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# Pennsylvania Geology

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Image of Bald Eagle meteorite (found in Pennsylvania) on display at the William Bucknell Observatory in Lewisburg, Pa. (see article on page 3).

*—Photograph by Mark A. Brown*

EDITORIAL

# Two Facets of Earth—
# Natural Resources and Natural Disasters

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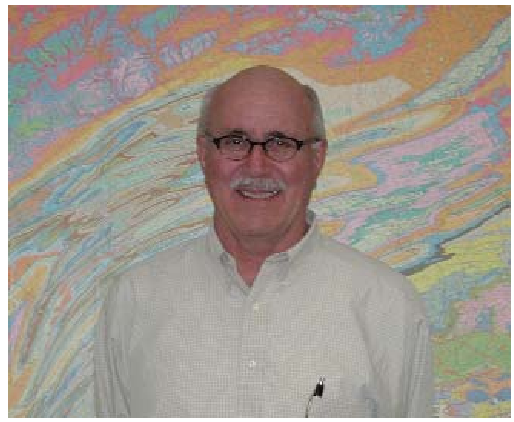

I was recently visited by a young lady in her senior year of college, a geology major, I am pleased to say. Her goal was to ask questions regarding the minerals industry, specifically, what a company should do when considering the development of a mining property. It was great fun, speculating on all the hoops a company should jump through to determine if the investment would be wise. We considered the following questions: has the company obtained all the various permissions, from environmental to political; is the market sound; what is a sound market; can the material be produced for a reasonable price and sold to render a "fair" profit; will a competitor move in or try to undercut the pricing; and will the project meet the rate of return required for the investment. We did ultimately hit on the need for a sound evaluation of the reserve picture, but it seemed less important than all the monetary aspects of the endeavor.

Many of you, our loyal readers, are geologists or are related to geology in some fashion. With that in mind, after the above exercise, I began to wonder what you would address first when asked about some grass-roots endeavor. It would certainly depend on the physical size of the project, the risk of a miscalculation to the owner, your field of expertise, the project budget, the anticipated life of the project, and so on. These are all important. At some point in the review, would you venture into the area of risk to the unsuspecting public?

Over the last few months, natural disasters have been in the news. But what is a natural disaster? Wikipedia, the free online encyclopedia, has a nice definition:

> A natural disaster is a major adverse event resulting from natural processes of the Earth; examples include floods, volcanic eruptions, earthquakes, tsunamis, and other geologic processes. A natural disaster can cause loss of life or property damage, and typically leaves some economic damage in its wake, the severity of which depends on the affected population's resilience, or ability to recover.

The definition refers to ". . . natural processes of the Earth . . ." so sinkholes, landslides, radon accumulations, methane migration, and groundwater containing naturally occurring, dissolved toxic metals must fall into this definition. And of particular note is the phrase, ". . . severity of which depends on the affected population's resilience . . . ." Any average citizen could be severely negatively affected by one or more of these events, which makes a natural disaster a personal disaster.

What is my point? Just this: as geologists, we have some understanding of natural processes and what resources can be exploited, as well as what disastrous events can occur. I believe we have a moral and ethical obligation to share our knowledge of potential catastrophes with our fellow human beings. So take an active role in the education of the public. Help them understand what is going on in your local area. And watch out for meteorites!

# Identifying a Piece of the Cosmos

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## Introduction

During the two years since I began working at the Bureau of Topographic and Geologic Survey, I have had the opportunity to participate in a variety of interesting projects, ranging from field work to developing digital maps with ArcGIS software. For the most part, my day is relatively normal and routine, but on occasion, that bit of normalcy becomes extraordinary; dare I even say extraterrestrial?

In the recent past, staff geologist Stephen Shank and I have been contacted by several people who thought they had found meteorites. These people called, wrote, or visited the Bureau office with rocks or objects they thought might have come from outer space. It is not something we normally do at the Bureau, but a finder's rock that has an unsettling weight and rare appearance does warrant some investigation. From the television series *Meteorite Men* to the recent news of a Minnesota couple finding a 33-pound meteorite in their field (Meersman, 2013) to the February 13, 2013, meteor raining fragments down onto Chelyabinsk, Russia (Kuzmin, 2013), people seem to be more aware of strange rocks on the ground. Although we really don't mind looking at some of the oddities that have been brought to us, we still have yet to see a rock where we can tell the finder that his or her find is most likely a true meteorite.

## What are Meteorites?

Let us define some terminology. **Meteorites** are rock or mineral fragments from the very early stages of the solar system's formation 4.57 billion years ago (Smith, Russell, and Benedix, 2011) and were probably once part of small- to medium-sized asteroids. The main asteroid belt is found in a region of space that resides between the orbits of Mars and Jupiter. An **asteroid** is one of hundreds of thousands of rocky bodies in this belt and is in orbit about the sun. It is an object usually a few hundred meters across or larger that did not become part of a planet. Collisions between asteroids produce numerous smaller chunks or rock fragments. A **meteoroid** is a smaller version of an asteroid or a chip off the parent asteroid, but they can also be dusty fragments shed from the nucleus of a comet. As Earth orbits the sun, it sweeps up some of this debris, collecting about 40,000 tons of additional material each year (Norton and Chitwood, 2008), which is hardly noticeable. A **meteor** is the brief flash of light visible at night when a meteoroid enters Earth's atmosphere (Figure 1); the misnomer for such a sighting is a shooting star. Frictional heat is generated as the meteoroid plunges through the atmosphere, leaving a brief luminous trail in the night sky. Most of the debris the earth slams into is meteoroid dust and fragments ranging from a few microns up to a few millimeters in diameter. If a much larger piece of rock survives its fiery descent through the atmosphere and reaches the ground, it is called a **meteorite.** On average, about 25 million meteors collide with the earth's atmosphere every 24 hours (Norton and Chitwood, 2008). The majority of meteors do not become meteorites. But, on occasion, Earth will encounter a larger than usual chunk of rock, which survives passage through the atmosphere and impacts the surface. Of the ones that survive, most go unnoticed or are lost in the oceans.

## Meteorites in Pennsylvania

In Pennsylvania, there have been only eight documented meteorite finds. They are the Pittsburgh, Bradford Woods, Mount Joy, Bald Eagle, Shrewsbury, New Baltimore, Chicora, and Black Moshannon

*Figure 1. A tiny meteoroid fragment enters earth's atmosphere, heating to incandescence and producing a brief flash of light, or a meteor. This image was captured during the 2001 Leonid meteor shower. The reddish-pink object is the Orion nebula, a star-forming region of glowing gas and dust.*

Park meteorites. This does not mean that more meteorites do not exist in Pennsylvania, it just means they have yet to be found. It is possible that some unsuspecting person has picked up an odd-looking, heavy rock, only to place it on the fireplace mantle not knowing that it is a meteorite. Although many sightings of meteors and fireballs streaking across the sky have been reported, it has been 72 years since the last witnessed meteorite fell from the sky over Pennsylvania.

The last documented meteorite find was on July 10, 1941, and it had a mass of 705 grams (1.55 pounds). The Black Moshannon Park meteorite, as it was named, was discovered by Robert Reed of Philadelphia, who, upon exiting his tent early that morning, heard the meteorite fall through the treetops and bury itself at the base of a nearby tree. The meteorite missed hitting the tent and his sleeping son by only four feet (Stone and Starr, 1932).

According to Marc Wilson, Minerals Collection Manager and Head of the Minerals Section at the Carnegie Museum of Natural History in Pittsburgh, the museum has 38 meteorites in its collection. Of the 38, three are Pennsylvania meteorites—the Bradford Woods meteorite (Figure 2), and slices of both the Shrewsbury and Mount Joy meteorites (Figures 3 and 4). Mr. Wilson confirmed that since the last reported find in 1941, no other authentic meteorites have been discovered in Pennsylvania. Mr. Wilson said:

> We entertain well over a hundred info requests via phone and email and in-person visits (the latter is by far the largest category) regarding meteorites that members of the public find anywhere from a field or back yard or in their bedroom (through a hole in the glass from which a trajectory established that "it must have come from outer space") or on top of their garage roof ("How else could it have gotten up there?"). Unfortunately, none of the thousands of samples brought in for verification over the 21 years of my tenure here have actually been meteorites. So, I guess we're stuck with eight for right now.

In 1932, the Pennsylvania Geological Survey published General Geology Report 2, *Meteorites Found in Pennsylvania*. More detail was added to a revision of the report released by the Bureau in 1967. In the publication, it was indicated that the majority of Pennsylvania meteorites were cut, sliced,

*Figure 2. Bradford Woods meteorite. Carnegie Museum of Natural History specimen CM21333. Dimensions: 8.5 cm x 7.4 cm x 6.2 cm, 730.34 grams (1.6 pounds). Photograph by Debra L. Wilson.*

and divided up between museums and educational institutions, most of which were outside the commonwealth and even outside the United States. Since then, more fragments have been cut from these specimens and sold to other institutions, museums, galleries, meteorite dealers, and collectors. Thus, locating many of the original specimens has been a daunting task. The Academy of Natural Sciences in Philadelphia originally possessed four of eight Pennsylvania meteorites, but it has since relinquished possession of its mineral and meteorite collections. From our search, we found that the Academy now retains only a slice of the Shrewsbury meteorite, and some of the other specimens were apparently sold to out-of-state museums and collectors. The William Bucknell Observatory in Lewisburg, Pa., still retains the largest fragment of the Bald Eagle meteorite (see cover photograph), which has a mass of 2,639.3 grams (5.8 pounds), and the State Museum of Pennsylvania in Harrisburg only has a 17-gram fragment (0.037 pound) of the New Baltimore meteorite (Figure 5), which had an original mass of approximately 16,333 grams (37 pounds).

For more information on the eight Pennsylvania meteorites, *Meteorites in Pennsylvania,* by the appropriately named Ralph Stone and Eileen Starr, can be accessed online from the Bureau's publications website at www.dcnr.state.pa.us/topogeo/publications/index.htm.

**Meteorite Types**

Meteorites are classified into three broad categories: stony meteorites, stony irons, and irons (Norton, 2002; Norton and Chitwood, 2008), which are then further divided into more detailed categories that will not be covered in this article.

As their name suggests, **stony meteorites, or stones,** look like ordinary rocks at first glance. This is because they once were part of the outer crust of an asteroid or planet consisting mainly of silicate minerals. Silicate minerals are an important class of

*Figure 3. Slice from the Shrewsbury meteorite. Carnegie Museum of Natural History specimen CM320. Dimensions: 10.5 cm x 8.7 cm x 1.7 cm, 370 grams (0.8 pound). Photograph by Debra L. Wilson.*

*Figure 4. Slice from the Mount Joy meteorite. Carnegie Museum of Natural History specimen CM29667 (back). Dimensions: 4.7 cm x 4.5 cm x 0.6 cm, 65.3 grams (2.3 ounces). Photograph by Debra L. Wilson.*


*Figure 5. Fragment from the New Baltimore meteorite (specimen ET 253) on the blue and white scale next to a cast replica of the original meteorite found in 1922 (specimen ET 268), both in the State Museum of Pennsylvania.*

rock-forming compounds that consist mostly of silicon and oxygen, or $SiO_4$, and make up nearly 95 percent of Earth's crust. Some stones contain tiny grains or inclusions called chondrules (Figure 6). Chondrules originated during the early stages of the solar system when tiny grains of matter within the solar nebula began to accrete, or stick together. Stony meteorites containing chondrules are referred to as **chondrites** (Norton and Chitwood, 2008). They may contain some extraterrestrial iron and will likely stick to a strong magnet. Stony meteorites that do not contain chondrules are called **achondrites** (Norton and Chitwood, 2008). Achondrites likely originated from igneous or volcanic processes within their parent planet or asteroid and are thought to have crystallized from a molten state, erasing all traces of the chondrules. Achondrites typically contain very little iron and will not stick to a magnet, making them much more difficult to find.

Although stony meteorites account for about 95 percent of all the debris that reaches Earth's surface (Lunar and Planetary Institute, 2013), they are the most difficult meteorite specimens to find. One identifying feature is that they are commonly covered with a black or dark-gray crust, called fusion crust (Figure 6). This crust is produced by the melting of the meteoroid's outer layers during its fiery descent through the atmosphere. As the meteoroid decelerates and begins to cool, the molten surface solidifies into a crust. The crust or rindlike material is usually paper-thin where the outer material of the meteoroid was ablated, or removed, by the intense heat of atmospheric entry. When stony meteorites are sliced open, their interiors have been unaltered by the searing heat because passage through the atmosphere is relatively brief and the object is cooled by the ablation process (Norton and Chitwood, 2008). If a stony meteorite goes undiscovered and is subjected to Earth's weathering processes, the outer fusion crust deteriorates and the meteorite is almost indistinguishable from common terrestrial rocks. Pennsylvania's Black Moshannon, Bradford Woods, and Chicora meteorites are stony meteorites (Stone and Starr, 1932).


*Figure 6. Cut section of the Bradford Woods stony meteorite (Carnegie Museum of Natural History specimen CM21333) showing the fusion crust, a chondrule, and metal flakes within a finer matrix.*

**Stony-iron meteorites** are very rare and unique compared to other meteorites. They account for about 1 percent of all the meteorites that fall to earth (Lunar and Planetary Institute, 2013) and consist of almost equal amounts of iron-nickel metal and silicate minerals. They have been divided into two types, the pallasites and mesosiderites. These meteorites roughly contain about equal proportions of rock (silicate minerals) and metal (iron-nickel) by volume and are thought to have very different origins from other meteorites. Stony-iron meteorites are rare and amongst the most beautiful and sought-after meteorites. **Pallasites** contain beautiful translucent crystals of gem-quality olivine, called peridot, suspended in a nickel-iron matrix (Norton, 2002). They are thought to have formed in large differentiated asteroids near the boundary where the iron core and silicate material meet. **Mesosiderites** contain high concentrations of silicate material (Norton, 2002), but unlike the olivine in pallasites, they consist of pyroxenes and feldspars within an iron-nickel matrix. Many of the mesosiderites appear brecciated and contain angular fragments and metallic inclusions. They are thought to have formed by the collision of two differentiated or semi-molten asteroids, causing their melted surface materials to mix with iron-nickel core material.

**Iron meteorites, or irons,** account for about 5 percent of the material that falls on the earth (Lunar and Planetary Institute, 2013). Iron meteorites usually contain no stone and typically consist of approximately 90 to 95 percent iron (Korotev, 2013), with the remainder comprised of nickel and minute amounts of sulfide and carbide minerals. Most iron meteorites are thought to have originated from the cores of asteroids that melted and differentiated early in their history. When searching for such meteorites, look for rocks that are quite dense and much heavier than the surrounding terrestrial rocks, and that are attracted to a strong magnet. An iron meteorite that is freshly broken or cut may reveal shiny iron flakes. Pennsylvania's Pittsburgh, Mount Joy, Bald Eagle, Shrewsbury, and New Baltimore meteorites are classified as iron meteorites (Stone and Starr, 1932).

**Is My Rock a Meteorite?**

So you have found an interesting rock and you want to know if it is a meteorite. Fortunately, there are a number of tests the average person can do to help decide if his or her rock is a meteorite or not. It does not always take a geologist or an astronomer to figure out if your rock is a meteorite, but sorting through the evidence of your find is part of the science behind meteorite identification. What follows is only a guide to assist in narrowing down the possibilities of determining whether or not an object is a meteor-right or a meteor-wrong (Figure 7) (see also Korotev, 2013).

*Figure 7. Which rock is the meteorite? Most meteorites are difficult to distinguish from terrestrial rocks. Left to right, top row: magnetite iron ore, granite, and industrial iron slag. Left to right, bottom row: pumice, stony-iron meteorite, and obsidian.*

**Appearance—Looks Are Not Everything.** Some meteorites do exhibit characteristics on the outside that may yield useful clues. Meteorites can come in a variety of sizes and shapes. They can be light or dark in color or a mix of both. Depending on the type of meteorite, their origin, and how they entered the atmosphere, they can appear elongated or spherical, or cone-, shield-, or flat-shaped. Most meteorites have irregular shapes and may have rounded edges, but they are not always smooth. Meteorites with irregular or jagged edges may have fragmented or exploded during their fiery descent through the atmosphere.

Take note if the object is heavy and dense. Density is how heavy a rock is for its size compared with other rocks. Depending on a meteorite's composition, it can range from 1.5 to 3.5 times as heavy as ordinary terrestrial rocks. If the object is heavier, denser, and looks much different than the surrounding rock, keep investigating. Most iron and stony-iron meteorites are dense and heavy for their size because they contain a fair amount of iron and/or nickel. However, there are also a number of terrestrial rocks that contain iron and are nearly as dense and heavy. Measuring the density of a rock is not a necessity; knowing the rock is dense and heavy for its size is usually enough information.

As mentioned above, freshly fallen meteorites (especially stony meteorites) may exhibit a fusion crust where the outer surface has been scorched by the searing heat of atmospheric entry. The crust, generally no more than a millimeter thick, will be dark in color (such as brown or black) and look similar to a thin veneer or varnish coating the outside of the meteorite. Over time, this fusion crust can deteriorate due to weathering. However, some light-colored terrestrial rocks, when exposed to the elements, will weather and oxidize to a black color.

In addition to a fusion crust, the exteriors of meteorites may show regmaglypts. Regmaglypts are shallow pits or indentions on the surface of the meteorite and resemble thumbprints as if pushed into soft clay (Figures 8 and 9). When a meteoroid enters the atmosphere and begins to melt, irregular surface features create turbulence. Supersonic jets of plasma flowing past the meteoroid can sculpt the surface, resulting in the thumbprint features. Regmaglypts are not only characteristic of meteorites found on Earth; meteorites exhibiting regmaglypts have been discovered on Mars by the rovers Opportunity and Curiosity (http://marsrovers.jpl.nasa.gov/newsroom/pressreleases/20050119a.html).

**Magnetic Personality.** Most meteorites contain some amount of iron or iron-nickel and are attracted to a magnet (Figure 10). Only a small percentage of meteorites are nonmagnetic. One of the easiest tests to conduct is to simply find a strong magnet and see if it will stick to the rock. In many cases a refrigerator magnet will do the trick. On the other hand, some meteorites may contain only a small percentage of iron, making it more difficult for the magnet to stick. In this case, a stronger magnet may be needed. Neodymium magnets are extremely strong and will easily attract rocks of low iron content. Many terrestrial rocks will also attract a magnet. Magnetite and hematite are common iron-bearing minerals often mistaken for meteorites because they are heavier and denser than other terrestrial rocks. Magnetite ($Fe_3O_4$) is strongly attracted to a magnet, whereas hematite ($Fe_2O_3$) is only weakly magnetic at best. Performing the magnet test is not a definitive test for a meteorite. However, if your find does not stick to a magnet, chances are it is not a meteorite.

*Figure 8. Image of the Holbrook, Ariz., meteorite. It is a stony (chondrite) meteorite exhibiting a black fusion crust and shallow regmaglypts. Carnegie Museum of Natural History specimen CM12329.1B. Photograph by Debra L. Wilson.*

**Streak Test.** If the sample is attracted to a magnet, the next step is to perform the streak test. Streak is the color of a crushed mineral's powder, and the test is usually performed by scratching or rubbing the mineral on the rough or unpolished side of a ceramic tile (Figure 11). This test is helpful for the identification of minerals such as magnetite or hematite

*Figure 9. Good example of regmaglypts in the Canyon Diablo meteorite, which formed Meteor Crater in Arizona about 50,000 years ago. Carnegie Museum of Natural History specimen CM319. Photograph by Debra L. Wilson.*

(iron oxides) which are not native to meteorites. Meteorites resting on the surface of the earth over long periods of time will experience chemical weathering when the iron-nickel metal changes into iron oxides. Most meteorites generally will not leave a streak on a ceramic plate unless they have been exposed to and heavily weathered by the elements. If the specimen leaves a reddish-brown to brick-red streak, the mineral is likely hematite. A grayish-brown to black streak may indicate that the specimen contains magnetite. If a ceramic tile is not available, the unglazed underside of a ceramic coffee cup or the inside portion of a toilet tank lid can be used for this test.

**Presence of Nickel.** If the specimen is dense, heavy, appears to have a fusion crust and regmaglypts, is magnetic, and passes the streak test, it is time to look for the presence of nickel. One of the more definitive tests for meteorite identification is to examine its internal structure and composition for the presence of nickel. Nickel is an element about as dense as iron and found mainly in two places: deep within Earth's core, and in crustal earth rocks that contain nickel-bearing minerals such as pentlandite and garnierite. Metal in meteorites almost always contains some percentage of nickel. An iron-nickel meteorite exposed to air and water on earth will oxidize, changing the iron to rust. Nickel has a much slower oxidation rate than iron and essentially will not oxidize like iron. If an iron-nickel meteorite completely oxidizes, what remains is rust and nickel.

*Figure 10. Most meteorites contain some iron. A fragment of the Canyon Diablo meteorite (iron-nickel) sticks to a strong magnet.*

The interiors of most iron meteorites contain alloys of iron and nickel (the minerals kamacite and taenite) believed to have formed by impacts of planetesimals during the formation of the solar system (Norton and Chitwood, 2008). Extremely high temperatures from the impacts heated and melted the planetesimals. As the planetesimals slowly cooled from their molten state, kamacite and taenite crystals formed, generating a distinct cross-hatched pattern (Figure 12). One test for iron meteorites is to look for a unique pattern of interlocking crystals on a freshly cut surface. The crystalline patterns, called Widmanstätten (pronounced VIT-mahn-shtetten), were discovered in 1804 by geologist William Thomson and later in 1808 by Count Alois von Widmanstätten, for whom the pattern is named (Norton

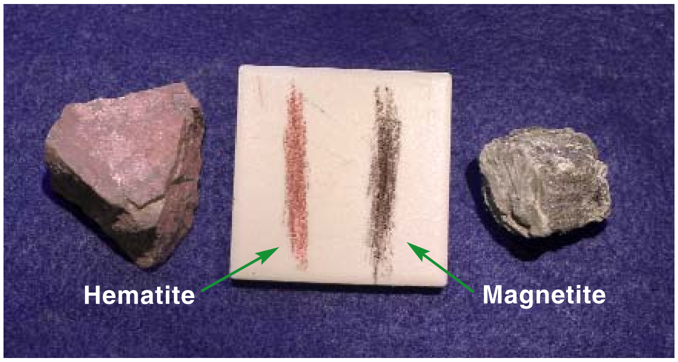


*Figure 11. Various minerals leave a characteristic streak when the rock is vigorously scratched on a ceramic tile. Iron oxide minerals such as hematite and magnetite will leave a distinct streak. Meteorites do not contain magnetite or hematite and generally will not leave a streak.*

and Chitwood, 2008). During the initial discovery, Thomson attempted to remove rust from the surface of a meteorite by using nitric acid. Shortly after applying the acid to the meteorite's surface, he noticed the strange cross-hatched pattern. As such, Widmanstätten patterns become visible when a meteorite is cut, polished, and briefly dipped into a dilute solution of nitric acid, which etches the crystal surfaces. Nickel-iron crystals of this type can form only if the molten metal cools slowly over millions of years. Therefore, Widmanstätten patterns are never found in counterfeit meteorites, or "meteor-wrongs."

In addition, the presence of nickel can be detected by a number of analytical methods including SEM (scanning electron microscope) analysis. In 2003, the Bureau acquired an SEM equipped with an EDS (energy-dispersive X-ray spectrometer) (Barnes, 2003). The device is designed to determine the chemistry of geological samples. Although used mainly for terrestrial rock analysis, it can be used to analyze the chemical composition of meteorites and detect the characteristic element, nickel (Figures 13 and 14). Just a fraction of a gram provides enough information to reveal a meteorite's composition. If a specimen exhibits all of the previous characteristics and contains nickel, chances are good that the specimen is a strong candidate for being a meteorite.


*Figure 12. Detailed slice of the Shrewsbury meteorite, discovered in 1907 in Shrewsbury, York County, Pa. Note the complex interlocking pattern of iron-nickel bands, or Widmanstätten pattern. Natural History Museum, Vienna, specimen Shrewsbury_J2286_LF1. Photograph by Ludovic Ferrière, Natural History Museum, Vienna, Austria.*

**Finder Beware.** Iron slag is oftentimes mistaken for a meteorite. During the eighteenth and nineteenth centuries, Pennsylvania was a leader in the American iron industry. Iron furnaces sprang up across the commonwealth (Figure 15), extracting molten iron from ore for cast-iron and pig-iron products (Silverman, 2013). Iron production was crucial, not only for industry, but for farm tools and creating cannons and musket balls to support the American Revolutionary and Civil Wars. During the smelting process, limestone, a fluxing agent, was used to separate nonmetallic impurities such as silica and phosphorous from the iron ore. This slag was discarded. In some cases, the slag retained a small amount of iron. Impurities sometimes caused the creation of small vesicles due to the release of gas during the smelting process, and the slag retained a glassy appearance due to rapid cooling, substantially weakening it. Much of this slag was strewn around the iron furnaces, and it was used in railroad beds and in fill across the state. A piece of iron slag found today will likely stick to a magnet, and, unfortunately for the finder, most specimens brought to the Pennsylvania Geological Survey turn out to be just that—iron slag. So, if your rock has

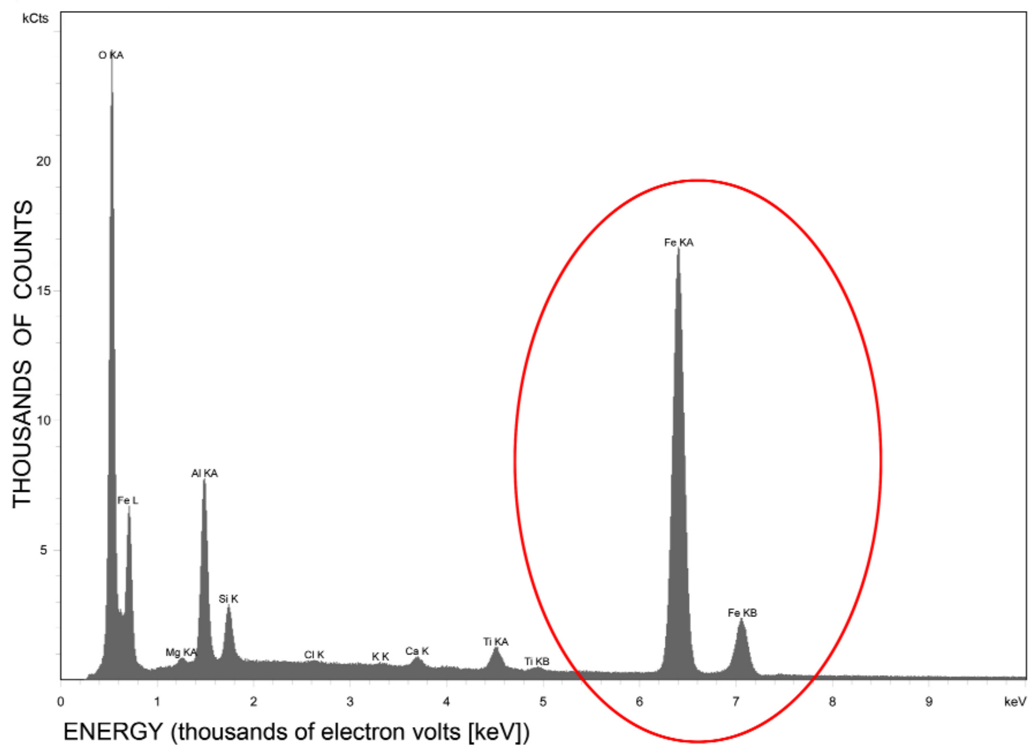


*Figure 13. SEM analysis of a suspected meteorite sample showing a strong signature of iron (Fe), circled in red, but no nickel (Ni). The sample was industrial slag. Analysis by Stephen Shank.*

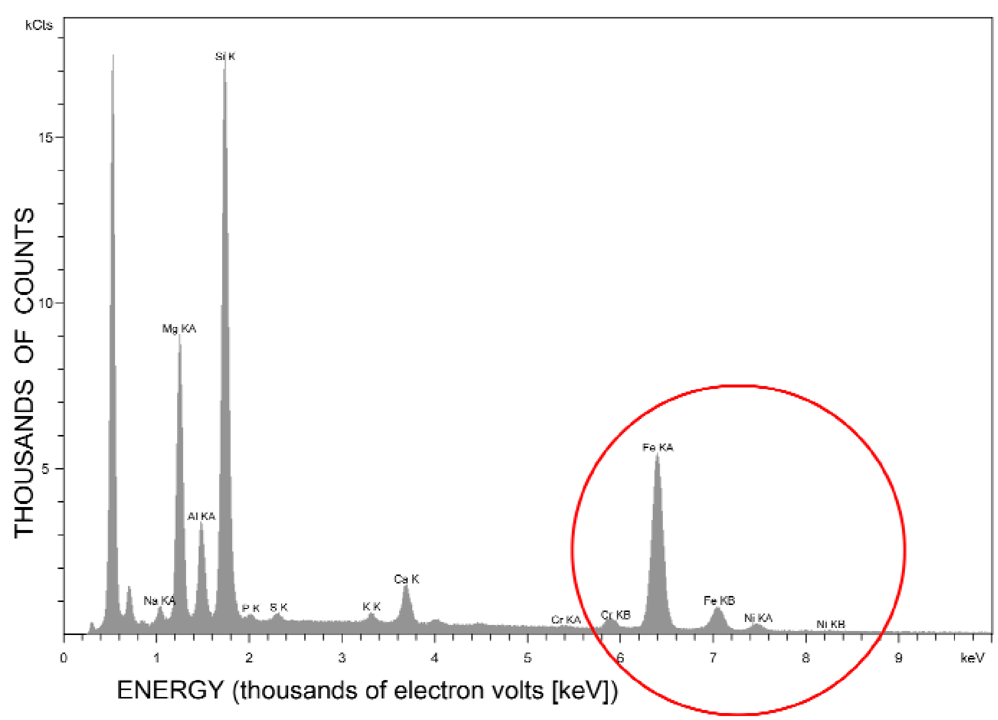


*Figure 14. SEM analysis of a stony-iron meteorite, confirming the presence of iron (Fe) and nickel (Ni) (circled in red). Analysis by Stephen Shank.*

*Figure 15. In this historic black-and-white photograph, a large group of men stand in front of a blasted industrial landscape dominated by a huge furnace and buildings at Greenwood Furnace State Park, Pa. (www.dcnr.state.pa.us/stateparks/findapark/greenwoodfurnace/).*

a glassy appearance or contains small holes or vesicles, it most likely is not a meteorite. In addition, iron concretions, pyrite nodules, bog ore, waste metal, chrome, and stainless steel are common meteorite mistakes that have shown up in our offices (Figure 16).

Meteorites have spent most of their existence in space and have undergone little chemical alteration since the formation of the solar system. Because there is no air or oxygen in space, meteorites are generally nonporous, solid, and contain few impurities. A meteorite generally does not have crystals or colored, matrix-like interiors unless it is a rare pallasite or type of chondrite. But getting to the interior of a meteorite to see its structure usually requires that it be cut.

**Where Can I See Pennsylvania's Eight Meteorites?**

Unfortunately, it has been more than 25 years since all eight Pennsylvania meteorites were on display together in one location. Between August 4, 1987, and through the summer of 1988, the Carnegie Museum of Natural History showcased all eight meteorites (Carnegie Museum of Natural History, 1987). The majority of those meteorites were acquired through temporary loans from various museums and universities. Currently there are no Pennsylvania meteorites on display at the museum. Marc Wilson, the curator, indicated that he would like to maintain a permanent meteorite exhibit. However, there must be adequate funding and interest, and the decisions to support such exhibits are often determined at a higher level. Similarly, there is still no single location within Pennsylvania that even houses specimens from all eight Pennsylvania meteorites.

The only location where the author found a Pennsylvania meteorite actively on display within the commonwealth was at the William Bucknell Observatory in Lewisburg. The observatory houses the


*Figure 16. Two of many samples brought to the Pennsylvania Geological Survey because they were thought to be meteorites. The sample on the left is likely the result of an industrial process (iron slag) and contains enough iron to stick to a magnet. The sample on the right is canister or grapeshot (location unknown), perhaps from the Revolutionary War or Civil War.*

Bald Eagle meteorite, which was discovered in 1891 (see cover photograph). Its shape resembles that of a club foot, and other than a 300-gram (0.66-pound) slice that was removed a few years after its discovery, it is a nearly complete specimen. According to Professor Ned Ladd, the meteorite is often used during public outreach events where the public as well as students can handle it. “The meteorite has a way of firing a student’s imagination,” said Ladd. “It provides an opportunity for them to come into contact with an object from outer space.”

The Smithsonian National Museum of Natural History in Washington, D.C., contains 45,000 catalogued specimens from more than 16,850 different meteorites in its inventory. According to the Smithsonian Institution’s collection database, 46 specimens come from five of Pennsylvania’s eight meteorites. The Smithsonian did not respond to the author’s request for information. Therefore, it is unknown whether any Pennsylvania meteorites are on display at the Smithsonian.

The Arthur Ross Hall of Meteorites at the American Museum of Natural History in New York City displays more than 150 meteorites and contains approximately 5,000 specimens representing about 1,255 different meteorites in its inventory. According to Dr. Denton Ebel, Curator, the museum has four specimens of Pennsylvania meteorites and currently displays a 772-gram (1.70-pound) sample of the Mount Joy meteorite. Outside of the United States, several large specimens of the Mount Joy meteorite reside in the Natural History Museum in Vienna, Austria. Dr. Ludovic Ferrière, co-curator of the meteorite collection, confirmed that the museum has over 50 specimens of this meteorite, totaling 203 kg (447.5 pounds). Two large specimens of this meteorite are on display. Renovations at the Vienna museum were recently completed, and it “now maintains not only the largest display of meteorites in the world, but also the nicest.” The author was able to confirm that a number of Pennsylvania meteorites are maintained at other museums and educational institutions outside Pennsylvania. Inquiries to these facilities about the meteorites either went unanswered or revealed that the specimens are in storage and not on display.

Retired teacher Edwin Charles of Mechanicsburg, Pa., actively collects mineral and meteorite specimens. Charles strongly believes that specimens of all eight Pennsylvania meteorites should be permanently housed and displayed in one Pennsylvania location, preferably in the State Museum of Pennsylvania in Harrisburg. Charles said,

> These meteorites originated during the early stages of the solar system's formation 4.5 billion years ago and found their way to Earth. Not only did these meteorites find their way to Earth, but they landed on commonwealth soil. They are unique and among the oldest objects ever to have been found; they traveled vast distances, and at huge velocities to reach earth. Relics such as these should be protected and preserved within Pennsylvania. It is unfortunate that such a rich history of our solar system and that of which was part of the commonwealth is not on display for all to see. Having a representative specimen from each of the eight meteorites permanently displayed in a single location in Pennsylvania would provide a great educational opportunity for present and future generations.

**Conclusion**

Despite large numbers of meteorites falling to earth each year, very few people actually see them hitting the ground. Most of them fall into the ocean and are forever lost. Meteorites that break up on entry and survive the fiery plunge through Earth's atmosphere are usually spread across a huge area. Most of these fragmented pieces go unnoticed because they are probably small and look much like any other rock lying on the ground. Because Pennsylvania is located within a humid climatic zone, it receives a fair amount of rain and snow. Any meteorite lying on the ground for an extended period of time will eventually succumb to the effects of chemical weathering. Meteorites tend to survive on the ground longer in dry, arid environments. In addition, much of Pennsylvania is rugged and covered by vegetation, making it even more difficult to find these space rocks.

Finding a meteorite is like finding a needle in a haystack. That is why meteorites are difficult to find and so rare. Just because meteorites are hard to find does not mean that you should not look or at least be observant. For folks hoping to find a meteorite, Marc Wilson offered some words of encouragement: "We do not always have the time to go out into the field and search for specimens. We must rely on other people to find the interesting stuff so we can do the science." So, before you pick up that strange-looking stone and toss it, do some investigating, because it just may be a piece of the cosmos.

**Disclaimer**

The information gathered within is to be used as a guide and is for educational purposes only. The Pennsylvania Geological Survey is not in the business of identifying meteorites and does not claim to have experts in the field of meteorites. The expertise and focus of the Bureau is mainly on terrestrial rocks and Pennsylvania geology. The Bureau cannot certify samples as authentic meteorites, nor can it buy, sell, or trade suspected or confirmed samples. When examining suspected meteorite samples, our geologists follow many of the same steps outlined in this article and can likely determine if the sample is of terrestrial or man-made origin, or at least we can narrow down the possibilities. Analyzing a sample on the SEM to test for the presence of nickel is a last resort. If the Bureau determines that a sample meets all of the requirements of a meteorite, the next step is to contact someone for verification.

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# BUREAU NEWS

**The Polish Geological Institute Visits Pennsylvania.** The Commonwealth of Pennsylvania recently welcomed petroleum geologists from the PGI (Polish Geological Institute; Warsaw, Poland), who had traveled to the United States for training workshops and meetings on shale gas development in the Appalachian basin. During their trip, Hubert Kiersnowski, Ireneusz Dyrka, and Marcin Janas attended the Field Conference of Pennsylvania Geologists (headquartered in Williamsport, Pa.) and visited Antes and Marcellus outcrops with representatives from the Department of Conservation and Natural Resources. Prior to their departure back to Poland, the group met with Pennsylvania Geological Survey geologists in Pittsburgh. Among the topics of discussion at this meeting were the similarities in the regional geology of Pennsylvania and Poland, technical approaches to assess shale gas reservoir quality and reserves, water resource issues (from private water supplies, water sourcing, and management for drilling activities, to contamination potential), and how to deal with public opposition to drilling through education and outreach. The Bureau provided these visitors with copies of relevant technical papers, oil history souvenirs, and a copy of *The Geology of Pennsylvania* (Special Publication 1), signed by our very own State Geologist, George Love. PGI provided our staff with copies of their current shale gas research and mapping publications, as well as the Conference Proceedings for GeoShale 2012, an international conference held by PGI in May of last year. We hope to collaborate with our new colleagues on shale resources in the future.

*Pictured, left to right: Marcin Janas (PGI), Kristin Carter (Economic Geology Division manager), Ireneusz Dyrka (PGI), and Hubert Kiersnowski (PGI).*

# FIELD CONFERENCE OF

The Field Conference of Pennsylvania Geologists met this year in Williamsport, Pa. Two days of geologic exploring took 170 geologists from Ordovician carbonates to Pennsylvanian coals, including a good portion of the Devonian. We explored sinkholes and springs, esker deposits, black shales, complicated structures, and detailed stratigraphy. The weather was perfect, as planned.

The pre-conference trips offered a variety of activities from fossil collecting to kayaking, and from biking to hiking. These trips provided the opportunity to explore geology at sites that could not accommodate the whole group, and they allowed us to explore in ways that bus travel cannot. The trips are led by volunteers. If you are interested in leading one in 2014, please let us know.

The officers set a goal to increase student attendance this year, and they achieved that goal, thanks to generous donors who helped with a reduced student registration fee, and to the wonderful group of students that attended. Twenty-one students from Kutztown, Edinboro, West Chester, Millersville, Shippensburg, Temple, University of Rochester, and Keystone College attended.

# PENNSYLVANIA GEOLOGISTS—2013

*—Photograph by Yuriy Neboga*

This year we instituted some changes from the past. We held student registration open longer, in order to accommodate their later return to school. We added vans to accommodate more geologists and the bum hip and knee club. The guidebook was digitally available to all, and printed copies were available only by request to reduce paper consumption. A road log was provided to all. It included driving directions and short articles for each stop. We also now accept credit cards. We are always looking for ways to improve our program, so please offer suggestions.

Next year's Field Conference is already shaping up. Don Hoskins is busy recruiting people to assist in the Carlisle-based "Pennsylvania's Great Valley and its Bordering South Mountain and Appalachian Mountains." It promises to be another great experience. Watch http://fcopg.org/ for details.

*—Rose-Anna Behr*

# STAFF NEWS

**Introducing . . . Brian J. Dunst,** who joined the Pittsburgh office of the Bureau as Geologist Supervisor in September 2013. He is responsible for a staff of four, made up of geologists and clerical support. Much of the work in that office is focused on subsurface geology, including petroleum exploration. An Erie native, he graduated from Indiana University of Pennsylvania with a B.S. in biology and geology, and he has also completed graduate courses in geochemistry and hydrogeology.

A long-time employee of the Department of Environmental Protection, Brian worked in the Storage Tank Section in the Pittsburgh Regional Office. He discovered that there are many gas stations in the 10 counties covered by the region! Over the years, cleanups changed from limited prescriptive soil and groundwater standards to include risk-based evaluations. Prior to that work, he was a surface-mining inspector for 5 years.

His private-sector employment history includes coal mine permitting, natural gas exploration, and mudlogging on oil and gas rigs in Pennsylvania, West Virginia, and Wyoming.

Having a wife who is also a geologist, geology-based vacations are inevitable for Brian, his wife, and their four children. The family has been to various locations in the United States, including Pennsylvania, always on the lookout for interesting geology wherever they go. To the kids' chagrin, even a beach vacation incorporated a stop at a recognized fossil dig.

In his spare time, Brian has a large garden to tend and enjoys smallmouth bass and steelhead trout fishing in our commonwealth's rivers and streams.

**. . . And Renee Speicher.** Renee Speicher is our newest staff member in the Pittsburgh office. She shares administrative support duties with her coworker, Lynn Levino. Renee is grateful for Lynn's extensive knowledge and patience while training her on the WIS (Wells Information System), PA*IRIS (Pennsylvania Internet Record Imaging System), and how to manage the daily inflow of oil and gas well record paperwork.

Renee's state service began with the Department of Public Welfare—she first worked at the Washington County Assistance Office for 16 years, then worked as a secretary to the Chief Operating

Officer of Mayview State Hospital. The closing of the hospital necessitated her move to Labor and Industry, where she was a secretary for a Workers' Compensation Judge for four years. After marrying in 2012, she packed up and sold the Washington County home she had restored and lived in for 17 years and moved to Butler County. She worked for a brief time for the Department of Transportation, then transferred to the Department of Conservation and Natural Resources in mid-October 2013. Renee is excited to join the Pennsylvania Geological Survey team. The office décor brings up fond memories for her of lugging a large rock on the school bus to her first grade show and tell. After all these years, Renee and her rock hope to call the Bureau home.

## NEW RELEASES

# Bradford County Data Release

The Pennsylvania Geological Survey recently published an open-file report on the results of a joint investigation with the USGS (U.S. Geological Survey) characterizing the stratigraphy, geohydrology, and water quality of a core hole in the northern tier of Pennsylvania. ***Geohydrologic and Water Quality Characterization of a Fractured-Bedrock Test Hole in an Area of Marcellus Shale Gas Development, Bradford County, Pennsylvania*** (Open-File Report OFMI 13–01.0), by Dennis W. Risser and John H. Williams of the USGS, and Kristen L. Hand, Rose-Anna Behr, and Antonette K. Markowski of the Pennsylvania Geological Survey, is a report and data release. The core hole that was drilled in the Gleason quadrangle in Bradford County, Pa., in May of 2012 penetrated the Pottsville through Catskill Formations in 1,664 feet of core.

The report summarizes the tests that were conducted on the core and water column, as well as the analytical results and explanations. The report also includes information on the dissolved gas and stable isotopes in water as well as the stable isotopes found in carbonaceous zones of the core. Geophysical logs provide detailed information about the fractures, flow zones, water quality, depth of fresh water, and include a gamma radiation log. The appendices include all the raw data results such as the complete core description, isotopic results of gas extracted from the core, downhole videos, water-quality analysis, and geophysical logs. This report is available on the Bureau's website (www.dcnr.state.pa.us/topogeo/publications/pgspub/openfile/index.htm). **Please be aware that the zip file for this report is 373 MB in size.**


# Resources of Sullivan County

Open-File Report OFWR 13–01.0, ***Groundwater and Petroleum Resources of Sullivan County, Pennsylvania,*** was recently released online by staff geologists Stuart O. Reese and Victoria V. Neboga. The 99-page report was completed in cooperation with the PADEP (Pennsylvania Department of Environmental Protection). PADEP coauthors are Seth Pelepko, William J. Kosmer, and Stewart Beattie. This digital publication includes overviews of hydrocarbon development and water management issues, county geology and hydrogeology, and water-quality data for 1,911 groundwater and spring samples. The samples were collected in association with gas drilling, allowing operators to document baseline conditions. The report provides inventory data for 29 Marcellus shale wells and a discussion of natural gas migration. The report also includes six 11- x 17-inch plates (1:150,000 scale) of countywide bedrock and surficial geology, sample locations, average water-well yields, depth to groundwater, and generalized shallow groundwater flow. An appendix containing chemical analyses of groundwater data also is included.

The report is available for download in PDF format from the Bureau's website at www.dcnr.state.pa.us/topogeo/publications/pgspub/openfile/index.htm#water.

# RECENT PUBLICATIONS

30 Outstanding Geologic Features in Pennsylvania website **(September 2013)**

Miscellaneous Investigation open-file report (373-MB zip file): **(September 2013)**

Geohydrologic and water-quality characterization of a fractured-bedrock test hole in an area of Marcellus shale gas development, Bradford County, Pennsylvania

Water Resource open-file report **(September 2013)**

Groundwater and petroleum resources of Sullivan County, Pennsylvania

# A GEOLOGIC MYSTERY—UPDATE

In the previous issue, we asked for comments on the Mystery Rock shown here and on page 17 of that issue. Stay tuned for an update in an upcoming issue. The mystery continues . . .

# GEOFACT 23

## The Peculiar Habits (and Observations) of Geologists

Thomas G. Whitfield
Pennsylvania Geological Survey

*The Law of Superposition states: "In undisturbed sediments, layers are deposited in a time sequence, with the oldest at the bottom and the youngest at the top." This photograph shows that geologists are law-abiding citizens, with the oldest at the bottom and the youngest at the top. Photograph by George E. W. Love.*

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