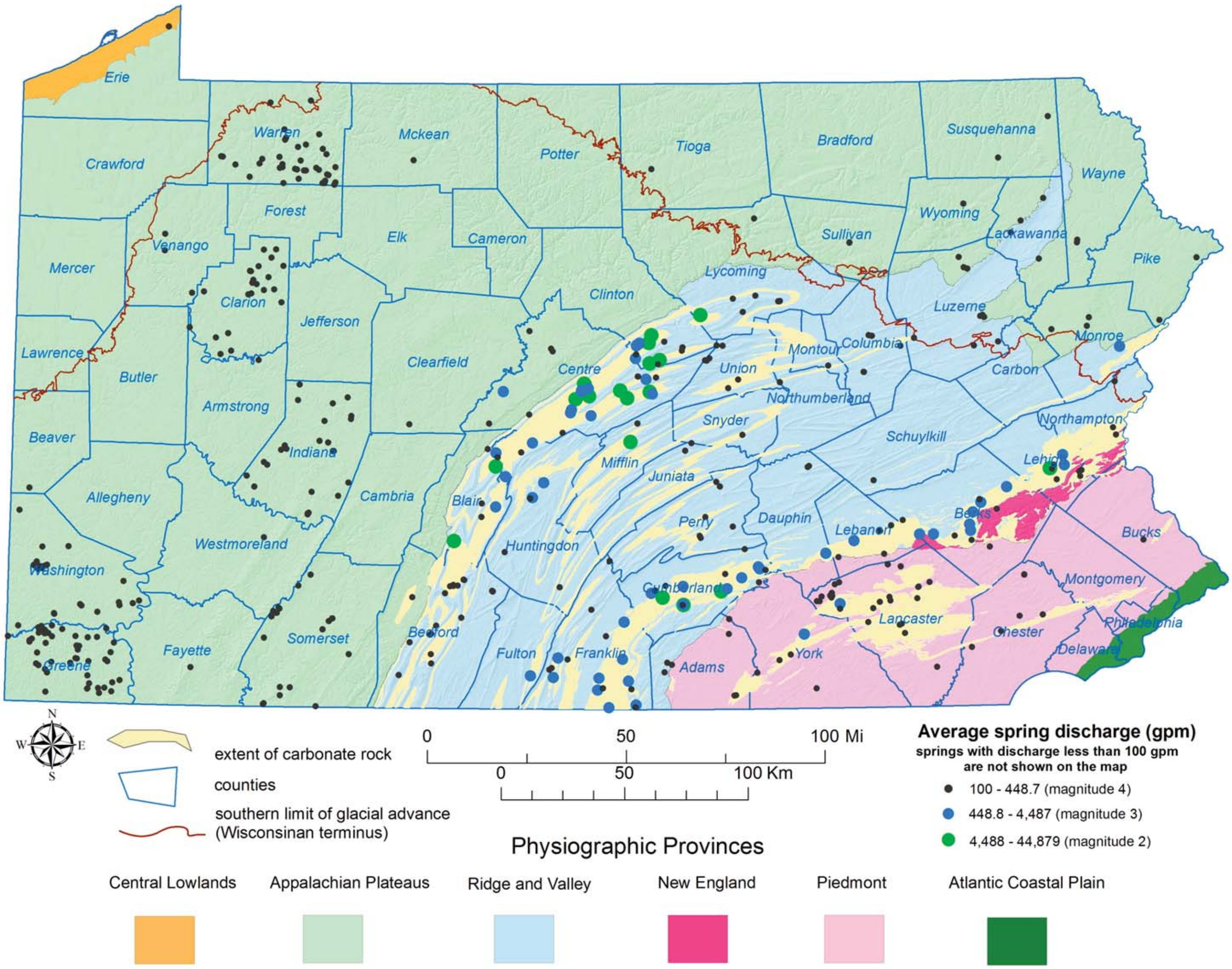

Figure 2. The magnitudes of springs in Pennsylvania and their distribution within the physiographic provinces (gpm, gallons per minute).

predominantly occur in carbonate rocks. Large fractures can develop in these rocks by dissolution of calcium carbonate minerals. Springs are characterized by the Meinzer classification system (Table 1). There are no first-magnitude springs in Pennsylvania, but springs here fall within all other magnitudes except eighth (Meinzer, 1927, Figure 2). In 1974, Flippo listed 11 springs of second magnitude on the basis of median spring discharges (a discharge of between 4,488 and 44,879 gpm). Later work by Saad and Hippe (1990) revealed that there are 15 springs of second magnitude located in the Ridge and Valley physiographic province, as discussed further below.

The occurrence of springs depends on geology, topography, and groundwater conditions of the region. Pennsylvania is divided into six physiographic provinces (Figure 2). Three of them occupy most of the state (about 98 percent): the Appalachian Plateaus province, the Ridge and Valley province, and the Piedmont. The other three occupy about two percent of the state: these are the Central Lowlands, the New England province, and the Atlantic Coastal Plain. Springs are almost evenly distributed throughout the three largest provinces noted above, with only one percent of springs situated within the smallest provinces.

Table 1. *Classification of Springs With Respect to Discharge*

(Modified from Meinzer, 1927; gpm, gallons per minute)

Magnitude	Range of discharge (gpm)
First	44,880 or more
Second	4,488 to 44,879
Third	448.8 to 4,487
Fourth	100 to 448.7
Fifth	10 to 99
Sixth	1 to 9
Seventh	1 pint to 0.9 gpm
Eighth	<1 pint per minute

The Appalachian Plateaus province (60 percent of the state), is a region of common springs. The underlying geologic formations consist mainly of sandstone, siltstone, shale, conglomerate, and some limestone and coal. They can store and transmit large quantities of water through numerous small spring outlets within the region, especially north of the glacial extent. Most of the springs in this region are gravity springs, which can be further classified as *seepage springs* (water percolates from small openings in permeable material), *fracture springs* (water flows from openings and fractures in the rock) (see photograph on cover), and *contact springs* (water flows to the surface through permeable material overlying a layer of impermeable material). Although this province encompasses more than a thousand springs, there are no springs of second magnitude, only one of third magnitude, and a dozen of fourth magnitude; the majority are seepage springs of the fifth magnitude or lower.

The second-largest physiographic province, the Ridge and Valley, is underlain by sedimentary rocks, including a relatively large percentage of carbonate rocks, and therefore includes the largest springs (by magnitude) in the state. Carbonate rocks, shown in Figure 2 in yellow, give rise to 75 percent of the springs that yield 100 gpm or more. The springs underlain by carbonate rocks are included in one of two types of flow systems. In the *diffuse-flow* system, water flows at low velocities along interconnected fractures such as joints, bedding planes, and other openings less than an inch wide. Big Spring in Cumberland County is an example of a carbonate spring having a diffuse-flow system, where water is transmitted at low velocities along joints and fractures. Noncarbonate rocks, such as sandstone and shale, also can be the source of large springs with diffuse-flow systems. Saad and Hippe (1990) listed nine third-magnitude springs discharging from a sandstone and three from shale and other rock types. However, the largest springs are associated with the *conduit* type of flow system.

Conduit-flow systems have large interconnected openings that range from an inch to 10 feet in diameter, which receive and transmit water freely. Some springs of the conduit-flow type exhibit seasonal variability from hundreds to thousands of gpm, and their highest flows are greater than 10,000 gpm. A conduit spring, Arch Spring (Figure 3) in Blair County, has large variations in discharge, from 2,000 to 13,500 gpm (Pennsylvania Geological Survey, 2017). It issues as a cave stream from a natural arch in the limestone, which resulted from the enlargement of a sinkhole and the collapse of part of the cave (Lohman, 1938). Many springs also issue from sandstone and shale, but their discharges typically are less than 100 gpm (Wood, 1980). In a study by Saad and Hippe (1990), based on either a single measurement or the median discharge of the larger springs in this province, the authors concluded that there are 39 springs of fourth magnitude, 83 of third magnitude, and 15 of second magnitude. Most of the springs in the Ridge and Valley province are used as domestic and public supplies; some are used as fisheries and for recreational purposes.

The central part of the third-largest province, the Piedmont, is underlain by carbonate rocks of Cambrian and Ordovician age, which form one complex interconnected aquifer, giving birth to the

Figure 3. Arch Spring, located in Blair County, issues from a natural arch in the Lowville limestone.

largest springs within this province. Some springs are used as public water supplies, yielding up to 100,000 gpd.

The New England province is underlain by highly deformed and folded sedimentary and metamorphosed volcanic rocks of Precambrian, Cambrian, and Ordovician age. These rocks are relatively unimportant water bearers, having springs of third or lower magnitude. A group of springs near Fleetwood in Berks County supplies water from Cambrian quartzite at 64,000 gpd and comprises one public drinking-water supply. Another group of springs issues from Ordovician limestone, which supplies water for Wernersville at more than 300,000 gpd.

The remaining small provinces, the Central Lowlands and the Atlantic Coastal Plain, contain less than a dozen known springs having yields typically less than 50 gpm.

WHAT IS THE LARGEST SPRING IN PENNSYLVANIA?

The magnitude of median discharge serves as the generally acceptable criterion for determining the size of springs. Flippo (1974) reported Nippono Spring in Lycoming County to be the largest spring, but Lohman (1939) noted that its yield during October 1932 was only 2,300 gpm, classifying it as of third magnitude (Figure 4). Another reading, made in November 1971, showed the biggest yield of 20,000 gpm, but there are no recent data showing that it should be classified as the largest spring. Mangan (1945) surveyed large limestone springs in Pennsylvania during the summer of 1944 and revealed that the two largest springs in the commonwealth were Boiling Springs and Big Spring, both in Cumberland County. The flow from these two springs would be adequate to supply drinking water to a city of 300,000 to 400,000 people. Recent measurements of Big Spring's mean flow during 2005–16 showed a moderate increase to 13,376 gpm, which makes it the fourth largest spring in Pennsylvania (U.S. Geological Survey, 2017).

There are large springs in central and south-central Pennsylvania that discharge from tubular solution channels in limestone and dolomite. These *tubular* springs having conduit-type flow systems

Figure 4. Nippono (Enchanted) spring, Lycoming County, which got its name from the turquoise water color.

constitute the largest springs in Pennsylvania. Lohman (1938) described Bellefonte (Big) Spring in Centre County as the largest spring in the area among six other springs of second magnitude, having a reported discharge of 14,000 gpm. Bellefonte (Big) Spring, which supplies water for Bellefonte and Milesburg boroughs and for a bottled-water plant, is a conduit type of spring. Its measured discharge varies from 8,000 to 14,000 gpm. The average reported daily spring flow is 11.5 million gpd, which makes it the largest spring in Centre County and the ninth in Pennsylvania (Bellefonte Borough Waterworks, 2015).

The tubular openings of Bellefonte Spring are concealed, and water discharges into the bottom of a large pool. The origin and character of the tubular solution channels of other springs are slightly different. Some springs discharge from large caves, such as Arch Spring in Blair County (Figure 3). Other springs discharge directly into surface streams, such as Mammoth Spring in Mifflin County (Figure 5). Boiling Springs is a group of springs, with the most prominent spring, called the Bubbler, situated behind the Boiling Springs Tavern (Figure 6). The springs issue from the Cambrian Elbrook Formation limestones, "boiling" in the northwestern corner of a picturesque "Children's Lake." Average discharge of the springs is about 16.5 mgd, which makes them the seventh largest springs in Pennsylvania (Becher and Root, 1981).

The aforementioned springs comprise a group of second-magnitude springs. Other well-known springs of the second magnitude include Huntsdale Hatchery Springs (Cumberland County), Ruhl and Seven Springs (Clinton County), Kelly Spring, and Rising Spring (Centre County) (Flippo, 1974).

SPRING SURVEYS

Monitoring spring water provides a unique "snapshot" of groundwater quality and quantity. Monitoring such parameters as temperature, pH, dissolved oxygen, electrical conductance, oxidation reduction potential, and flow rate provides insight into the flow behavior of the springs, especially for

Figure 5. Mammoth Spring in Mifflin County discharging from a cave opening in the Benner and Loysburg limestones. Photograph by James Shaulis.

the highly vulnerable karst-aquifer springs. Unfortunately, the Pennsylvania Geological Survey did not collect substantial physical and chemical data on springs in the past. In 2016, the bureau acquired and began using a water-quality probe to collect basic information on spring water.

The bureau is currently involved in a statewide dataset compilation of springs, taken from previous publications, existing datasets, field notes, and unpublished data relevant to springs. The bureau is also periodically collecting new field data.

This information is entered into the Pennsylvania Groundwater Information System (PaGWIS) database, which is available to the public. PaGWIS has been updated and augmented with new spring records collected by field geologists during the 2014–17 field seasons. Field data are entered into an iPad using a specific application.

The PaGWIS database currently contains approximately 1,900 spring records. This database is updated when a geologist finds a new spring during fieldwork or makes a measurement of an existing spring and enters data in the office. A redesigned search tool in PaGWIS provides the public a way to search and download spring records using multiple criteria and map searches for a given location.

ENVIRONMENTAL CONCERNS

Some springs should be managed with care, especially those close to solution openings in carbonate rocks. Springs in limestone regions can be connected to topographic depressions caused by collapsed caverns (sinkholes) at higher elevations. Water level in the sinkholes may rapidly fluctuate due to variations in runoff and infiltration. Water quality of these *karst* springs may be particularly susceptible to contamination from the land surface. Surface activities can have a quicker and broader impact on karst spring areas.

Figure 6. The Bubbler, the largest spring at Boiling Springs, Pa., emerges from wide solution openings in the Elbrook Formation limestones.

As previously mentioned, roadside springs have consistently been shown to be poor sources of drinking water. Water-quality testing is the only way to be sure that the water is safe to drink.

CONCLUSIONS

Springs occur in every principal rock type in Pennsylvania, but most prominent springs issue from carbonate rocks of the Ridge and Valley physiographic province. It should be noted that most of the springs in Pennsylvania do not have continuous records of discharge. Seasonal variability, especially for the conduit-flow type of spring, could create a problem when categorizing springs into groups. Occasional measurements of discharge are available for some springs, but these will not accurately represent the average discharge of a spring. Multiple instantaneous discharge measurements might be helpful only to determine an approximation of the relative size of the springs, but not their variability in discharge.

The flows of almost all springs in Pennsylvania exhibit some seasonal variability and depend on underlying bedrock, the amount of precipitation, and the size of the openings through which the springs discharge. Numerous small springs, which issue under near-surface conditions, may become dry during occasional droughts, but are readily flowing after heavy precipitation. Springs underlain by carbonate rocks have greater variation of water flow, where large volumes of water move quickly in and out of the aquifer. Spring-water chemistry can reveal important information about aquifer water quality. Spring water generally reflects the character of the rock that makes up the spring's aquifer, and also serves as a window into the groundwater. For example, spring water is elevated in dissolved solids in areas underlain by carbonate rocks. Springs issuing from sandstone and shale might be less mineralized, but may contain elevated concentrations of iron and manganese and some dissolved gases, such as hydrogen sulfide. The water from most of the limestone springs has a uniform cool temperature throughout the year, which is important for the numerous fish hatcheries in the Ridge and Valley province. Large springs are also utilized as public water supplies and are used by many industries and recreational facilities.

More data on magnitudes of flow and quality are needed to assess long-term changes of the springs. The monitoring of springs can provide hydrologic information that is impacted by long-term climatic changes or short-term changes corresponding to human influence.

REFERENCES

Becher, A. E., and Root, S. I., 1981, Groundwater and geology of the Cumberland Valley, Cumberland County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 50, 95 p.

Bellefonte Borough Waterworks, 2015, Water quality report—The Big Spring in Bellefonte: http://bellefonte.net/wp-content/uploads/2013/06/2015-Annual-Water-Quality-Report.pdf, accessed on July 1, 2017.

Cumberland County, Pennsylvania, 2011, Chapter 4, History past and present: https://www.ccpa.net/documentcenter/view/15781, accessed August 29, 2017.

Flint, N. K., 1965, Geology and mineral resources of southern Somerset County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., County Report 56A, 267 p.

Flippo, H. N., Jr., 1974, Springs in Pennsylvania: Pennsylvania Department of Environmental Resources, Office of Resources Management, Water Resources Bulletin 10, 46 p.

Forrester, M. J., Jr., 1991, Guide to the Appalachian Trail in Pennsylvania [8th ed.]: Appalachian Trail guides, no. 5, Cogan Station, Pa., Keystone Trails Association, 177 p.

Historical Doubling Gap Center, 2017, The prosperous years, http://historicaldoublinggapcenter.blogspot.com/p/prosperous-years.html, accessed on July 1, 2017.

Lohman, S. W., 1938, Ground water in south-central Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 5, 315 p.

_________ 1939, Ground water in north-central Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 6, 219 p.

Mangan, J. W., 1945, Pennsylvania springs and their volume of flow: Pennsylvania Department of Internal Affairs Monthly Bulletin, v. 13, no. 5, p. 26–27.

Meinzer, O. E., 1927, Large springs in the United States: U.S. Geological Survey Water-Supply Paper 557, 94 p.

Pennsylvania Department of Environmental Protection, 2016, Pennsylvania public water system compliance report for 2016: Department of Environmental Protection, http://files.dep.state.pa.us/Water/BSDW/DrinkingWaterManagement/PA_DEP_2016_Annual_Compliance_Reportl.pdf, 40 p., accessed on September 8, 2017.

Pennsylvania Geological Survey, 2017, Pennsylvania Groundwater Information System (PaGWIS): Pennsylvania Geological Survey, 4th ser., http://dcnr.state.pa.us/topogeo/groundwater/pagwis/index.htm, accessed on July 1, 2017.

Saad, D. A., and Hippe, D. J., 1990, Large springs in the Valley and Ridge physiographic province of Pennsylvania: U.S. Geological Survey Open-File Report 90–164, 17 p.

Swistock, Bryan, Boser, Susan, Oleson, Diane, and Madden, Mark, 2016, Roadside springs: University Park, Pa., Penn State Extension, http://extension.psu.edu/natural-resources/water/drinking-water/cisterns-and-springs/roadside-springs, accessed on September 8, 2017.

U.S. Geological Survey, 2017, Groundwater watch—Active spring monitoring sites: https://groundwaterwatch.usgs.gov/SitesSP.asp?S=01569460, accessed on July 1, 2017.

Wood, C. R., 1980, Summary groundwater resources of Centre County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 48, 60 p.

BUREAU UPDATES

A Maverick's Ideas—Reverse Sequence of Alleghany Fold-and-Thrust Tectonics

In 1991, the late Rodger T. Faill gave a talk at the combined Northeast-Southeast regional meeting of the Geological Society of America (GSA) in Baltimore, Md., where he presented evidence to suggest that, in the central Appalachians, deformation progressed in a reverse sequence, from the Appalachian Plateau back toward the Piedmont (Faill, 1991). Shortly thereafter, he prepared a manuscript detailing these ideas, which was never completed. He last revised his manuscript in 2000 or 2001, having moved on to other projects before he completed it. The unpublished manuscript was found in his files after his death. Apparently, he had decided to resurrect the project in his retirement, but was unable to complete it (Pennsylvania Geological Survey, 2014). This work was consistent with his reputation as a maverick who saw evidence that others did not, and it went against the generally accepted interpretations of the time.

The majority of published work has indicated a forward sequence of deformation in many orogenic belts (a number of studies are referenced in the unpublished manuscript). Rodger had a number of ideas that were contrary to generally accepted theories (kink-band folding [Faill, 1973], Mesozoic basin development [Faill, 2003, 2010], and Piedmont deformation [Faill and Wiswall, 1994; Faill and Smith, 1994, 2010]). He had valid arguments for his ideas and could be quite convincing.

Rodger's reverse-sequence ideas were never fully developed, but his evidence is worth considering. The manuscript is not sufficiently complete for publication, and there is currently no one to complete it, because he worked on these ideas alone (as he did on many of his projects). Therefore, because of the potential significance of this work, we have decided to make his unpublished manuscript available "as is."

Much of Rodger's evidence for reverse progression of deformation is negative evidence. He would have expected to see certain features if there had been a forward progression, and he did not see them. He did not, however, have geologic dating evidence that would show that a particular first-order fold formed before the adjacent first-order fold, which would prove the direction of progression.

One of the complications we encountered in working with his manuscript is that we had a difficult time locating figures to which he refers in the manuscript. We found some early hand-drawn and drafted figures in his files at the Pennsylvania Geological Survey, which we have reproduced with the manuscript. These may have been figures that he used in his 1991 GSA presentation. Some of his figures were probably similar to those in his *American Journal of Science* article, *A Geologic History of the Appalachians, Part 3: The Alleghany Orogeny* (Faill, 1998). However, some references to figures in the manuscript have no figures to accompany them. Either he never completed them or we never found them.

A map that should be referenced while reading this manuscript is Rodger's *Folds of Pennsylvania* map (Open-File General Geology Report 11–01.0). It can be downloaded from www.docs.dcnr.pa.gov/cs/groups/public/documents/document/dcnr_016183.zip.

The unpublished manuscript should be referenced as follows:

Faill, R. T., 2000, Reverse sequence of Alleghany fold-and-thrust tectonics, north-central Appalachians, U.S.A., Pennsylvania Geological Survey, 4th ser., unpublished manuscript, 34 p.

It can be found at www.dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_20033069.pdf.

REFERENCES

Faill, R. T., 1973, Kink-band folding, Valley and Ridge province, Pennsylvania: Geological Society of America Bulletin, v. 84, p. 1289–1313.

Faill, R. T., 1991, Out-of-sequence (west-to-east) deformation in the central Appalachian foreland: Geological Society of America Abstracts with Programs, v. 23, p. 28.

Faill, R. T., 1998, A geologic history of the north-central Appalachians, Part 3—The Alleghany orogeny: American Journal of Science, v. 298, p. 131–179.

Faill, R. T., 2003, The early Mesozoic Birdsboro central Atlantic margin basin in the mid-Atlantic region, eastern United States: Geological Society of America Bulletin, v. 115, p. 406–421.

Faill, R. T., 2010, Tectonics of the Mesozoic Gettysburg and other basin remnants of the Birdsboro basin, in Wise, D. U., and Fleeger, G. M., eds., Tectonics of the Susquehanna Piedmont in Lancaster, Dauphin, and York Counties, Annual Field Conference of Pennsylvania Geologists, 75th, Lancaster, Pa., Symposium volume, p. 99–110.

Faill, R. T., compiler, 2011, Folds of Pennsylvania—GIS data and map: Pennsylvania Geological Survey, 4th ser., Open-File Report OFGG 11–01.0.

Faill, R. T., and Smith, R. C., II, 1994, Table 13–C of Stop 14, Peach Bottom section at the Susquehanna River, in Faill, R. T. and Sevon, W. D., eds., Various aspects of Piedmont geology in Lancaster and Chester Counties, Pennsylvania: Annual Field Conference of Pennsylvania Geologists, 59th, Lancaster, Pa., Guidebook, p. 185.

Faill, R. T., and Smith, R. C., II, 2010, The Peach Bottom area in the Pennsylvania-Maryland Piedmont, in Fleeger, G. M., and Whitmeyer, S. J., eds., The mid-Atlantic shore to the Appalachian highlands: Geological Society of America Field Guide, v. 16, p. 1–30.

Faill, R. T., and Wiswall, C. G., 1994, The Cream Valley fault—transformation from thrust to strike-slip displacement, in Faill, R. T. and Sevon, W. D., eds., Various aspects of Piedmont geology in Lancaster and Chester Counties, Pennsylvania: Annual Field Conference of Pennsylvania Geologists, 59th, Lancaster, Pa., Guidebook, p. 73–84.

Pennsylvania Geological Survey, 2014, Rodger T. Faill: Pennsylvania Geology, v. 44, no. 4, p. 8–13.

—Gary M. Fleeger and Anne B. Lutz

From the Stacks . . .

Jody Smale, Librarian
Pennsylvania Geological Survey

Listed below are some of the more recent additions to the library's collection. Whether you want to prepare for the national geology licensing examination (National Association of State Boards of Geology, or ASBOG®) or hope to catch up on the newest publications from the Geological Society of America (GSA), look no further than the bureau's library!

- Forts, floods, and periglacial features—Exploring the Pittsburgh Low Plateau and Upper Youghiogheny Basin, edited by Joseph T. Hannibal and Kyle C. Fredrick, GSA Field Guide 46, 2017.
- Geology study manual—2015 review for the national (ASBOG®) geology licensing exam, by Patti Sutch and Lisa Dirth, REG Review, Inc., 2015.
- Practice quizzes—2012 review for the national (ASBOG®) geology licensing exam, by Patti Sutch and Lisa Dirth, REG Review, Inc., 2012.
- The scientist's guide to writing—How to write more easily and effectively throughout your scientific career, by Stephen B. Heard, Princeton University Press, 2016.
- Unconventional—The development of natural gas from the Marcellus Shale, by Daniel J. Soeder, GSA Special Paper 527, 2017.
- The worst of times—How life on earth survived eighty million years of extinctions, by Paul B. Wignall, Princeton University Press, 2015.

A Look Back in Time

This photograph was taken on May 31, 1935, by Charles K. Graeber during the Fifth Annual Field Conference of Pennsylvania Geologists at the Holmesburg granite quarry in Philadelphia County. This was a large elliptically shaped pit known for its good building stone. Granite gneiss from this quarry can be found in numerous buildings throughout Pennsylvania, Delaware, and New Jersey.

To read more about the Holmesburg granite quarry, please see the following:

Gordon, Samuel, 1935, Stop B-1—Holmesburg granite quarry, *in* Philadelphia area of southeastern Pennsylvania: Annual Field Conference of Pennsylvania Geologists, 5th, Philadelphia, Pa, Guidebook, p. 16.

Stone, R. W., 1932, Building stones of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 15, p. 248–250.

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Articles pertaining to the geology of Pennsylvania are enthusiastically invited.

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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) or Adobe Illustrator (v. 8 or above) files.

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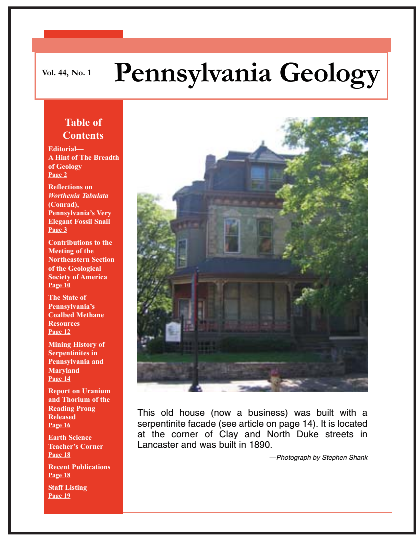
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This old house (now a business) was built with a serpentinite facade (see article on page 14). It is located at the corner of Clay and North Duke streets in Lancaster and was built in 1890.

—Photograph by Stephen Shank

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