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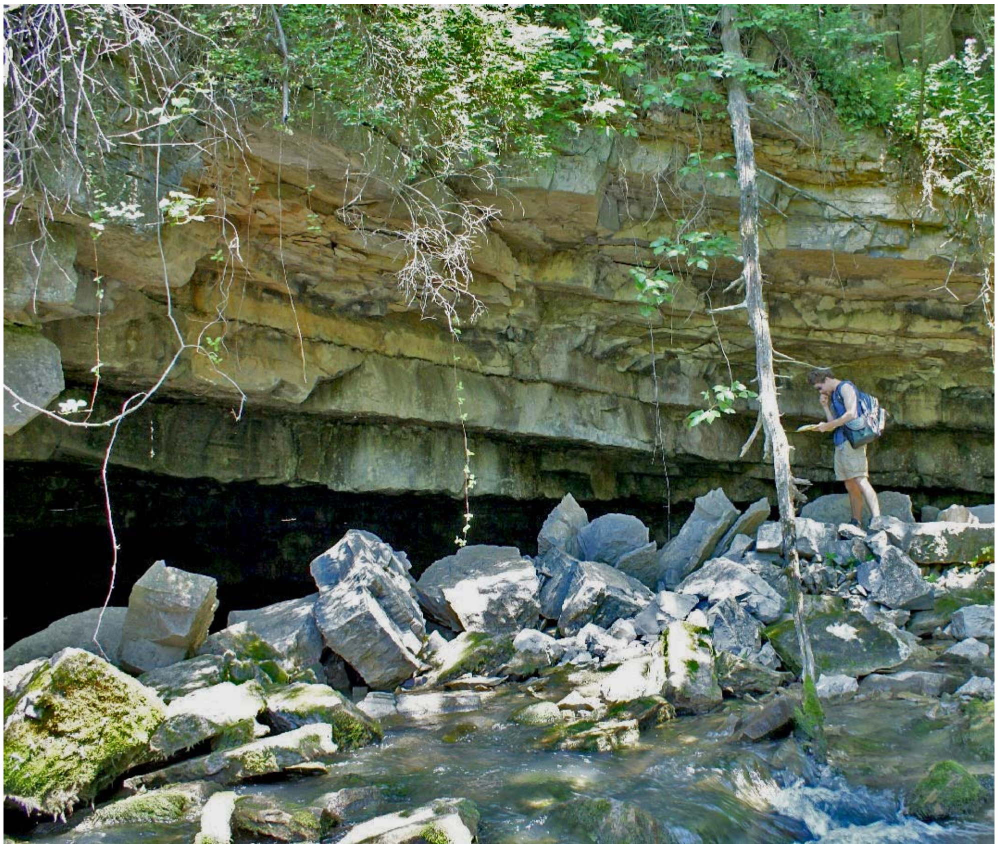


Mammoth Spring in Mifflin County is Pennsylvania's third largest spring (see article on page 15). Discharging from a cave opening in Ordovician Benner and Loysburg limestones, the wet cavern was discovered by early settlers in the region, but it was not until 1926 that two boys discovered a dry cave about 400 yards upstream from the spring discharge point. Both the dry and wet caverns were open to the public in 1929 under the name of Alexander Caverns. Today, Alexander Caverns is not a commercial cave, and access to the caverns is not permitted. From Geyer and Bolles (1979).

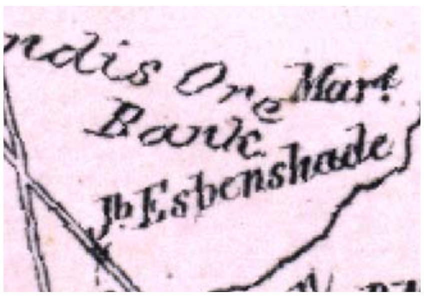
—Photograph by Kevin Tarbert, former intern at the Pennsylvania Geological Survey, 2007.

EDITORIAL

The Value of History (Or Don't Be a Goldfish)

Jay Parrish, State Geologist
Pennsylvania Geological Survey

Recently I got a call asking about a Lancaster County property where unexplained voids were appearing. I took a look at the 1864 *Atlas of Lancaster County, Pennsylvania* by H. G. Bridgens, and here's what I saw:



Between the homeowner's name and location names was the notation "Ore Bank." If no one had recorded that this was how the land was used in 1864, we would be wondering today why there were unexplained voids on the property.

In this issue, you will see an article about the Marcellus. We get a lot of questions about this unconventional gas-producing formation from the general public. Our job includes making geologic data available to the public.

Years ago we mapped the Marcellus. Recently, we produced lidar data for the state. Both forms of information have been put to use by landowners and exploration firms. Had we not created those datasets, we would have had nothing to offer when the wave of interest occurred over the Marcellus.

Likewise, whatever data we collect today will be the baseline data for "before Marcellus." Aerial photography and lidar are obvious choices, but we are also collecting seismicity data to create a baseline of what is normal when it comes to seismicity in Pennsylvania. While some may say we already have seismic data, consider that it is highly biased toward urban areas. For the first time PASEIS, our seismic network in partnership with Penn State, will be collecting data in rural areas.

We can't always anticipate what data will be of interest. Lidar was originally seen as primarily a boon to FEMA and county governments. Instead, the primary users have been gas companies.

At times you may find a friend or neighbor who does not understand the value of some geologists collecting information. Or you might question the geologist as to why he or she spends so much time looking at rocks that are of no apparent interest. We have a long history. Had our predecessors not mapped the Marcellus, today we'd be far behind in what has become a rush for data.

History is important. Without it, everything is the present, and we end up being like a goldfish, a creature that has been said to have a memory of just a few seconds. We never know what might be terribly valuable information. Only by studying the earth and preserving the data can we hope that what we have collected will be of use to future generations.

Geochemistry of the Marcellus Shale—A Primer on Organic Geochemistry

Jaime Kostelnik, Senior Geologic Scientist
Pennsylvania Geological Survey

The Marcellus Formation (informally called Marcellus shale) is causing quite a stir in Pennsylvania these days. From newspapers to radio and television, everyone is talking about the 385-million-year-old black shale layer sitting about a mile below Pennsylvania's landscape that has the potential to provide a huge amount of natural gas to the commonwealth and our country for many years to come. Even so, a look underground shows us that the Marcellus is not the only black shale unit underlying Pennsylvania, and it's certainly not the thickest.

The lowermost formation of the Devonian-age Hamilton Group (Figure 1), the Marcellus shale is mostly fine grained, black in color, and contains abundant amounts of organic material making it geologically prone to producing hydrocarbons. Not every shale is created equal, and not every fine-grained, dark-colored rock has the same gas-producing potential as that of the Marcellus; there are many geological and chemical characteristics of a rock unit that must be understood before the first well is drilled. So why is the Marcellus so special? Read on.

Behind every prospective natural gas or oil play there is a good source rock, and organic-rich, fine-grained shales like the Marcellus are the best in Pennsylvania. Petroleum geochemistry is used to evaluate these source rocks and to determine if the rock has produced oil and gas in the past or if it has the potential to produce these in the future. Understanding the geochemical characteristics of the Marcellus shale is an extremely useful tool for predicting the best spots in Pennsylvania for drilling and development. Geologists consider many things when assessing the likelihood that a rock will produce oil and gas, such as depth, thickness, and attitude (whether or not it has been faulted and folded). Geochemistry is an additional element useful for determining the likelihood that oil and gas will be discovered in a particular location. Understanding the geochemical transformations that occur in organic-rich rocks isn't magic, but the process requires a special recipe that includes the organic matter in a rock and "cooking" it into the oil and gas that we drill for today.

Petroleum Systems

The essential elements of a petroleum system are the source rock, reservoir rock, seal rock, and overburden rock (Magoon and Dow, 1994). A *conventional petroleum system* is made up of distinct units: (1) the source rock, an organic-rich rock layer that produces oil and/or gas, (2) the reservoir where the hydrocarbons are stored, and (3) the cap rock or seal, which is an impermeable layer that keeps the hydrocarbons in the reservoir from escaping. The hydrocarbons eventually migrate out of the source rock into the reservoir and are trapped by the cap rock (Figure 2). Conventional oil and gas plays occur in isolated reservoirs associated with stratigraphic or structural traps. The Lower Devonian Oriskany Sandstone is a good example of a conventional reservoir in the Appalachian basin.

In contrast, the Marcellus shale is considered to be an *unconventional petroleum system* in which the reservoir, the seal, and the source rock are one and the same. Unlike the discrete occurrence of *conventional petroleum systems*, unconventional petroleum systems typically consist of blanketlike deposits covering large areas of the subsurface (the U.S. Geological Survey calls them *continuous*

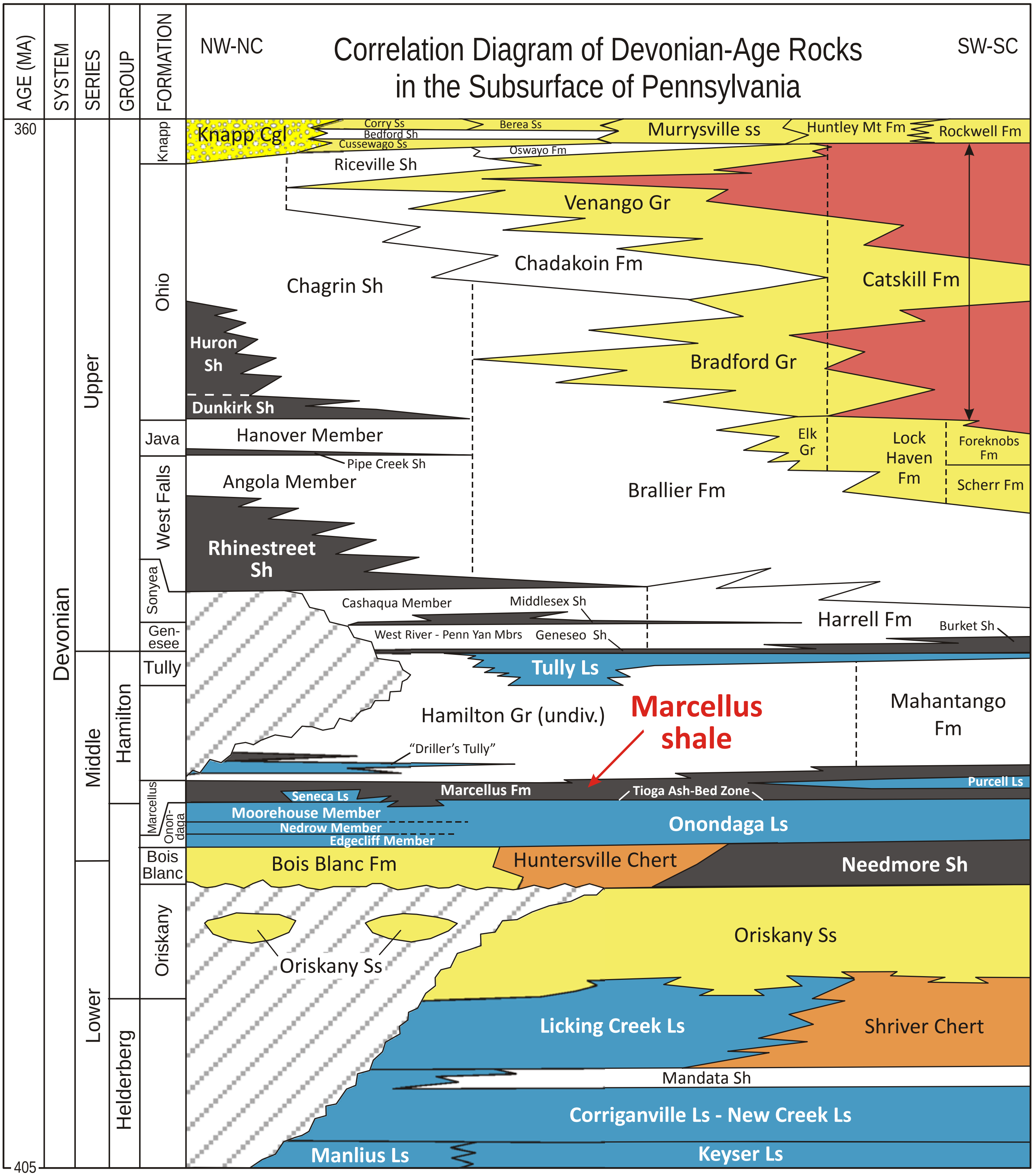


Figure 1. Generalized stratigraphic column of Devonian-age rocks underlying western and central Pennsylvania. Organic shale units are shown in dark gray, and the Marcellus shale is indicated with a red arrow. Modified from Carter (2007).

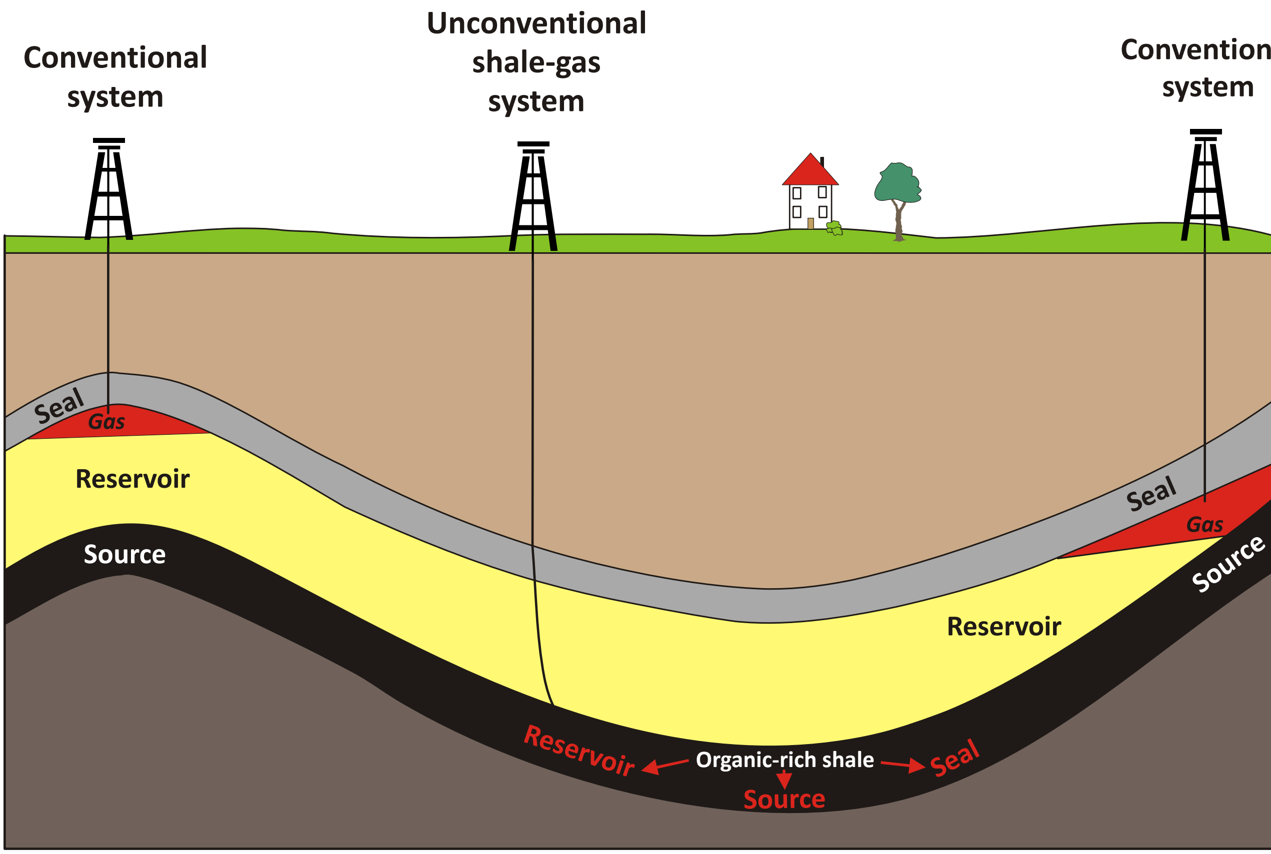


Figure 2. Schematic diagram illustrating the elements of a conventional petroleum system and an unconventional shale-gas petroleum system. Modified from Schmoker and Oscarson (1995).

petroleum systems). Usually, there is not a well-defined trap or seal rock recognized in these systems, and permeability (the connected open space in the rock) is typically very low (Schmoker and Oscarson, 1995). Hydrocarbons are generated from organic matter within the shale and do not migrate far from the source rock; they are trapped in micropores and rock fractures. Although successful development of the Marcellus shale gas play requires an understanding of all components of the unconventional petroleum system, this report focuses specifically on evaluating the Marcellus shale as a source rock and on its likelihood of producing hydrocarbons.

Evaluating the Petroleum System

How deep is the rock unit? How thick is the rock? Does it underlie all of Pennsylvania? How much porosity is available in the rock to hold hydrocarbons, and how easily do those hydrocarbons move through the reservoir? What is the mineral composition of the rock? Has the unit been fractured, faulted, or folded? These are just some of the questions that must be answered when evaluating the quality of a conventional natural gas or oil reservoir. The self-contained, unconventional nature of the Marcellus, however, requires a different approach to reservoir evaluation. Not only must we answer the questions listed above, but we must also consider the source-rock quality of the unit—the Marcellus acts as both the reservoir and the petroleum source. As a result, geochemistry becomes vital in characterizing the rock. The geochemical data tell us the quality of the Marcellus as a source rock and may be useful, when combined with other geologic data, in pinpointing the best locations for productive Marcellus drilling.

The Source-Rock Database

A source rock is any fine-grained, organic-rich rock that generates hydrocarbons upon burial. If an organic-rich rock has not produced known commercial quantities of gas or oil, but meets the source rock criteria, it is considered a potential source rock (Dow, 1977). Sediment burial is a necessary step because it allows the sediment to be subjected to the elevated temperatures necessary to convert organic material to hydrocarbons (geochemists euphemistically call this "cooking"). We evaluate a source rock by addressing three fundamental questions:

- How much organic matter is present?
- What kinds of organic matter are present?
- How mature is the rock (how much has it been cooked)?

Geologists at the Pennsylvania Geological Survey have compiled geochemical data for the Marcellus and other rock units that have been traditionally recognized as source rocks in Pennsylvania. This source-rock database can be downloaded from the Survey web site at www.dcnr.state.pa.us/topogeo/oilandgas/sourcerock_index.aspx. The data are derived from samples taken from 22 well cores and 10 outcrops of Paleozoic- and Mesozoic-age rocks from across the state. Thirteen of the cores include Marcellus shale, which was sampled from multiple depths over the entire cored intervals. Eleven of the wells are located in the Appalachian Plateau, one in the Ridge and Valley, and one in the Central Lowlands. Where the Marcellus shale was not distinguished as a separate unit, Hamilton Group data were analyzed for this paper. The well locations are shown on Figure 3, and the Marcellus data extracted from the database are summarized in Table 1.

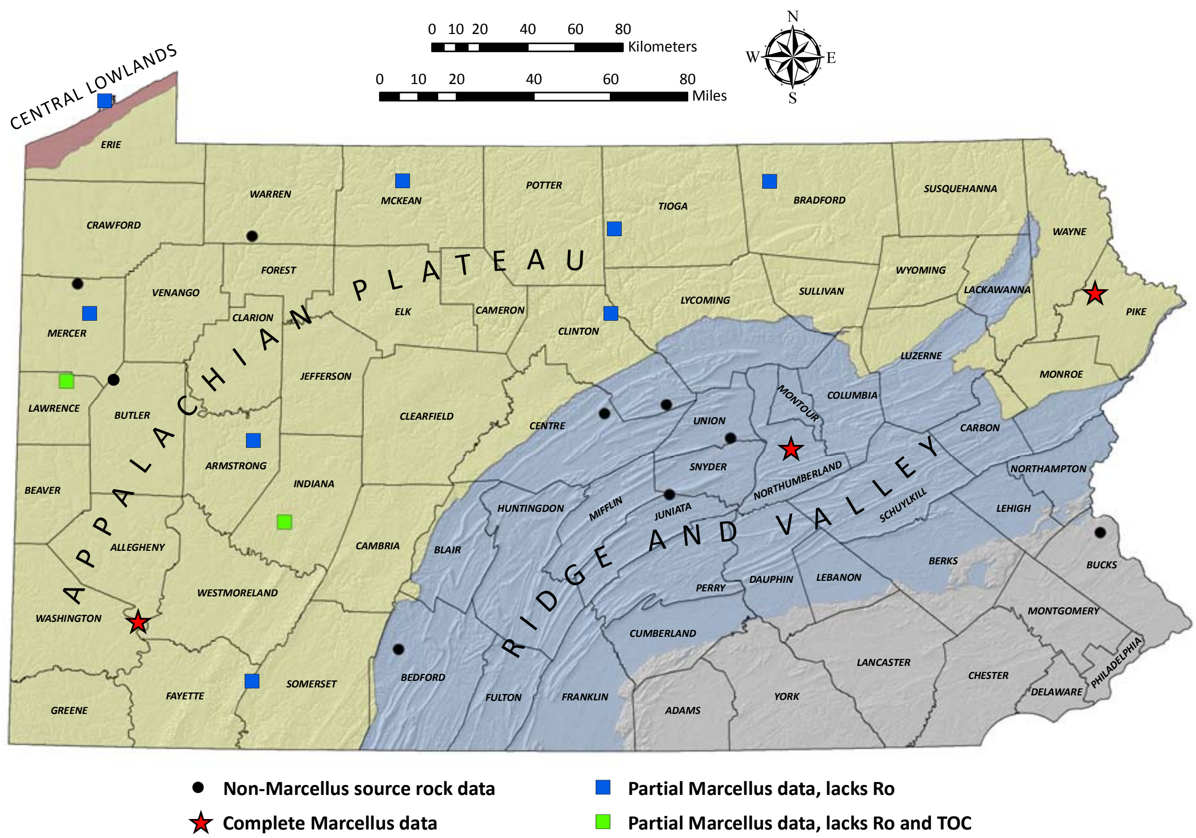


Figure 3. Locations of cored wells used in the source-rock database, including those sampled for Marcellus data.

Table 1. Summary of Marcellus Shale Data Available From the Source-Rock Database[1]
(Mean values are reported. Sample frequencies and depths vary by well.)

County	Permit number	TOC (%)	S1 (mg HC/g rock)	S2 (mg HC/g rock)	Tmax (°C)	Ro (%)	No. of samples
Allegheny	003–20980	3.34	0.68	0.16	—	2.47	7
Armstrong	005–21201	3.64	.45	.14	546	—	2
Bradford	015–20010	2.78	.38	.24	354	—	6
Clinton	035–20276	2.31	.23	.09	—	—	2
Erie	049–20846	4.85	2.84	32.60	442	—	5
Indiana[2]	063–25073	—	.05	.31	—	—	1
Lawrence	073–20022	—	14.33	45.42	438	—	1
McKean[2]	083–37291	.89	—	—	—	—	5
Mercer[2]	085–20036	1.30	.89	2.83	434	—	2
Northumberland[2]	097–20002	1.43	.39	.10	350	3.22	14
Pike	103–20003	1.24	.13	.09	352	4.57	11
Somerset	111–20045	2.89	.48	.24	335	—	2
Tioga	117–20057	3.70	.36	.09	—	—	3

[1]Abbreviations are explained in Figure 4 and in the text.
[2]Includes data from the Hamilton Group, undivided.

The majority of the measurements contained in the source-rock database were collected using a laboratory procedure known as Rock-Eval pyrolysis. The parameters measured are used to determine the quantity (how much), type (what kind), and maturation (amount of cooking) of the organic matter in the shale. This technique involves heating the rock sample in two steps. The initial heating phase releases any oil or gas that has already been generated by the source rock; the second heating converts, or “cracks,” the remaining organic matter in the rock to hydrocarbons. The amount of heat necessary to create these chemical reactions in the rock tells us something about the history of the rock and the extent of thermal maturation (cooking) it has already undergone. A third step measures the amount of CO_2 released during pyrolysis; this value is proportional to the amount of oxygen present in organic matter contained in the rock. Figure 4 is a typical graph generated by Rock-Eval pyrolysis. The parameters measured by Rock-Eval pyrolysis are indicated on the graph and defined in the caption to the figure.

Additional measurements in the source-rock database include total organic carbon (TOC) and vitrinite reflectance (Ro). TOC is determined in the laboratory by dissolving away any inorganic carbon, which is present as carbonate minerals, and measuring the organic carbon that remains. Ro is measured using reflected light microscopy. A light source is passed through the microscope, and the amount of light reflected back by the organic particles is measured by a specialized piece of microscope equipment known as a photomultiplier.

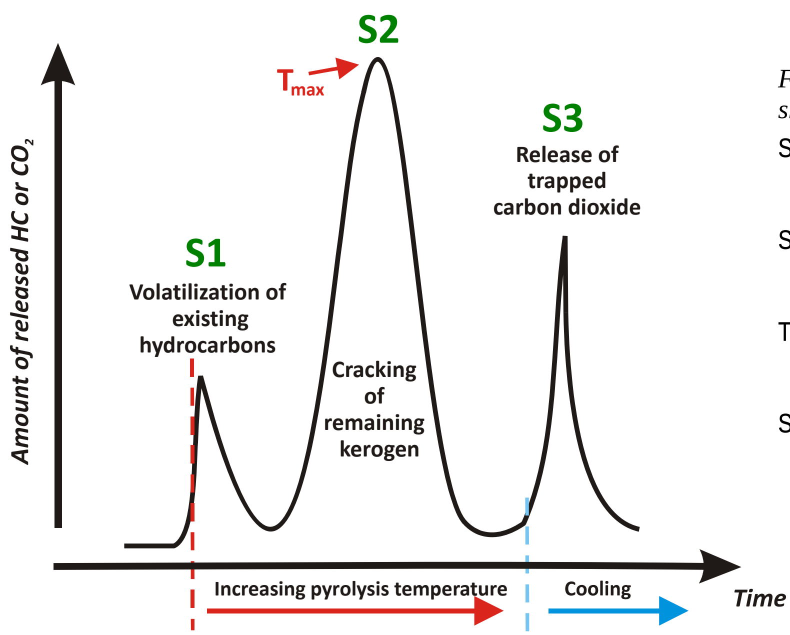


Figure 4. Typical Rock-Eval pyrolysis output graph showing S1, S2, S3, and Tmax.

S1 Curve representing the amount of existing hydrocarbons (HC) in the rock that are expelled when the rock sample is heated at 300°C for 3 minutes.

S2 Curve representing the amount of HC generated by the cracking of the remaining kerogen in the rock as the temperature is increased from 300°C to 600°C.

T_{max} Temperature at which the maximum amount of hydrocarbons is generated (corresponds to the top of the S2 curve).

S3 Curve representing the amount of carbon dioxide (CO_2) generated from the rock during pyrolysis.

Organic Carbon—How Much?

The first parameter that we measure in the rocks is how much organic matter is present. Most sedimentary rocks contain some type of organic matter; with few exceptions, economic accumulations of hydrocarbons originate from the organic matter in these rocks. Organic matter represents the remains of ancient algae, bacteria, land plants, and other once-living organisms that were deposited on ocean bottoms, mixed with bottom sediments, and over time, converted to hydrocarbons (Figure 5A). As a result, the organic material found in source rocks such as the Marcellus shale is controlled by a combination of the depositional environment and the productivity of the organisms in the ocean water. Therefore, the areas with the highest amount of organic carbon should correspond to the most productive original depositional environments. In addition to having a source of organic material, it is important that the environment be anoxic (oxygen deficient), a condition necessary for preserving the organic material (Hunt, 1996). The organic material becomes a part of the rock record when it is buried by new sediments that are transported into the depositional environment. This increase in sedimentation or settling of new layers is controlled by changes in sea level and tectonic (mountain-building) events. Mountains act as a source of sediments when they erode and are washed into the sea. As the sea fills with sediment, the organic layer moves deeper and deeper into the ocean floor and eventually begins undergoing the chemical reactions that are only possible at temperatures and pressures higher than what we observe at the surface of the earth (Figure 5B).

The organic richness of a potential source rock can be measured directly as the rock’s TOC (Jarvie, 1991) and is reported in weight-percent carbon (e.g., 1.0 percent TOC means there is 1 gram of organic carbon in 100 grams of rock sample). TOC is a very useful “first-pass” predictor of a rock’s petroleum-generating potential. Rocks with less than 1.0 percent TOC are generally considered “lean” and are unlikely to produce hydrocarbons (Peters and Moldowan, 1993; Hunt, 1996). Shale units throughout the world average 0.9 percent TOC, whereas shale source rocks average 2.2 percent TOC (Miles, 1994).

Our geochemical database includes Marcellus TOC data for 11 wells in Pennsylvania (Figure 3). The data range from a mean of 0.89 percent in McKean County to a mean of 4.85 percent in Erie

County, having an overall average of 2.58 percent. The Marcellus is a known source rock in Pennsylvania, so it is not surprising that it measures greater than the 1.0 percent TOC cutoff at nearly all locations (Laughrey and Baldassare, 1998).

In the absence of TOC data, the S1 and S2 Rock-Eval parameters indirectly measure both the quantity of organic matter in the rock and its generative potential. S1 and S2 are reported in milligrams (mg) of hydrocarbon per gram (g) of dry rock. Minimum values of S1 = 1.0 mg/g and S2 > 5.0 mg/g are necessary for a source rock to be considered as having adequate generative potential (Peters and Cassa, 1994). Marcellus S1 and S2 values are summarized in Table 1. Although most of our S1-S2 values do not meet the criteria above, the TOC values are good and more indicative of the potential.

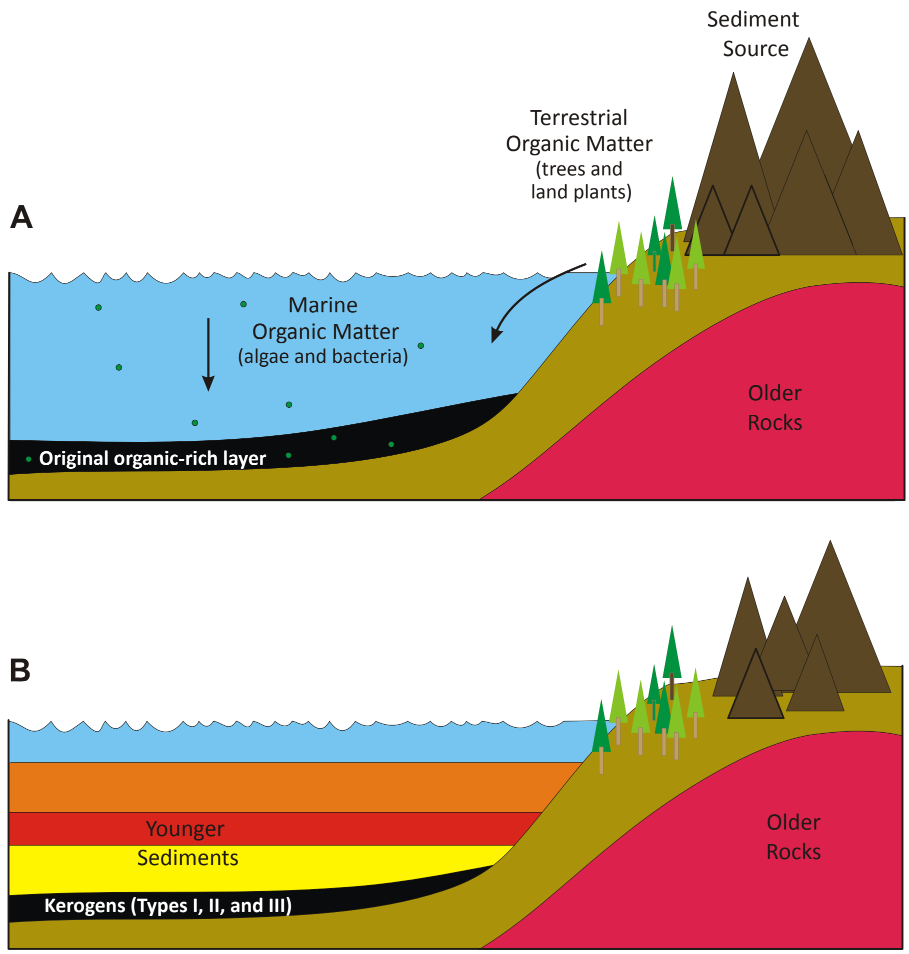


Figure 5. A. Potential sources of organic matter deposited with the Marcellus shale. B. Over time, original organic material is buried by younger sediments, and the organic matter is converted to kerogen. The type of kerogen that forms depends on the source of the original organic material.

Organic Carbon–What Kind?

After determining if TOC is adequate for the rock to be considered a potential hydrocarbon source, we must also characterize what type of organic matter contributes to the TOC. The type of organic matter depends on the environment of deposition and will determine what types of hydrocarbon can be generated. TOC is made up of both *kerogen*, which is insoluble, and *bitumen*, which is soluble. Kerogen makes up about 90 percent of the organic carbon in sediments and is ultimately transformed to bitumen, oil, and/or gas. Bitumen, which is the lesser part of the organic carbon, can also be cracked to gas.

Four different types of kerogen form from the breakdown of organic matter in potential source rocks, and they are classified based on their hydrogen, carbon, and oxygen content (Peters and Cassa, 1994). The typing is important because it gives a clue to both the source of the organic material and the type of hydrocarbons that it will likely produce. Kerogen types I and II are derived from algae and bacteria in the marine environment and are most likely to form oil. Type II kerogens occur in most of the world's source rocks (Peters and Moldowan, 1993) and account for most of the world's petroleum. Type III kerogen is derived primarily from land plants and forms gas when buried. It is common for source rocks

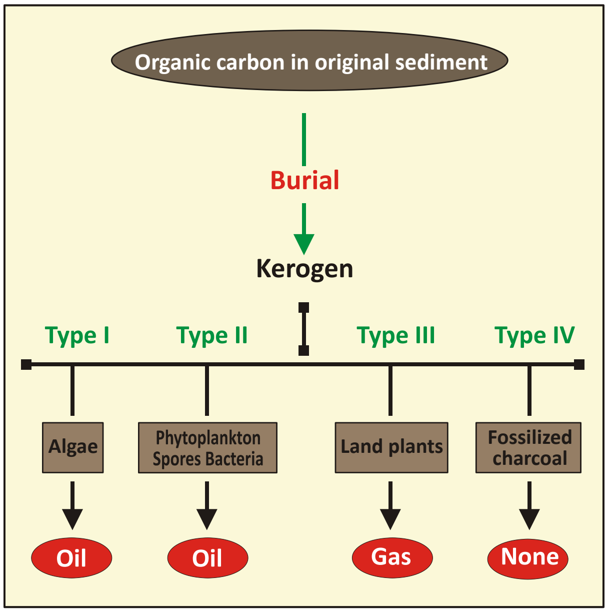


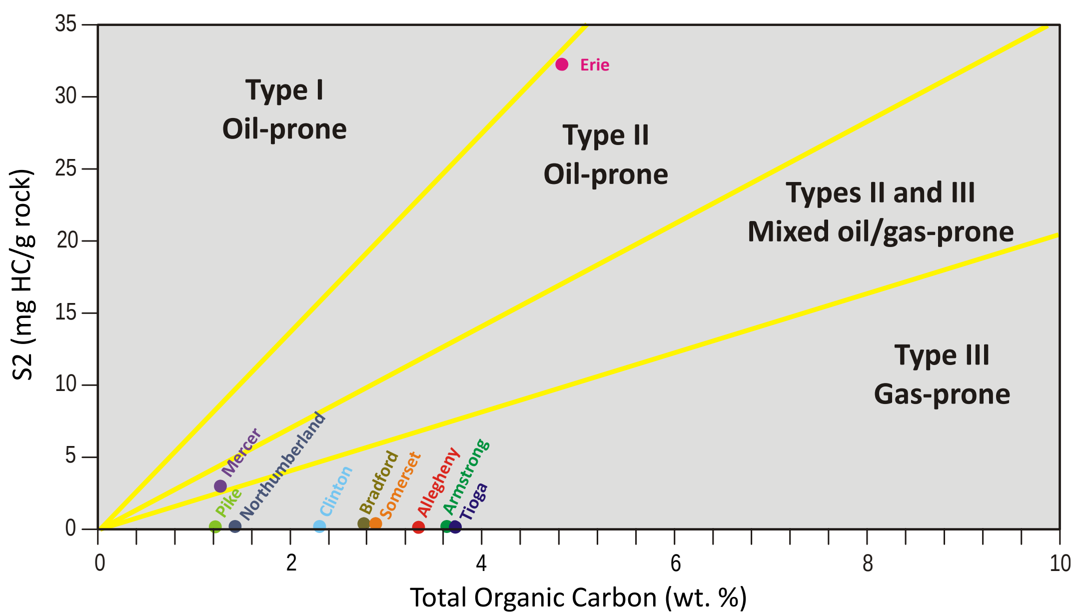
Figure 6. Kerogen types, associated sources of original organic material, and expected petroleum products.

to contain mixes of types II and III kerogen and produce both oil and gas. Type IV kerogen represents fossilized charcoal from wildfires in the geologic past and has no potential for producing hydrocarbons. Figure 6 shows the types of kerogen found in source rocks.

Kerogens can be classified using a rock's chemical composition or visual properties determined by microscopic examination. Determining the hydrogen richness of the source rock is one example of how chemical composition can be used for kerogen typing. A rock's hydrogen richness is directly related to kerogen type and thermal maturity.

Discounting thermal maturity, the relationship between hydrogen richness and kerogen type (along with the expected hydrocarbon types) can be determined graphically using S2 and TOC (Figure 7). Kerogens with high hydrogen content tend to produce oil, whereas hydrogen-poor kerogens tend to produce gas (Hunt, 1996). With the exception of those from the Erie and Mercer County wells, all of the Marcellus samples represented on Figure 7 are hydrogen poor, plotting near the x-axis. The graph indicates that all of the hydrogen-poor samples contain type III kerogens and generate gas, but because the hydrogen content of a source rock decreases as it generates and expels hydrocarbons, thermal maturity must also be considered when interpreting the graph. The Erie and Mercer County samples are less mature and plot correctly on the graph, but the higher maturity of the other samples complicates the interpretation of their data. The graph should not be used alone for kerogen typing those samples. It is always important to consider thermal maturity and use both chemical and microscopic methods when determining kerogen type.

Figure 7. Graph of mean TOC versus mean S2 showing the kerogen types associated with the organic matter in the source rock.



Thermal Maturation

So far the elements of the source rock recipe are simple—lots of organic matter from plants, algae, bacteria, and other organisms mixed in the ocean and stirred into the sediments on the ocean floor. The most important step of all comes next—cooking it all up! No matter how much organic matter is present in the rock, it is only a potential source of hydrocarbons. In order to convert the organic matter to kerogen and, ultimately, to hydrocarbons, it must be heated to the right temperature.

Maturation or cooking occurs when organic material is subjected to heat and pressure. It happens in a series of processes known as diagenesis, catagenesis, and metagenesis (Figure 8) (Tissot and Welte, 1984). Each of these steps corresponds to different temperatures, depths, and chemical alterations of the organic matter in the rock. Diagenesis starts following the deposition of the initial organic-rich sediments as they are buried by new, younger sediments. Burial continues, and eventually the sediments lithify and become part of the rock record. Over many millions of years of burial, the rock will be subjected to higher temperatures, and more pronounced chemical changes will occur during the processes of catagenesis and metagenesis.

Diagenesis occurs at temperatures less than 60°C. During this phase, organic matter is converted to kerogen. At approximately 60°C, the rock enters the "oil window," where it begins generating liquid hydrocarbons (Hunt, 1996). During catagenesis (at temperatures between 60°C and 150°C), Types I and II kerogens generate oil (Hunt, 1996). Above 150°C, the rock begins generating gas. At this point, the rock is considered to be postmature relative to oil generation (Hunt, 1996). A rock may go through any number of these stages during its geologic history. The more stages it goes through, the more complete its thermal alteration that we observe today. Temperature-dependent geochemistry parameters allow us to sort out the history of the rock and to understand how it may have been buried in the past. Its thermal maturity determines whether the rock has the potential to continue to produce oil and gas in the future, or if all of its hydrocarbons have already been expelled.

Thermal maturity can be determined chemically (e.g., using Rock-Eval pyrolysis) or visually (e.g., using a specialized microscope that measures vitrinite reflectance (Ro)). Vitrinite is a component of land plants; Type III kerogens are derived from vitrinite (Dow, 1977). Microscopic physical changes occur to the vitrinite particles as they are heated, causing changes in the way that they reflect light. Ro is a measure of the amount of light reflected from vitrinite particles in a rock sample. As the thermal maturity increases, the amount of light reflected (percent Ro) increases. Ro is the most commonly used thermal indicator in the petroleum industry. A minimum Ro value of 0.6 percent is necessary for hydrocarbon generation, and a rock with a Ro > 1.35 percent is considered postmature and will generate gas (Peters and Cassa, 1994).

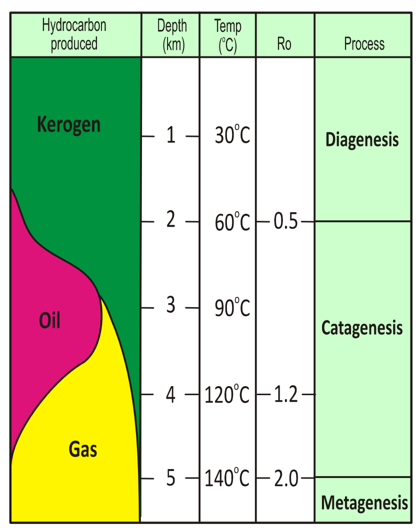


Figure 8. Graph of subsurface processes, depths, temperatures, and vitrinite reflectance values associated with the conversion of organic matter to hydrocarbons in petroleum source rocks. Modified from Tissot and Welte (1984).

T_{max} is the temperature at which the maximum amount of remaining hydrocarbons is instantaneously released from the rock during Rock-Eval pyrolysis. The higher the T_{max} value, the more mature the source rock. T_{max} values range from 435°C to 470°C for oil generation, and rocks with values exceeding 470°C have generated gas (Peters and Cassa, 1994).

The Pennsylvania Geological Survey source-rock database only contains Ro measurements for three wells located in Allegheny, Northumberland, and Pike Counties (Table 1). The mean Ro values from these wells range from 2.47 percent to 4.57 percent, indicating a postmature source rock. Repetski and others (2008) provided a comprehensive report of the thermal maturation of source rocks in the Appalachian basin. Their data included Marcellus samples from 30 Pennsylvania wells whose Ro values indicate immature, mature, and postmature levels of thermal alteration in the Devonian shales. Their data show a trend of increased thermal maturation of Devonian shales to the southwest and northeast. Their lowest Ro readings (i.e., indicating immature levels) occur in northwestern Pennsylvania and are problematic because the Devonian shales in that region are known hydrocarbon producers. Collection and Ro analyses of additional Devonian shale (including Marcellus) samples in northwestern Pennsylvania may help to resolve the cause of these anomalously low readings.

The Marcellus Shale

So how might we apply this information to gain a greater understanding of the Marcellus shale in Pennsylvania? As an example, let’s travel deep beneath the surface in southern Allegheny County where we encounter the Marcellus shale at a depth of more than 1.3 miles. Clues tell us it was once much deeper than it is today. During the Middle Devonian age (385 million years ago) at the time of Marcellus deposition, Pennsylvania along with our Allegheny County location was part of a basin developed in front of the beginnings of the growing Acadian Mountains. This foreland basin developed as the Acadian Mountains were being built up to the east from the collision of tectonic plates, including what is present-day North America. The newly forming mountains were being eroded even as they were rising, filling the foreland basin with clay- to gravel-sized sediments. These muddy sediments mixed with the remains of land plants, dead algae, and other organisms in the sea, which provided the organic content in the shale. Geochemical data from an Allegheny County well in our database indicate that the Marcellus rock has a very high production potential with an average TOC of 3.34 percent.

All of these materials, the mud and the organic debris, were subsequently buried under probably more than 2 miles of rock and sediment at some point in geologic time (Rowan, 2006). As early sediments covered the Marcellus, elevated basin temperatures and diagenesis occurred, converting the existing organic matter to kerogens. Over time, the burial depths and temperatures continued to increase, which converted the kerogens to oil and gas. In Allegheny County, the Marcellus Ro values from our well range from 2.35 percent to 2.60 percent, indicating that the rock reached a postmature state of thermal maturation and was heated to temperatures sufficient to convert any early oil or organic matter to gas. Some of this gas migrated to conventional reservoirs that occur above and below the Marcellus (for example, the Oriskany Sandstone below the Marcellus), but most of it stayed in place. As a result, after hundreds of millions of years of burial, the Marcellus shale has become the most popular exploration target in Pennsylvania and perhaps the Appalachian basin at large.

The example above illustrates how information extracted from the source-rock database can be used for evaluation of an organic-rich unit, but the database also contains a wealth of additional information that will be a valuable tool to the trained petroleum geologist. At the Pennsylvania Geological Survey, we will continue to evaluate Pennsylvania’s source rocks using the database, and at the same time, we will move forward collecting new data related to the Marcellus shale and other organic-rich rock units in the subsurface. Source-rock and thermal-maturity research efforts promise to be integral in developing a firm understanding of the oil and gas resources underlying our commonwealth.

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Geoarchaeology in York County

Rose-Anna Behr, Geologic Scientist
Pennsylvania Geological Survey

In the past couple of years, I have had the opportunity to participate in several geoarchaeology projects. Just like the name implies, it is a combination of geology, geography, and archaeology! The Bureau of Topographic and Geologic Survey has a magnetometer, which detects subtle changes in the earth's magnetic field. It is kind of like a giant metal detector but much more sensitive and powerful. We put this instrument to use at two different sites (Figure 1).

The first site studied was the York Iron Company (1854–90) mine site in P. Joseph Raab County Park, York County, Pa. The mining operation was one of the largest in the county, with open pits, adits, and shafts, and ore being transported by rail to furnaces in Ashland, Md.,

Figure 1. Rose-Anna out in the field with the Survey's magnetometer.

and Harrisburg, Pa. Since 2003, the park has organized student-run archaeological excavations to teach techniques of archaeological exploration and interpretation. More than 400 artifacts, including chisels, picks, star bit ends, shoes, and clay pipes, have been found (Figures 2 and 3).

Figure 2. Part of a miner's lamp (missing bottom) found at the York Iron Company mine site.

Figure 3. X-shaped drill bits were placed at the end of a rod, which was hammered by hand with a quarter turn between each strike. In this fashion, workers drilled holes in the rock to insert explosives. As the bits became dull, they were discarded.

Stone foundations and the hoist house floor were excavated, but the railroad from the mine to the mainline had never been found. In 2007, a magnetic survey revealed a likely location. The following summer, students unearthed a 36-foot-long standard-gauge rail, in place, 9 inches below the surface (see Figure 4). The unveiling of this standard-gauge rail is significant, in that previously only narrow-gauge rails had been found. This standard-gauge rail, installed in the later years of the mine's operation, connected to the main line of the railroad.

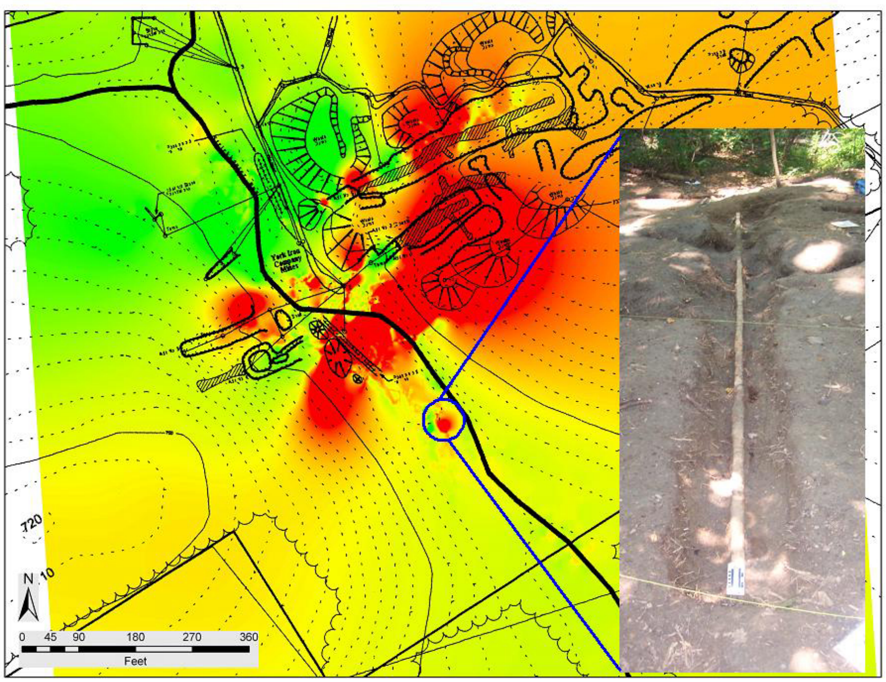

Figure 4. Map showing the magnetic anomaly in red (circled) and photograph of the excavated rail (right) at the York Iron Company mine site.

The second location was at Codorus State Park, southeast of Hanover, York County, Pa., at the former site of the Mary Ann Furnace (1762–1801). The furnace and forge made cannons and shot for the Continental Army, in addition to cast iron stoves. A field examination revealed a steep hillside high enough to have facilitated loading the furnace. Further examination revealed bits of limonite, limestone, and charcoal—key ingredients in the iron-making process. Near the base of the hill, slag fragments are abundant. This is thought to be the location of the furnace, though no foundation blocks can be seen at the surface. The magnetic survey showed a significant compact magnetic anomaly at the base of the hill where we believe the furnace sat. This may be a mass of iron, known as a salamander, which accumulated in the bottom of the furnace. This summer, student-run archaeological excavations will be conducted and may confirm the location of the furnace.

Pennsylvania's Top Ten Springs

Bill Kochanov, Senior Geologic Scientist
Pennsylvania Geological Survey

Big Spring is number 5 on Pennsylvania's list of largest springs. Photograph by Kevin Tarbert, former intern at the Pennsylvania Geological Survey, 2006.

Pennsylvania's Top Ten Springs[1]

No.	Name	County	Median discharge (gpm)
1	Nippono (Enchanted) Spring	Lycoming	18,000
2	Ruhl and Seven Springs	Centre	14,000
3	Mammoth Spring	Mifflin	14,000
4	Unnamed Spring	Clinton	13,000
5	Big Spring	Cumberland	12,500
6	Huntsdale Hatchery Springs	Cumberland	12,000
7	Boiling Spring	Cumberland	11,500
8	Arch Spring	Blair	8,000
9	Bellefonte (Big) Spring	Centre	8,000
10	Kelly Spring	Centre	7,000

[1]From Flippo (1974).

Pennsylvania is home to many springs. There are some that seep out from the ground at a very slow, almost imperceptible rate, while others discharge thousands of gallons per minute (gpm).

Springs are places where groundwater meets the land surface. The route to that discharge point typically relies on the composition and orientation of the bedrock as well as the groundwater pathways developed in the surficial materials overlying the bedrock (i.e., the groundwater needs a flow path to get from one area to another).

Pennsylvania's top ten springs (Flippo, 1974) are second-magnitude springs, and although their uses may have changed over the years, these waters are primarily used as fish hatcheries and for municipal water supplies due to their relatively consistent flow and good quality.

There are many large springs throughout the United States. Wakulla Springs in Florida, for example, is considered a first-magnitude spring, discharging 173,611 gpm or 250 million gallons per day (Florida Geological Survey, 2006). That's almost ten times the average discharge from Pennsylvania's largest spring!

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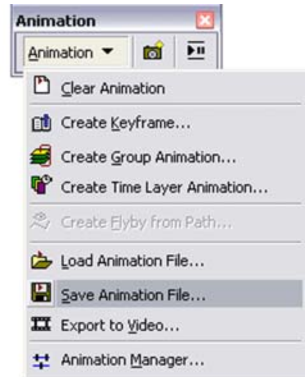
GIS CORNER

Oil and Gas Well Animation

Victoria Neboga, Geologic Scientist,
and Michael Moore, Chief of GIS Section
Pennsylvania Geological Survey

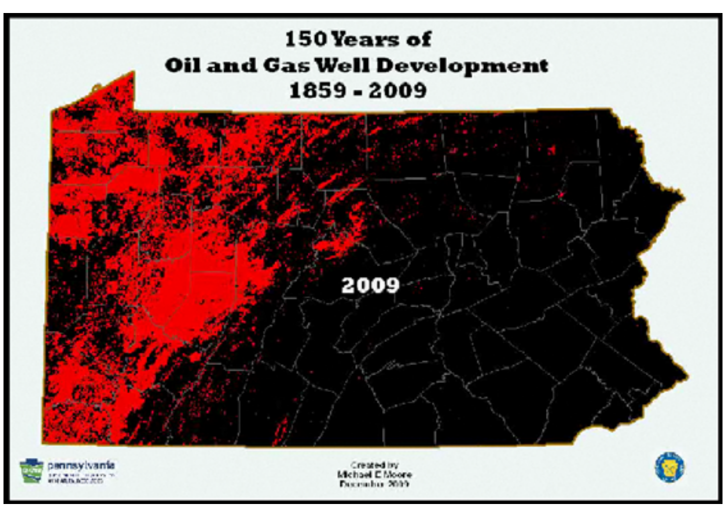


Making decisions based on geography is basic to human thinking. The radio informs you of an automobile accident, and a few seconds later, you are taking an alternate route to work. Humans routinely make decisions by applying information to a "mental map." Not surprisingly, sophisticated software programs known as Geographic Information Systems (GIS) are now available to expedite these decisions by linking information to location.

In this new feature corner of the magazine, we will look at interesting and sometimes unusual ways GIS is being used at the Survey. The example in this issue is a map that comes to life!

GIS Section Chief Michael Moore used the animation tools in ArcGIS Desktop, our GIS software, to animate 150 years of oil and gas well drilling in Pennsylvania—it begins in 1859 with the Drake Well (the world's first oil well) and culminates in 2009. He used the data in the Pennsylvania Geological Survey's Wells Information System (WIS) database to create his 30-second display. The animation adds the wells drilled each year until more than 123,000 oil and gas wells are displayed. Many of the older wells in the database had unknown construction dates. These wells were "assigned" a date of January 1, 1901, and because of this, there appears to be an abnormally large number of wells completed in the first year of the twentieth century.

You can view 150 years of Pennsylvania oil and gas development at www.dcnr.state.pa.us/topogeo/oilandgas/PA_Petroleum_Development.pdf. You will need a media player to run the animation; Adobe Flash Player is a free cross-platform application available from www.adobe.com. Once the map is displayed, press the play icon in the lower left corner to see the drilling activity. And imagine what it'll be like when updated for Marcellus drilling in a few years!



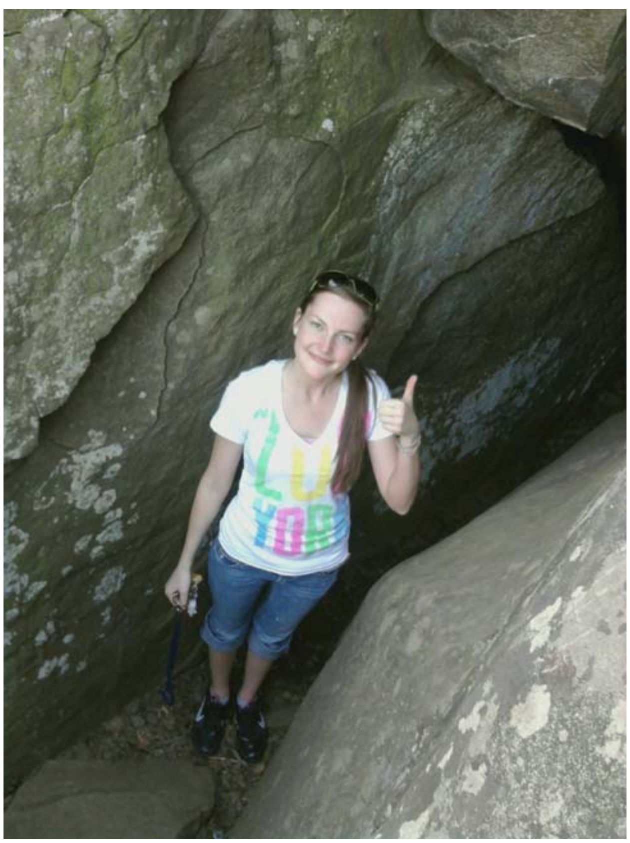
GEOHERITAGE CORNER

Devils Den

Victoria Neboga, Geologic Scientist,
and James Shaulis, Senior Geologic Scientist
Pennsylvania Geological Survey

In the summer 2009 issue of Pennsylvania Geology, we introduced you to the Pennsylvania Natural Heritage Program (PNHP) and the concept of geoheritage. In this corner, we highlight one of the more than 100 geologic sites being managed by the PNHP and our bureau.

The selected site is Devils Den, the most popular site on the Gettysburg battlefield, Adams County, Pa. In a 3 or 4 hour period on the afternoon of July 2, 1863, this broken outcrop of bare rock witnessed some of the bloodiest fighting of the battle (Inners and Smith, 2008). Each year thousands of tourists clamber over its boulders, but few probably know that these heights are the outcrops of a diabase sill, appropriately enough called the Gettysburg Sill, that intruded the Triassic sandstones and shales in Early Jurassic time (201±1.3 Ma) (Froelich and Gottfried, 1999).

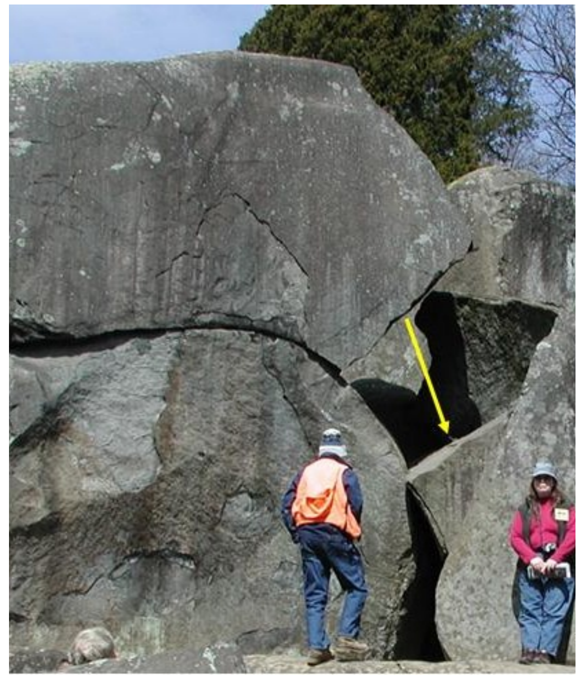


The most striking features of the diabase at Devils Den are the extensive fractures that divide the rock mass into huge blocks and the rounded rock edges caused by exfoliation.

The large diabase bodies, the most prominent of which are from the intrusive sheet of York Haven Diabase, are coarse grained and granular, and are composed of black grains of plagioclase and white and gray grains of pyroxene (Smith and others, 1975). This mineralogy is evident on weathered surfaces where the pyroxene crystals stand out in relief as the plagioclase crystals weather back. The most striking weathering feature of the diabase at Devils Den, however, is the extensive open-fracture network that divides the rock mass into huge blocks (typically with rounded edges) (Inners and Smith, 2008). The exposed diabase mass is disrupted by the gradual opening of the large-scale fractures and subsequent breakage of the rock along exfoliation surfaces. The exfoliation process is visible as rounded weathering partings (thin scales) on the surface of and several feet down into the diabase.

In the Gettysburg basin, the York Haven Diabase sheet has been estimated to be about 2,500 feet thick at the type locality (Smith, 1973). It is resistant to weathering relative to the surrounding Triassic sediments and incredibly durable. During the Civil War battle, the movements of the two armies toward Gettysburg, and the battle itself, were influenced by the geology of the region in which the campaign was conducted. Throughout the battle, the topographically prominent York Haven Diabase as boulders in Devils Den and, more typically, as field stone fences provided what little natural protection was available to the troops (Smith and Keen, 2008). The Gettysburg campaign is an excellent example of intelligent use by commanders of both armies of terrain and topography and, therefore, of geology (Brown, 1962). Today, the York Haven Diabase is a highly desired dimension stone and provides high-quality, durable railroad ballast.

A wooden bridge crosses a large, open, subvertical fracture.



The yellow arrow points to a triangular block of diabase that has fallen as a huge exfoliated sheet from the overlying rock.

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A Fond Farewell to Lynn Goodling

After 30 years of distinguished service to the people of Pennsylvania and, most particularly, to her co-workers and friends at DCNR's Topographic and Geologic Survey, Lynn Goodling has retired.

Lynn spent 22 years with the Pennsylvania Bureau of State Parks, Division of Park Operations, Program Services Section. After her distinguished Parks career, she decided to move to our bureau in August of 2002, where she took over the duties of Administrative Officer. Her can-do attitude and friendly personality soon had her involved in many functions, ranging from helping staff with job-related HR concerns to purchasing highly sophisticated laboratory equipment. She helped attract student geologists to work as interns within the Survey. Lynn was instrumental in managing the budgets for the bureau and the PAMAP program (the vehicle through which the entire commonwealth was recently photographed and measured in great detail). She processed the paperwork to fill our vacant positions and performed other personnel services as needed. Within the department, Lynn was the bureau's representative for the DCNR Safety Committee and the bureau's training coordinator. Because of her ubiquitous reach into the workings of the organization, she was known to all who had contact with the bureau. In her spare time (hard to imagine she had any), Lynn did and continues to devote her talents to the Girl Scouts.

All her friends at the bureau wish her a long and happy retirement.

SURVEY NEWS

PAMAP

New PAMAP data were released on the Pennsylvania Spatial Data Access (PASDA) web site in the beginning of this year. Both orthoimagery and lidar elevation data for Dauphin, York, Lancaster, and Lebanon Counties are now available for downloading at www.pasda.psu.edu/. These data were collected in the spring of 2008 and processing and quality assurance has recently been completed. More information about the program can be obtained from www.dcnr.state.pa.us/topogeo/pamap. The highly detailed lidar elevation data (with 3.2-foot-pixel resolution) can be used for many purposes. As it becomes available for all of Pennsylvania, we expect creative users to find as many applications as there are reasons to look at the shape of the land.

Contact—Helen Delano

Drill-Hole Database

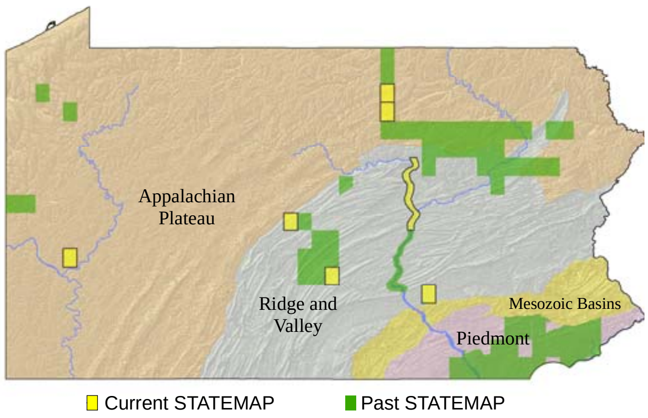
The Pennsylvania Geological Survey, in cooperation with the Indiana University of Pennsylvania, is creating a digital database of drill records and coal analyses obtained from the former Rochester and Pittsburgh (R & P) Coal Company. This information is mostly from Armstrong, Clearfield, Indiana, Jefferson, Washington, and northern Westmoreland Counties. A unique feature of this database is that it will be tied to over 85,000 scanned photographs of core, as well as to downhole geophysical logs and computer-generated strip logs. This will render the database especially useful for a myriad of stratigraphic and resource studies and as a teaching aid. When operational, the user will be able to search and download the digital files through the Survey's web site for subsequent use and analysis. The Survey's coal database is expected to be released in 2011 and will be announced on our web site.

Contact—Bill Bragonier or Gary Fleeger

STATEMAP

The Pennsylvania Geological Survey was awarded $190,582 for FY2009 under the U.S. Geological Survey National Cooperative Geologic Mapping Program (STATEMAP). The award funds ongoing geologic mapping projects in central and north-central Pennsylvania, as well as new projects in the Pittsburgh and Harrisburg areas. These projects are to be completed in the fall of 2010.

Contact—Gale Blackmer

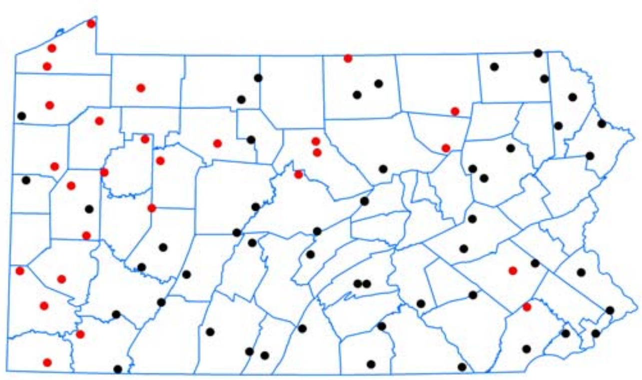


North American Soil Geochemical Landscapes Project

The North American Soil Geochemical Landscapes Project is a continent-wide sampling program developed by the Canadian, Mexican, and U.S. Geological Surveys to better define baseline values for inorganics, organics, and microbiological species in soils.

Three samples are taken from each location. A surficial sample (0 to 5 cm deep) represents the soil that humans most frequently come into contact with and is important for human health and risk assessment. Samples from the A and C horizons represent the upper soil horizon and the lower parent material, respectively. So far, samples have been collected from 50 of 77 locations, and the remainder should be completed this year. The samples were sent to the U.S. Geological Survey in Denver; from there they will go to XRAL Laboratories in Canada for analysis.

Contact—Steve Shank



Locations of collected soil samples (black), and locations of samples to be collected later this year (red).

Our New "Face"

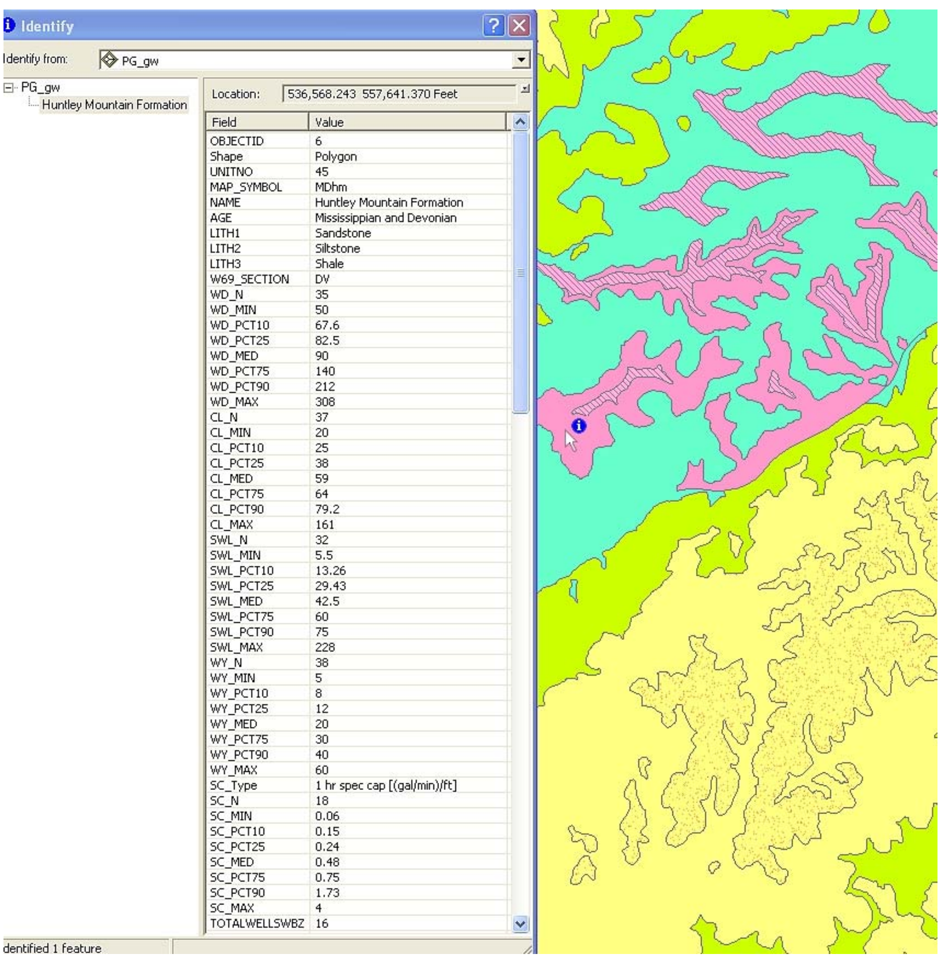
The Pennsylvania Geological Survey now has its own page on Facebook. We will be posting updates from the bureau and links to events, news stories, and other items more or less relevant to Pennsylvania and geology. If you are a Facebook user, go to http://www.facebook.com/PennsylvaniaGeology or search for *Pennsylvania Geology* and click on the link with our blue and gold logo. As our community grows, we hope to see some feedback and discussions develop.

Contact—Helen Delano

NEW RELEASES

Bedrock Aquifer Characteristics GIS Dataset

In the new release, *Digital Bedrock Aquifer Characteristics by Physiographic Section of Pennsylvania*, staff geologist Stuart O. Reese used three Survey products to merge geologic, water, and physiographic data. The first, released in 2001, is the online geographic-information-system (GIS) dataset *Bedrock Geology of Pennsylvania* (www.dcnr.state.pa.us/topogeo/map1/bedmap.aspx), which was based on and slightly modified from the second edition of Map 1, *Geologic Map of Pennsylvania*, compiled by T. M. Berg and others and published in 1980. (The printed copy of Map 1 is no longer available, but images of the map have been posted on and can be downloaded from the Survey's web site.) The water data come from Water Resource Report 69 (W 69), *Hydrogeologic and Well-Construction Characteristics of the Rocks of Pennsylvania*, by Gary M. Fleeger, Thomas A. McElroy, and Michael E. Moore. This report, which was published in 2004 on CD–ROM, is mainly a Microsoft Access database. The third product, the fourth edition of Map 13, is a page-size map published in 2000 that shows the physiographic provinces and sections in the Commonwealth of Pennsylvania.



Stuart used ESRI ArcGIS Desktop software to clip the digital bedrock geologic polygons to the boundaries of the 23 physiographic sections of Pennsylvania and then joined selected water-well construction and ground-water data for the bedrock geologic units from W 69 to the resultant polygons. The attributes (data) include quantitative information on water-bearing zones and statistical information on well depth, casing length, static water level, well yield,

Example of a portion of the digital aquifer characteristics data associated with the Huntley Mountain Formation in the Deep Valleys physiographic section.

and specific capacity. The statistical summaries include the number of water well records (10 or more required); minimum and maximum values; and 10th, 25th, 50th (median), 75th, and 90th percentiles of values.

The derivative GIS data are available for downloading as an ESRI geodatabase and as shapefiles. Metadata (information about the dataset and how it was prepared) are included with the files. The new dataset is available at www.dcnr.state.pa.us/topogeo/groundwater/dac_data.aspx. For more information, contact Stuart Reese.

Fact Sheet on Bedrock Water Wells

The Bureau of Topographic and Geologic Survey has released a new fact sheet written by staff geologist Stuart O. Reese that contains guidelines for homeowners and contractors on the construction and maintenance of bedrock water wells, the most common type of private water well in Pennsylvania. The guidelines offer ways to better protect private wells by instructing well owners on proper placement and construction. There are no state regulations concerning location, construction method, materials, yield, or water quality of private water wells. Therefore, private water well owners have to be caretakers of their own water supplies.

State law DOES require drillers to have a Water Well Driller's license and a valid rig permit, however, and drillers also must provide a copy of the Water Well Completion Report describing where, when, and how the well was constructed to both the Bureau of Topographic and Geologic Survey and the homeowner.

The fact sheet addresses siting, construction, well testing, and best practices in an easy-to-read and understandable format. It can be found at www.dcnr.state.pa.us/topogeo/groundwater/water_wells_fs_2010.pdf. For more information, contact Stuart Reese.

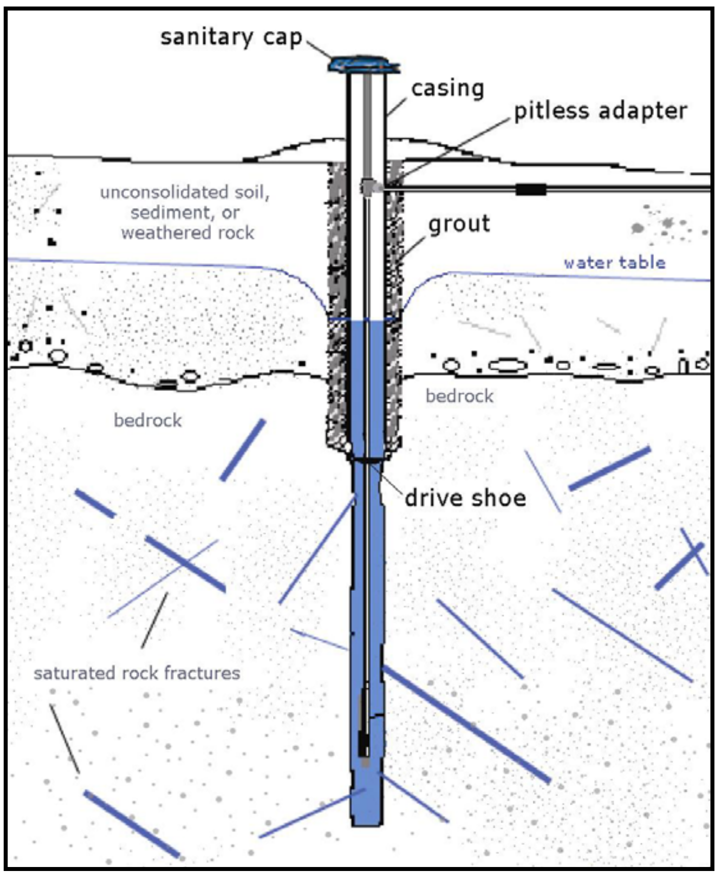


Figure from the fact sheet showing components of an open-hole water well located in bedrock.

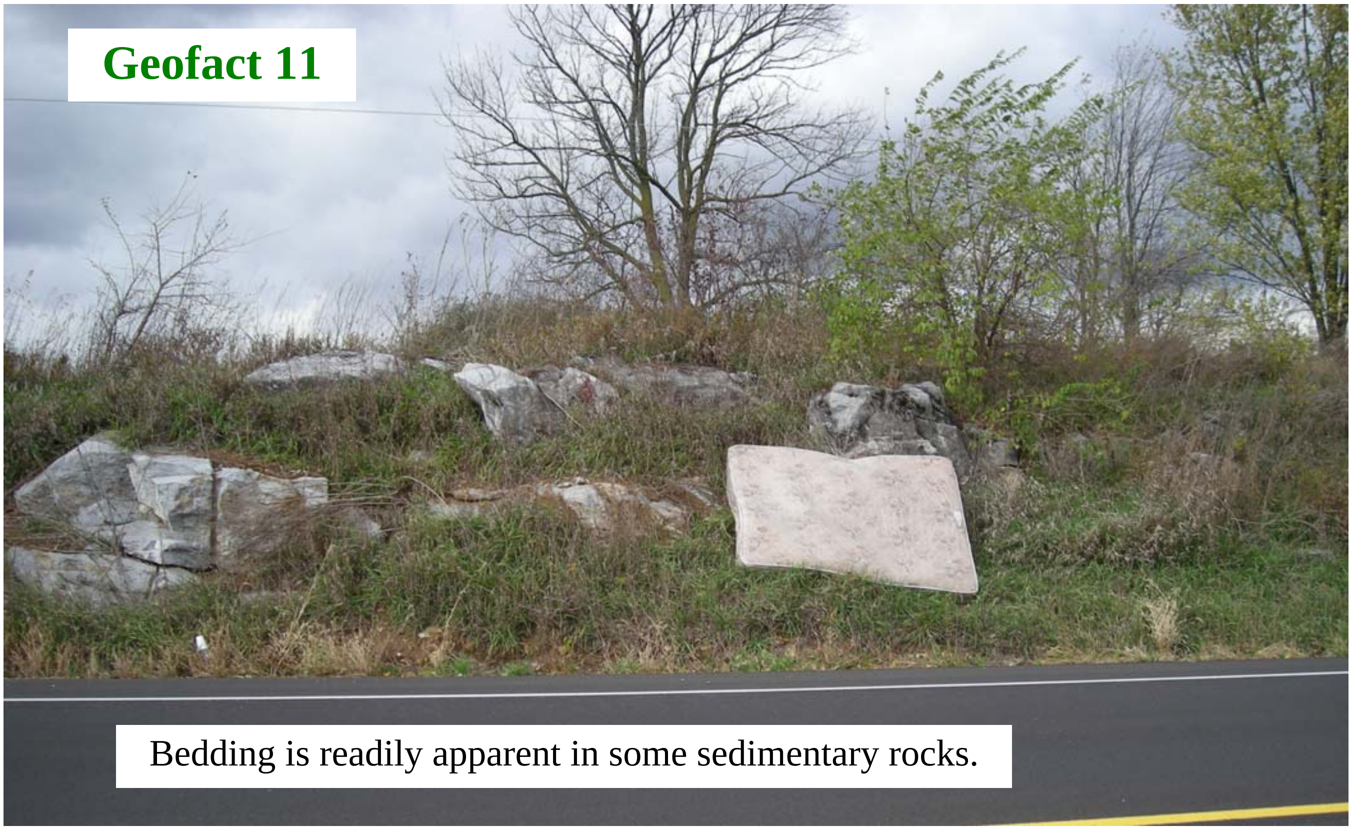
GEOFACTS

The Peculiar Habits (and Observations) of Geologists

James R. Shaulis, Senior Geologic Scientist,
and Helen L. Delano, Senior Geologic Scientist
Pennsylvania Geological Survey

Geofact 10

Even after exposure to saline brine and the application of great heat and pressure over long stretches of geologic time, rock chips still aren't that flavorful.



Bedding is readily apparent in some sedimentary rocks.

RECENT PUBLICATIONS

Pennsylvania Carbon Sequestration in the Carbon Capture Journal: **(June 2010)**

- The Bureau of Topographic and Geologic Survey's landmark reports regarding geologic carbon sequestration opportunities in Pennsylvania have been highlighted in the latest issue of the online Carbon Capture Journal.

Dataset: **(June 2010)**

- Digital Bedrock Aquifer Characteristics by Physiographic Section of Pennsylvania

Fact Sheet: **(April 2010)**

- Recommendations for construction of private water wells in bedrock

Bedrock geology open-file report: **(April 2010)**

- Bedrock Geologic Map of the Mansfield Quadrangle, Tioga County, Pennsylvania

Surficial geology open-file reports: **(April 2010)**

- Surficial Geology of the Harford 7.5-Minute Quadrangle, Susquehanna County, Pennsylvania
- Surficial Geology of the Thompson 7.5-Minute Quadrangle, Susquehanna County, Pennsylvania

Bedrock geology open-file report: **(March 2010)**

- Bedrock Geologic Map of the Kirkwood Quadrangle and Pennsylvania Portion of the Rising Sun Quadrangle, Chester and Lancaster Counties, Pennsylvania

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Contributed articles are welcome.
Guidelines for manuscript preparation may be obtained at
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