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# Pennsylvania Geology

## Table of Contents



The two Big Spring source springs in Cumberland County, Pa., responded differently to a large rain event of July 2004. The larger west spring (foreground) became turbid with sediment. The east spring (background) remained clear (see article on page 3).

*—Photograph by Todd Hurd*

EDITORIAL

# Geologists as Mentors

George E. W. Love, State Geologist
Pennsylvania Geological Survey

This issue of *Pennsylvania Geology* covers karst-influenced groundwater flow, drilling, two memorials for friends and colleagues, and recognition for a job well done. The range we cover is rather striking, but I want to focus on an underlying theme that runs through this seemingly diverse grouping—the sharing of information and the mentoring of tomorrow's practitioners.

The first and second articles focus on some of the technical aspects of our profession—we are trained to use inductive reasoning for our descriptions, maps, drawings and expectations. Certainly watching water flow "downhill" laden with tracers is such an example—it will "come out down below." And hypothesizing that standing in the middle of a carbonate valley with nearby rocks dipping "in your direction" means you can predict when a drillbit will encounter those rocks at depth—give me money for 1,700 feet of core and I'll tell you what is happening. Maybe this is not Geology 101, but it is certainly not a tough graduate course. In both cases, young geologists are being exposed to data collection; are being asked to explain what they are seeing; and are scratching their communal heads wondering why "it ain't so." Shippensburg's Todd Hurd is guiding some young minds, posing questions to stretch their thinking; the bureau's Aaron Bierly has, as he says, come to "expect the unexpected," a lesson we seasoned geologists have learned is the rule. These young folks are learning to turn on their imaginations and draw upon mentors and colleagues to deductively produce explanations for the unknown and frequently unseen.

This brings us to the two memorials, descriptions of geologists who loved the science and who guided others, through mentoring, to develop the deductive reasoning so critical to our field. I did not know these gentlemen, and I am poorer for that. Those of you who did know them have said the things I can only hope might be found in comments made about me by my colleagues at some time in the future.

Next, we as a profession recognize one of our own for her work directed at informing and sharing the science of geology and how it impacts our lives. Kristin Carter gives of her time to promote geology, and we are better off for it.

Finally, the bureau and DCNR's information technology group are doing their part to make access to geologic information faster, easier, and maybe even more readily understandable. We are excited about the website and welcome suggestions to improve the offerings. That said, we do have certain rules we must live by, so suggestions such as the removal of all the trees so that we can see the rocks may just fall on deaf ears!

We are all the product of our education, our observations, and the good fortune to have met and worked with mentors. Be one! Karl Terzaghi of soil mechanics fame once said he had never met a person he could not learn something from. Do not underestimate what good you can do.

# Determination of Preferential Groundwater Flow Patterns to Cumberland County Springs with Fluorescent Dye Tracing

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## Introduction

Carbonate springs of southern Pennsylvania are important as water resources for productive wild fisheries, trout hatcheries, and municipal supplies (Kochanov, 2010), yet karst groundwater basins are vulnerable to surface contaminants (Kacaroglu, 1999). Water and contaminants may pulse rapidly through karst flow systems to springs (Vesper and others 2003). In the Great Valley section of the Ridge and Valley physiographic province (locally known as the Cumberland Valley), agricultural nutrients and pesticides and runoff from impervious surfaces of developed areas rapidly enter the karst drainage system through sink collapses or sinking streams (Figure 1) and are carried rapidly to springs. Walderon and Hurd (2009) estimated that Letort Spring Run in Carlisle carries more than 170,000 kilograms per year (374,786 pounds per year) of nitrate-N, much of which resurges directly at springs. This much loading from the springhead of a single tributary in the lower Susquehanna basin means that there is a need for better management of runoff to our karst basins. Such management focus must occur above the point of spring resurgence, and along identified flow paths, for the protection of local water quality and for decreased nutrient loading to the Susquehanna and Potomac Rivers and to the Chesapeake Bay. As karst areas of Pennsylvania are developed, there will be similar vulnerability of karst groundwater to associated industrial contaminants. For example, industrial activity at Letterkenny Army Depot in the Great Valley resulted in groundwater contaminated with volatile organics that flowed rapidly along pathways traced with fluorescent dyes to area springs (Aley and others, 2004).

In order to better manage land and water resources in these areas, it is necessary to first delineate the contributing areas of karst springs with fluorescent dye tracing (Käss, 1998). In karst environments, regional groundwater flow may cross topographic divides, and rapid flow through karst solution channels makes it necessary to utilize fluorescent dye tracing with, or in place of, hydrological models. Without an understanding of pathways and travel times to springs, there is little that can be done to identify and mitigate pollutants associated with a particular spring or to plan for a safe water supply in instances where carbonate springs are utilized for this purpose.

## Fluorescent Dye Traces

In early 2003, I became interested in identifying source areas for Big Spring, one of the largest karst spring systems in Cumberland County (Figures 2 and 3) and Pennsylvania's fifth largest spring (Kochanov, 2010). In 2003, Big Spring was rapidly recovering from eutrophication (an increase in dissolved nutrients and plant growth, and a decrease in dissolved oxygen) caused by aquaculture discharge (Hurd and others, 2008), and a limestone quarry just a little over a mile south and east of the two primary source springs was undergoing the permitting process. Big Spring received much scrutiny because of these and other potential impacts on water quality or quantity, due to both its historical value as a wild-brook-trout fishery and its use as a municipal water supply. A contributing spring in Newville serves the borough and adjacent township, and the channel is permitted as a secondary

A

B

*Figure 1. Karst features in Cumberland County. A. A sink collapse in the Zullinger Formation within a detention basin on a quarry property on the southeastern boundary of Big Spring's surface watershed. B. A swallet in a surface stream fed by quarry pump water in the surface watershed of Green Spring/Bullshead Branch.*

supply. The source springs together contribute a mean discharge of 0.79 $m^3/s$ (cubic meters per second) or 28 cfs (cubic feet per second) (U.S. Geological Survey, 2009). The estimated contributing area for the springs is 76 $km^2$ (square kilometers) (29.3 $mi^2$ [square miles]), whereas the surface basin area is only about 9 $km^2$ (3.4 $mi^2$) (Hurd and others, 2010). These calculations clearly point to regional flow patterns from source areas beyond the topographic basin.

Through Donald Seigel, Department of Geology at Syracuse University, I met Martin H. Otz, who has extensive global experience conducting fluorescent dye tracing projects, along with his wife Ines and father Heinz. The Otz family conducted field reconnaissance in Cumberland County and helped

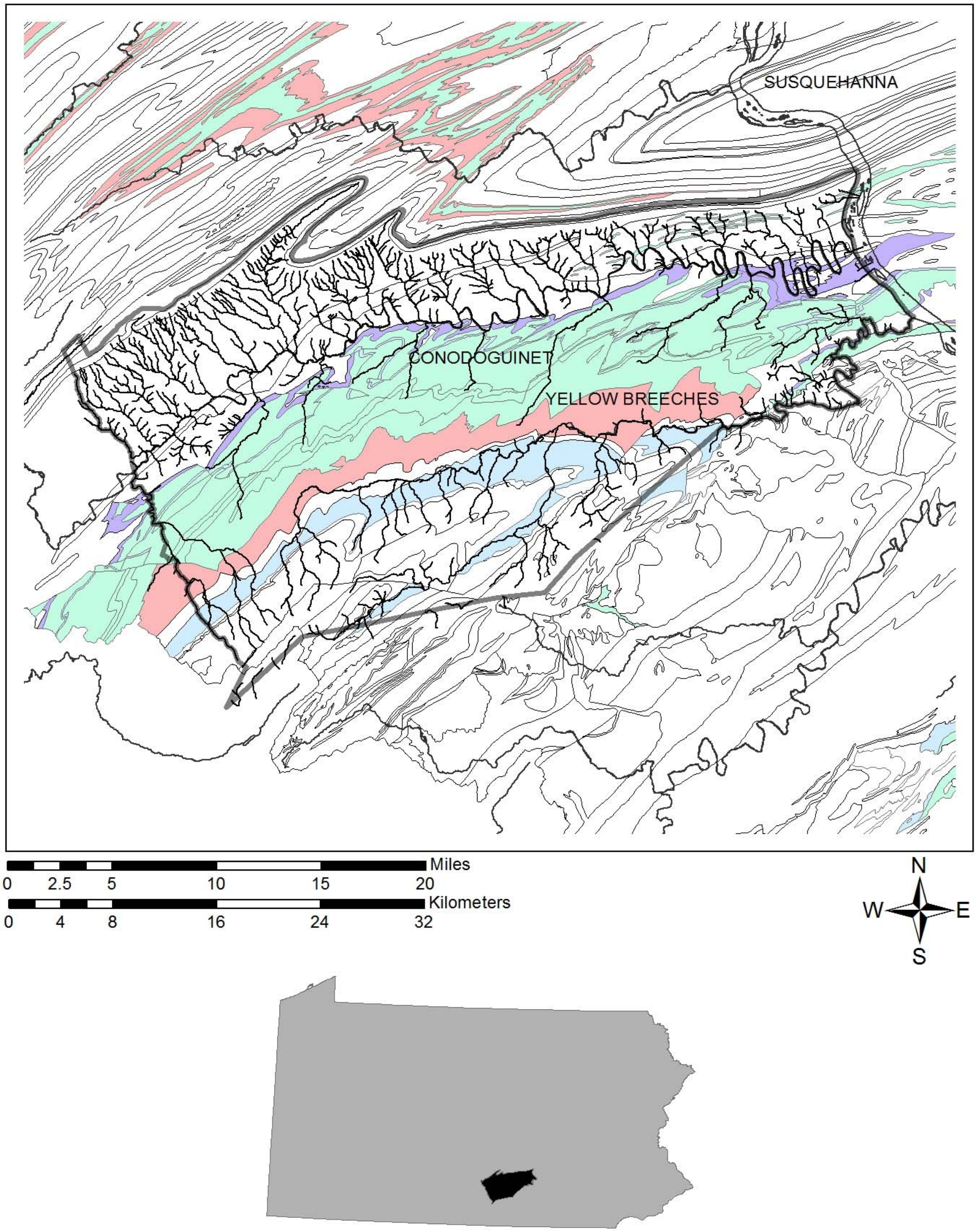


*Figure 2. Streams of Cumberland County, Pa., showing the influence of karst geology in the Great Valley. Surface drainage to the Susquehanna River occurs from the Yellow Breeches Creek along the flank of South Mountain and from the Conodoguinet Creek along the flank of North Mountain. Nutrient-rich springs with largely undefined source areas surface at the valley center and flow north to Conodoguinet Creek. Blue, Cambrian Tomstown Formation; pink, Cambrian Elbrook Formation; blue-green, Cambrian and Ordovician limestones (Cambrian Zullinger and Shadygrove Formations, Ordovician Stonehenge [including the Stoufferstown Member], Rockdale Run, and Pinesburg Station Formations; Ordovician St. Paul Group, and Ordovician Myerstown Formation); purple, Ordovician Chambersburg Formation. Map data (major rivers, streams, bedrock, and counties) from PASDA (Pennsylvania Spatial Data Access, 2012).*

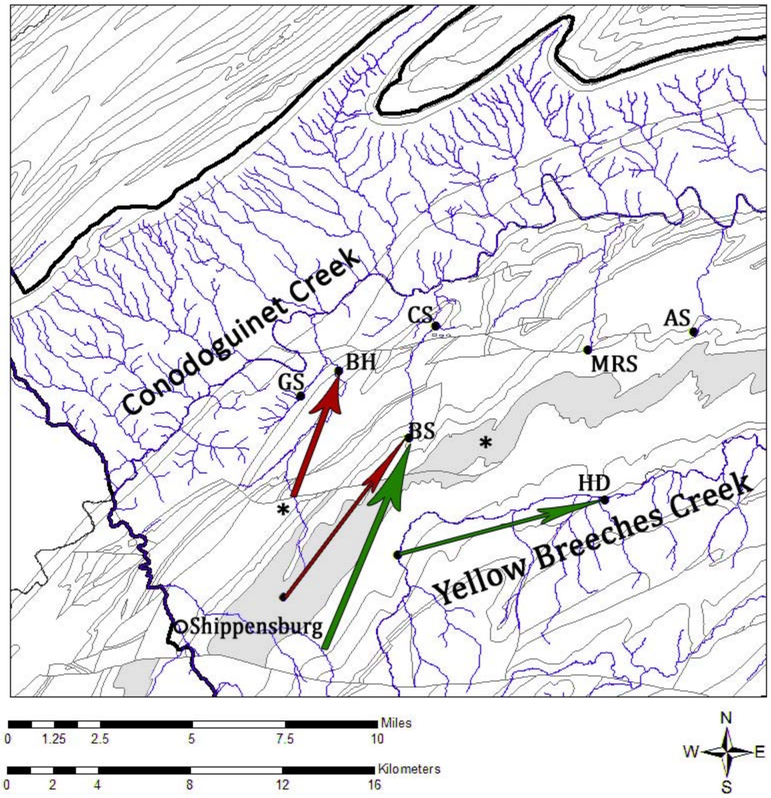


*Figure 3. Groundwater flow in western Cumberland County as determined by fluorescent dye tracing. Thin arrows show groundwater flow determined by Hurd and others (2010); bold arrows show groundwater flow direction determined in 2009. Uranine (URA) was used to trace interbasin flow from upper Burd Run/Middle Spring to Big Spring and flow from the upper Yellow Breeches to Hunstdale Springs. Sulforhodamine B (SRB) was used along with sodium naphthionate to trace flow in the Bullshead Branch system and from a sinkhole in the Zullinger Formation near the Interstate Route 81 and State Route 174 interchange. The Zullinger Formation is shown in light gray, and the asterisks show locations of limestone quarries in the region. Springs sampled were Big Spring (BS), Green Spring (GS), Bullshead Branch (BH), Cool Spring, Newville's municipal supply (CS), Mount Rock Spring (MRS), Alexander Spring (AS), and Huntsdale Springs (HD). Burd Run of Middle Spring was also sampled but there was no definitive detection of uranine, suggesting a different source water than that sinking higher in the watershed.*

me plan a fluorescent dye trace of Big Spring's source areas. In addition to determining general source areas, we wanted to determine if there was a hydrological connection from a recently permitted quarry east of Big Spring or to surrounding springs, in order to address stakeholder concerns over potential changes in flow and turbidity.

Our plan was to delineate the contributing areas of Big Spring and surrounding springs using tracer release points to the south and west, and eventually from the south and east boundary of Big Spring's surface basin where the recently permitted quarry was being constructed (Figure 3, eastern asterisk). The Department of Environmental Protection, Bureau of Mining, did not require a fluorescent dye trace in order to approve the quarry permit, citing adequacy of a flow model that indicated slow (meters per day) localized northward groundwater flow (Continental Placer, 2003) and concerns about coloration of water that might result from the dye. Consultants did note, however, that some of the Cambrian Zullinger Formation that underlies most of the property is fractured. Moreover, the newly constructed detention pond never filled, due to rapid drainage into an associated sink (Figure 1A), indicating rapid groundwater flow to unknown receptors.

Fluorescent tracers were chosen based on their known effectiveness and low levels of human or ecotoxicity (Field and others, 1995; Käss, 1998). For initial traces (Hurd and others, 2010), water and charcoal receptor samples were analyzed by Nano Trace Technologies™ (Martin and Ines Otz) and by the Crawford Hydrology Lab (University of Western Kentucky), respectively, using synchronous scanning spectrofluorometers. For subsequent studies, analyses were completed with Perkin Elmer LS series fluorescence spectrometers.

We conducted fluorescent dye traces from sinking reaches of the Yellow Breeches Creek to the south and a sink collapse in western Cumberland County close to Shippensburg in the Zullinger Formation (Figure 3). Chichester (1996) noted that the Yellow Breeches loses water to the Conodoguinet Creek via springs in the valley center. Nevertheless, Becher and Root (1981) mapped a groundwater divide between the Yellow Breeches and the springs of western Cumberland County. This mapped divide suggested continuity between groundwater in the upper Middle Spring watershed near Shippensburg and the springs in the valley center, although well levels in the region generally indicate more northward groundwater flow.

**Rapid Regional Flow Patterns**

Hurd and others (2010) described rapid flow to Big Spring (about 2 km or 1.2 mi per day) closely parallel to geologic strike from 9 km (5.6 mi) away (Figure 3). This rapid flow path is highly susceptible to surface contaminants. The sinkhole where sulforhodamine-B dye was released receives runoff from a large impervious area into the Zullinger Formation from Interstate Route 81 and a developed area near the State Route 174 interchange outside of Shippensburg. An open ditch between the impervious area and the sink collapse crosses under Interstate Route 81 and could easily conduct highway spills to the sink. Also in that study, loss of water was traced from the Yellow Breeches Creek in Walnut Bottom to carbonate springs at Huntsdale State Fish Culture Station with uranine (sodium fluoresceine) fluorescent dye. This flow was slower, likely due to the influence of the colluvial mantle between the release point and these springs in the southern portion of the Great Valley. Nevertheless, groundwater traveled relatively fast (about 9.5 km/month, or 6 mi/month) and followed the general trend of geologic strike, in this case remaining within the Yellow Breeches drainage (Figure 3). There was no sign of this tracer in Big Spring or any of the north-flowing spring creeks around Big Spring. These results pointed to a source area for Big Spring to the west, and the sinking tributaries of Middle Spring Creek appeared to be potential candidates.

The Burd Run subbasin of Middle Spring Creek is unique in that its channel is continuous across the Great Valley. The tributaries sink strongly where the South Mountain colluvium thins, and the surface channels serve as overflow for the complex karst system beneath. In Shippensburg, Burd Run receives steadier flow from carbonate springs and joins another branch of Middle Spring Creek to become the largest tributary of the Conodoguinet Creek on the Great Valley's north side. All tributaries of Middle Spring Creek commonly sink completely up-gradient from Shippensburg, especially the eastern (Thompson Creek) branch of Burd Run. This is an interesting area in terms of karst surface features and caves, and it includes Cleversburg Sink and other caves (Smeltzer, 1958).

During the spring of 2009, Shippensburg undergraduate David Miller, Jr., and I traced a 10 km (6.2 mi) interbasin flow path from Thompson Creek to Big Spring (Figures 3 and 4). Effective linear velocity was determined to be 0.6 km/day (0.4 mi/day), using uranine released at a railroad bridge near Airport Road at the boundary between the Elbrook and Zullinger Formations. Interestingly, dominant dye breakthrough occurred first in the smaller east source spring, the opposite result of the 2005 trace into the failed detention basin further out in the Zullinger (Hurd and others, 2010). Both traces showed flow to the source springs from the same general vicinity, yet with specific flow to particular springs and some crossover that likely depends on precipitation and water level (Figure 4). It is interesting to note that discharge was increasing between 0.71 $m^3/s$ (25 cfs) and 0.85 $m^3/s$ (30 cfs) in the first trace, when breakthrough occurred first and most strongly in the west source spring. Discharge was decreasing between these same values in 2009 when there was first and strongest breakthrough in the east source spring (Figure 4). The east source spring does not show turbidity response to large rain events, whereas the west spring shows turbulent flow and discharge of sediment from associated conduits (see cover). The east source spring also exhibits higher electrical conductivity (574 vs. 537μS/cm

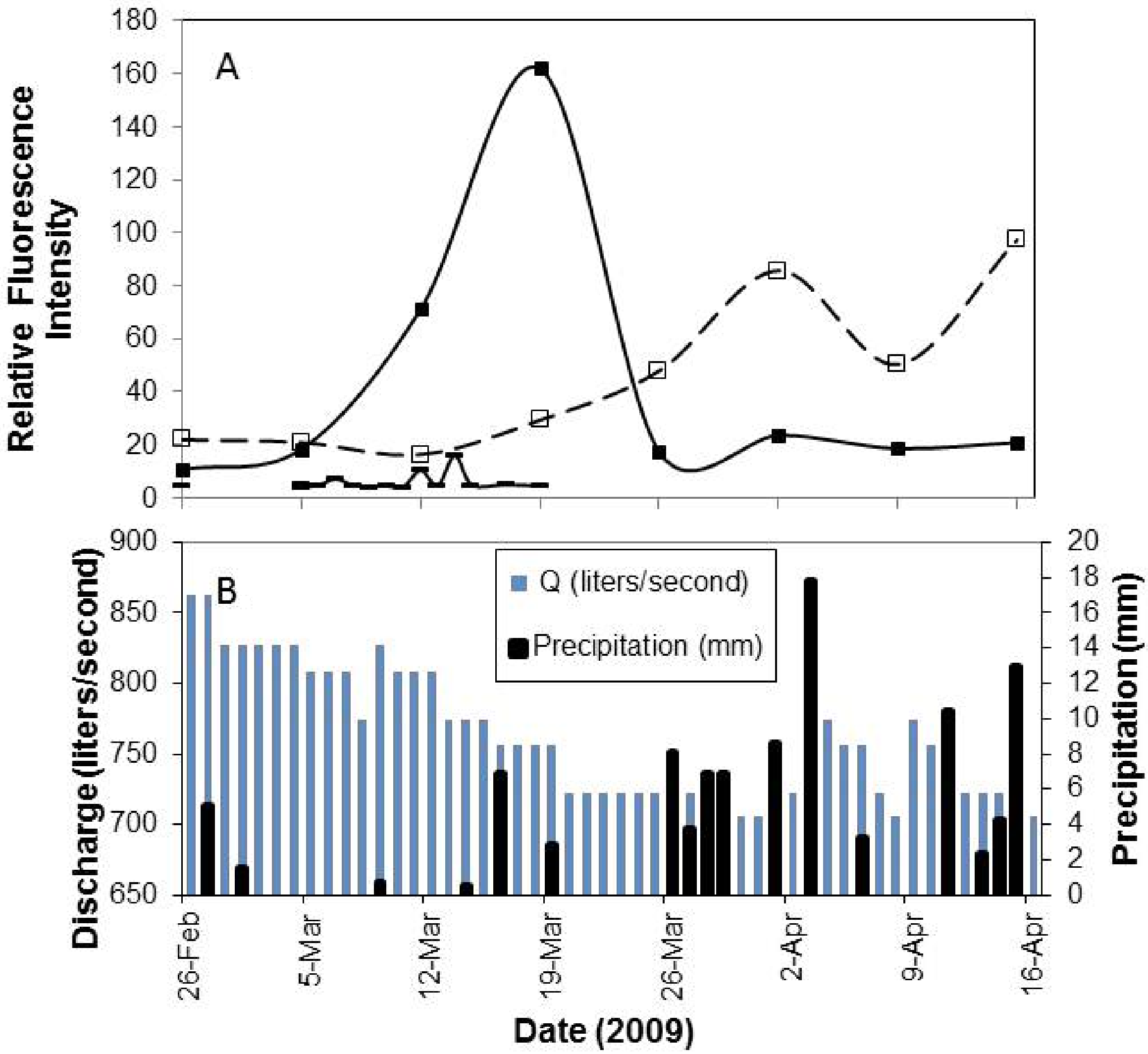


*Figure 4. A. Breakthrough (dye detection) of uranine in Big Spring source springs released from upper Burd Run/Middle Spring 10 km (6.2 mi) away. Relative Fluorescence Intensity (RFI) of uranine (sodium fluoresceine) showing breakthrough at Big Spring East (solid squares) and Big Spring West (open squares), detected in charcoal eluate after February 26, 2009, release, and under 1 ppb (part per billion) in water from Big Spring East two weeks following release (flat line symbols). Charcoal receptors were changed weekly and so indicate a slight lag in breakthrough. 160 RFI = 10.3 ppb uranine in eluate. B. Big Spring discharge (Q, shown in light blue) (Bruce Lindsey, U.S. Geological Survey, personal communication) and precipitation at Shippensburg University.*

[microsiemens per centimeter] in a recent measurement). These patterns demonstrate unique contributing flow paths from different surface inputs in the upper Burd Run/Middle Spring watershed. Big Spring is an Exceptional Value (EV) stream in its upper reaches. An EV stream receives Pennsylvania's highest water use designation based primarily on water quality. It is also a secondary water supply for Newville and Centerville and is susceptible to contaminant spills from the distant highway interchange or railroad line where the tracers were released. Different travel times of the tracers indicate the approximate response time needed to protect the stream and water supply if highway or railway spills were to occur, in addition to specific hydrogeological flow paths.

Other recent fluorescent dye traces showed flow from a sinking stream of the Bullshead Branch subbasin of Green Spring Creek (Figures 1B and 3) to a major spring of Bullshead Branch (Figure 3).

One connected spring is utilized as a residential water supply. This flow is also rapid (2 km/day or 1.2 mi/day) and generally parallel to strike, although the area is also heavily faulted (Becher and Root, 1981). This faulting appears to influence sinking of surface waters and flow direction in the area (Figure 3). This system has proven more complex to trace, due to more sediment, the structural complexity, and variable pumping of pit water in another limestone quarry (Figure 3, western asterisk) that influences the surface flow and also possibly groundwater flow patterns. After being pumped, the surface flow is exposed directly to pastured livestock, eroding pastures, fields, and roadsides, then sinks rapidly (Figure 1B) into the Ordovician Rockdale Run Formation near the Pinesburg Station Formation and St. Paul Group (Becher and Root, 1981). The swallet where loss of surface flow occurs is plugged intermittently with sediment. Sodium naphthionate released at this site was detected intermittently at greater than 10 times the background, but sulforhodamine B did not break through at more than 5 times the background from this release point (Figure 5), perhaps due to adsorption on sediment or dilution into separate receiving waters. Results from both dyes suggested that lower Big Spring as well as Bullshead Branch of Green Spring Creek rapidly received water from this site, but more work is needed to confirm these and other karst flow patterns and their potential to carry sediments and surface pollutants

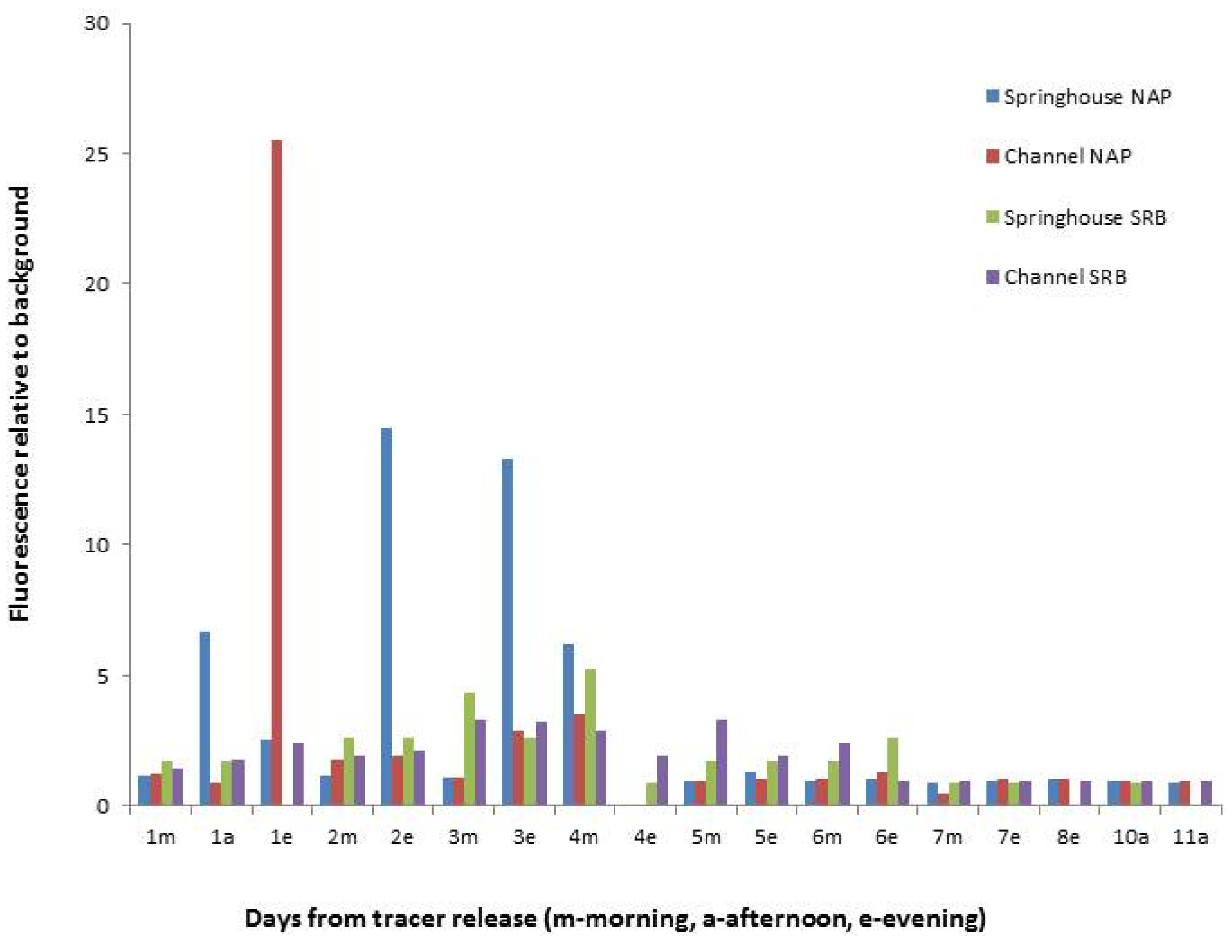


*Figure 5. Sodium naphthionate (NAP) broke through intermittently between days 1 and 4 in major springs of Bullshead Spring Branch following release into the strongly faulted Rockdale Run Formation of the valley center, about 5 km (3.1 mi) away. The trace was repeated with a small quantity of sulforhodamine B dye (SRB), which likely adsorbed onto sediments, or possibly went to other receptor springs. Both tracers returned to background levels within one week, indicating strongly preferential flow patterns in the karst.*

to springs. Also of note is that all positive traces were detected in water at the parts per trillion level, far below visible detection, or at parts per billion level after being concentrated on activated carbon. Modern fluorescent dye tracing techniques utilize smaller quantities of non-toxic fluorescent tracers that typically result in subvisible concentrations in receptor springs in rivers. These techniques can therefore safely demonstrate actual groundwater flow patterns in karst geology for improved understanding and protection of our water resources.

## Acknowledgments

The Big Spring Watershed Association, Alexander Stewart Foundation, Pennsylvania State System of Higher Education, Shippensburg University Undergraduate and Graduate Research Programs, and Shippensburg University Center for Land Use all provided funding for these studies. In addition to assistance from the Otz family, Ashley Brookhart-Rebert was the Shippensburg University graduate student on the initial project, and Nick Crawford of the University of Western Kentucky (Crawford Hydrology Lab and Center for Cave and Karst Studies) and Tom Feeney of Shippensburg University also provided planning assistance. I thank Martin and Ines Otz of Nano Trace Technologies™ and Tom Feeney for ongoing assistance and collaboration, Shippensburg undergraduates David Miller, Jr., and Renae Saum, and former Shippensburg student Kaja Spaseff for field assistance, Robert Schott of DEP Water Quality for consideration of best fluorescent dyes to use, and two anonymous reviewers for improvements to the manuscript.

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# Core Drilling Challenges Within the Elizabethtown Quadrangle

Aaron Bierly
Pennsylvania Geological Survey

Along Aberdeen Road, a rural road just outside of Elizabethtown, Lancaster County, is a hayfield with swallows flitting around and a rather vocal twittering kingbird. To the south, a wooded, boulder-laden hillside rises, supporting scattered residential dwellings, and looking north, gently rolling knolls of farmland plunge toward Conewago Creek. This was the site I chose for my very first core drilling operation, for under the sod I hoped to capture an interesting story that started close to 230 million years ago. I calculated that within this hayfield I could core 1,700 feet through the Triassic New Oxford Formation and possibly encounter tongues of the Gettysburg Formation, which would grade into a series of metamorphic rocks whose source of alteration was a diabase sill dipping to the northwest. I would be able to study these rocks by examining the core obtained from drilling. Little did I know how defiant this innocent-looking plot of land would be.

Drilling of the core started on June 19, 2012, and encountered bedrock 12 feet down. After setting casing, coring was begun. Core recovery was difficult in the weathered sandstone, but predictable, as some of it acted like claystone and was ground to silt and carried away (Figure 1). However, significant core loss continued down to around 165 feet. Approximately 99 feet was chewed up by the core bit. An additional complication involved drilling the “red” beds, which were composed dominantly of claystone and siltstone. This stone tended to break into one- to two-inch rubble. Interestingly, the rock that was preserved in the core commonly had either a high silt content or had turned to argillite, with some evidence that we were approaching the zone of contact metamorphism, especially when a few scattered voids were filled with epidote, a metamorphic mineral.

This weathered zone and the rubbly claystone interval caused continuous trouble during the drilling operation as it caused the surface casing to slip on multiple occasions, resulting in delays. This


*Figure 1. Two boxes of core from the drilling project. Each box is two feet wide and can hold up to ten feet of core. Note that approximately 25.7 feet of core was lost in the drilling process from the core in the box to the right. The red claystone interval occurred from 84.7 feet to approximately 235 feet.*

was a looming concern throughout the project. By the end of the operation the casing, which started at 22 feet bgs (below ground surface), was only at 130.7 feet bgs.

Core recovery improved greatly with near 100-percent recovery of the rock as the fine siliciclastics became altered, occasionally to a dark-gray hornfels that sometimes resembled aphanitic diabase (Figure 2). However, the presence of high-angle joints within these brittle rocks (Figure 3) caused some delay; the average drilling run was only 6.4 feet before the inner barrel would get blocked up because the core inside slipped along these joints, rotated, and jammed. In some instances, fractures were so abundant that much of the time at the site was devoted to reassembling the core (Figure 4).

*Figure 2. Hornfels from approximately 327.0 to 337.6 feet.*

At approximately 425 feet the last major barrier occurred because the New Oxford sandstone had been completely converted to a light-gray quartzite. Not only did the fractures continue to haunt us, but the increased hardness of the rock made it significantly more difficult to drill. At least one drill bit was destroyed and several others would not cut for very long. Only 30 feet drilled in a day was not uncommon, whereas the expected length drilled in a day was maybe 100 to 150 feet. Due to this slow pace and the need for a specialized drill bit it was decided to end drilling at 577.0 feet (short 1,123 feet from our intended goal) on July 23, 2012.

Unconfined compression strength tests were performed and analyzed by the Pennsylvania Department of Transportation on two of the quartzite samples after the end of the drilling. The first sample was taken at 492 feet and had a strength of 19,640 psi (pounds per square inch). The second sample was taken near the bottom of the hole at 566 feet and had a reading of 40,960 psi. These results are much higher than the expected strength and help explain why drilling was so difficult through this unit.

Being new to the bureau and new to core drilling, I found this to be more of a learning experience than I had hoped for. Despite the many pitfalls, the project was not a failure. My initial questions were never answered, but the complications do give insight for future core drilling projects that may provide a similar scenario. The core also revealed many interesting properties of the Triassic strata that were


*Figure 3. Core interval 328.3 feet to 337.6 feet. Medium dark gray hornfels; note the high-angle fracture containing calcite in the middle core segment.*

*Figure 4. All of the 2012 bureau interns in the Middletown office received the opportunity to assist in the Elizabethtown core drilling project. In this case, intern Rick Kaiser is reassembling core. Note the 15 rubber bands (arrows) that Rick has already placed on the core to keep the densely fractured rock intact.*

not observed during mapping, and the fact that more than 400 feet of core was indeed recovered should not be overlooked. Perhaps there are clues within these samples that will reveal a new chapter to Pennsylvania's geology.

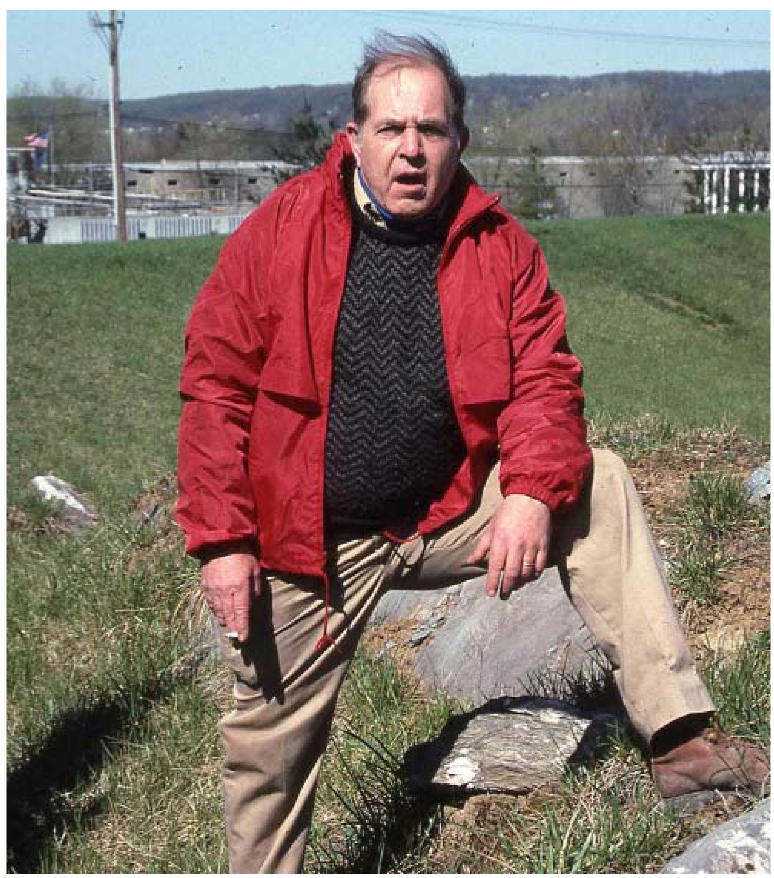
IN MEMORIAM

# David B. MacLachlan, A Geologist's Geologist 1931–2012

David B. MacLachlan served in the Geologic Mapping Division of the Pennsylvania Geological Survey for 37 years. Most of his geologic work focused on the geology of Precambrian through Mesozoic rocks in southeastern Pennsylvania, especially the various complex nappes, thrusts, carbonate valleys, and areas where these features interacted to influence groundwater depth and yield. He died at his home in San Francisco, Calif., on September 2, 2012, at the age of 81.

David, known more widely among his geological coworkers as "Mac," was gifted with a powerful intellectual mind. He was certainly already gifted when he entered Williams College, Boston University, and Columbia University and availed himself of classical as well as geological studies. He was also a Korean War veteran, having served in both the Marine Corps and the Army.

Most often, Mac's brain was attracted to complex structural geology problems that he himself recognized. Many of these problems had not been previously tackled and some were not even noticed prior to his grappling with their solution. So respected was Mac that others who had unsolved geologic problems of their own took them to Mac for solution. Mac preferred that you provide him with an excellent outcrop and your own interpretation. Also desirable was that the outcrop clearly demonstrate more than one period of deformation or a process unexpected at that locality. He would then examine all the evidence for himself, from hand-lens scale to map scale, and make a pronouncement. These pronouncements tended to be loud, well organized, and, for some, terrifyingly honest. Those who accepted and even sought his opinions tended to advance their geologic skills. Those who clung to their less well-thought-out hypotheses might be in for a bit of a well-intended but ferocious onslaught at some unanticipated future time.



Bob Smith (former staff geologist, now retired) had the advantage of carpooling with Mac for over a decade. One morning when Bob picked up Mac at his home, Mac was unusually happy. Williams College had recently polled his graduating class to determine their incomes decades later. Mac was pleased to discover that he was not at the bottom of the list because one of his classmates had entered into religious life and taken a vow of poverty. Bob soon learned not to discuss politics with Mac while either one was driving. Discussing geology was a somewhat safer topic, but not entirely without its hazards, as Mac rapidly drew complex geologic cross sections in the air with a lit, hand-rolled cigarette while driving a standard-shift vehicle.

It came about that Bob became less apprehensive about tapping Mac's intellect. Mostly by serendipity, Bob had stumbled across and recognized wildflysche (a tectonically induced chaotic submarine sedimentary breccia deposit) in the east end of the Cornwall open-pit iron mine. Mac was more than happy to see it and did confirm that that it was wildflysche. Likewise, when Bob thought he might be seeing a brittle Mesozoic overprinting on ductile Alleghanian faulting in the Tunnel Hill-Jacks Mountain fault system of Adams County, Mac was glad to examine it and confirm what was in this case Bob's very tenuous interpretation. And so it went with a few other key exposures that Bob found and many more that were brought to Mac's attention by other geologists, mainly, but not limited to, those of the Geologic Mapping Division.

Mac did not take the simple approach to any problem, but usually looked at the big picture and considered every possible piece of evidence. John Barnes, staff geologist, discovered this one day when he asked Mac how his project in Berks County was progressing. Mac answered by presenting a complete geologic history of the area that he was studying, starting with the Big Bang and progressing through time and space to present-day Berks County. Former Survey geologist Bernie O'Neill recounted how he had shared a room with Mac for a period, and how during that time Mac had literally worn out a rug by pacing while he thought through all aspects of a problem, likely literally looking at it from all directions as well as weighing all the evidence for and against each model. Unfortunately, this extreme anguish in coming to the most nearly correct model based on the available data also made Mac difficult to supervise.

It was not uncommon for Mac's supervisor and friend, Sam Root, to go along on the field proof tests. Sam and other supervisors after him were friends with Mac, but they were also held accountable if he failed to deliver a required product within the approved schedule. The best they could do was to go into the field with him to learn what he was thinking, and then try to prod him along with his already favored hypothesis. This is not to say that Mac did not produce many carefully done and accurate geologic maps that are used today to support resource utilization, including groundwater development, only that it was difficult on the friends who had to supervise him to get products out in a timely manner.

One classic example came about during preparation for the 1991 Field Conference of Pennsylvania Geologists in the South Mountain anticlinorium. Sam Root, Bob, and Mac were tasked with coming up with a summary of the structural geology of the South Mountain anticlinorium of Adams, Franklin, and Cumberland Counties. For a day or two a week over a couple of months, Sam, with some input from Bob on the Catoctin Metabasalt and Catoctin Metarhyolite, which he had just begun looking at, cobbled together a guidebook-quality paper for the field trip. At each stage, Mac was asked to provide his insight and input, but he was not able to put pen to paper. The deadline came and went and Sam turned in their draft for review, providing a courtesy copy to Mac. That courtesy draft got Mac thinking in high gear about the South Mountain anticlinorium. He then spent the entire night writing a rebuttal to Sam and Bob's paper which he titled "A Tale of Two Mountains, Both South." It excoriated Sam and Bob's paper, correctly we now think, based on Bob's later finding two different Catoctin Metabasalt compositions and abundant Catoctin Metarhyolite associated with only one of them. But Mac was able to reach his conclusion without having to sledge out, prepare, and analyze dozens of metabasalt samples from over the whole area and look at their $TiO_2$ content. He merely mentally reexamined the structures he had seen and reevaluated earlier geologic mapping by previous geologists.

For supervisor and friend Sam Root as well as Bob, the paper contradicting their work was unexpected but not unappreciated. Sam just smiled and noted that he was glad that Mac had gotten some good work out. Sam saw it as part of the duties associated with both hats that he wore to expedite Mac getting the geologic thoughts in his head out to the geologic community. From there, other geologists in turn could make them available to geology students and the resulting applications to the general public. Bob saw an additional upside to Mac's rebuttal. It stands as an enduring example of Mac's writing style. Other Survey geologists, such as Rodger T. Faill, found Mac to be a helpful reviewer in that, if you got a manuscript past Mac, there was a good chance it was worth pursuing the topic.

Mac was not without his humor. After state offices had been closed for some days because of a severe winter storm and with temperatures far below normal, in the minus teens to minus twenties,[1] Bob, with some transportation difficulties, made it back to work at the Survey. This journey had included nearly a mile of walking for Bob and likewise for Mac an hour later. Once inside, Mac, dressed in the extreme winter gear that he had acquired when he was assigned to Mt. Washington in New Hampshire by the Army Signal Corps, approached Bob and, in a booming voice so that all around him could hear, jokingly queried, "So, Bob, tell me about global warming!!!"

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[1]In Bob's backyard, it was −14ºF on January 19, 1994, −16ºF on January 20, and −22ºF on January 21.

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*—Robert C. Smith, II, and John H. Barnes*

## IN MEMORIAM

# Robert W. Metsger
# 1920–2012

Robert W. Metsger, longtime friend of the Pennsylvania Geological Survey and retired geologist from the New Jersey Zinc Company, passed away on March 30, 2012, shortly before his 92nd birthday. Most geologists may remember Bob for his generous welcoming of students and professionals on field trips to the Friedensville mine in Pennsylvania and the Franklin and Sterling Hill mines in New Jersey. Bob also lectured at numerous colleges and universities, and served on thesis committees at Lehigh University.

*Robert Metsger (right) and an unidentified field trip participant.*

Although he worked in mining, his geologic interests were broad, and he maintained many academic contacts. He worked within his own community and other areas to address geoenvironmental issues, including the Tocks Island Dam proposed project, creative reuse of closed quarries, tremolite (asbestos) contamination, and effects of lead from the Palmerton, Pa., zinc smelter. Bob engaged academic colleagues to cooperate in research, for example, hosting a deep seismograph from Columbia University 1,850 feet below sea level in the mine at Ogdensburg, N.J. In Pennsylvania, he worked on karst issues in the Saucon valley related to the Friedensville mine, cooperating with the U.S. Geological Survey and the Pennsylvania Geological Survey.

Bob was an active member or fellow of the Field Conference of Pennsylvania Geologists, the Geological Society of America, the Society of Economic Geologists, and the American Institute of Professional Geologists. A more extensive memorial will be available on the Geological Society of America's website.

*—Helen L. Delano*

SURVEY NEWS

# American Association of Petroleum Geologists Honors Kristin M. Carter

John Harper
Pennsylvania Geological Survey

Kristin M. Carter, supervisor of the Petroleum and Subsurface Geology Section in the Pittsburgh office of the bureau, received the prestigious 2012 Meritorious Service Award from the American Association of Petroleum Geologists's (AAPG) Division of Environmental Geosciences (DEG) at the annual Eastern Section meeting in Cleveland, Ohio, in September. Kris had worked in the environmental geology field before coming to the bureau in 2001, and she and her staff have researched and extensively aided in the pursuit of geological carbon sequestration through the Midwest Regional Carbon Sequestration Partnership since its inception in 2003. Current studies also include research into the geological and environmental impacts of shale-gas drilling.

*Kristin Carter receiving the 2012 DEG Meritorious Service Award from the AAPG Eastern Section President, David E. Harmon.*

Kris quickly learned the ropes at the bureau and gained both experience and expertise in computer mapping, Appalachian basin geology, and applications of Pennsylvania's oil and gas data. She has a keen interest in oil-industry history and has written papers on a variety of historical topics for the *Oilfield Journal*, *Oil-Industry History*, and *Pennsylvania Geology.* She also serves as an advisor to the Board of Directors of the Friends of Drake Well, Inc., at the Drake Well Museum in Titusville, Pa.

Kris received her award primarily for serving in an exemplary manner as Editor-in-Chief of *Environmental Geosciences*, DEG's internationally acclaimed environmental journal, as well as chair of the DEG Publications Committee, since 2010. She has even engaged some of the Survey's student interns in DEG by having them write articles and serve as student editors of the DEG's newsletter. After all that, she might have rested on her laurels, but instead has just accepted reappointment to an additional two-year term. This kind of responsibility requires a significant amount of personal time, but Kris's energy is boundless. Through her efforts, Kris has brought national recognition to the Eastern Section of AAPG. These few examples serve as a testament to her commitment to environmental geology, environmental and geologic education, DEG, and *Environmental Geosciences.*

Her award reads, "In recognition of outstanding leadership and excellence in service to environmental geology and the goals of the Division of Environmental Geosciences, including serving as Editor-in-Chief of *Environmental Geosciences.*"

Congratulations, Kris!

# New Interactive Geologic Map Goes Online

Part of the Pennsylvania Department of Conservation and Natural Resources' website is a web mapping application that focuses on recreation and public-interest topics. The Pennsylvania Geological Survey's interactive geologic map is a recent addition to this data-sharing application and joins the State Park and State Forest themes that were posted earlier this year. Presented is a colorful version of the statewide bedrock geology that, with a click of the mouse, provides users with a brief description of the rocks under their feet (see sample, below). Similarly, users can interact with the display to see the magnitudes of earthquake epicenters that were recorded in Pennsylvania and surrounding areas from 1724 to 2003. Other accessible information includes descriptions and photographs of scenic geologic features (plus driving directions), publications about the geology of selected state parks, and the southern limit of the last glacial advance into the state, which was reached approximately 20,000 years ago. Users can find this map at www.gis.dcnr.state.pa.us/maps/index.html?geology=true.

Not forgetting the topographic portion of our mission, visitors to the map can select and zoom to the highest elevation point in each county or see and read about the physiographic subdivisions of the state. The topographic high points were picked from a statewide digital elevation model created from lidar-derived data that were collected as part of the PAMAP program (for an explanation of the PAMAP program, visit www.dcnr.state.pa.us/topogeo/pamap/index.aspx).

All of the geologic data presented on the department's interactive map can be searched geographically or by name and extracted to GIS or AutoCAD formats, or to Google Earth. PDF files of the map displays can be created and saved.

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