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Pennsylvania Geology

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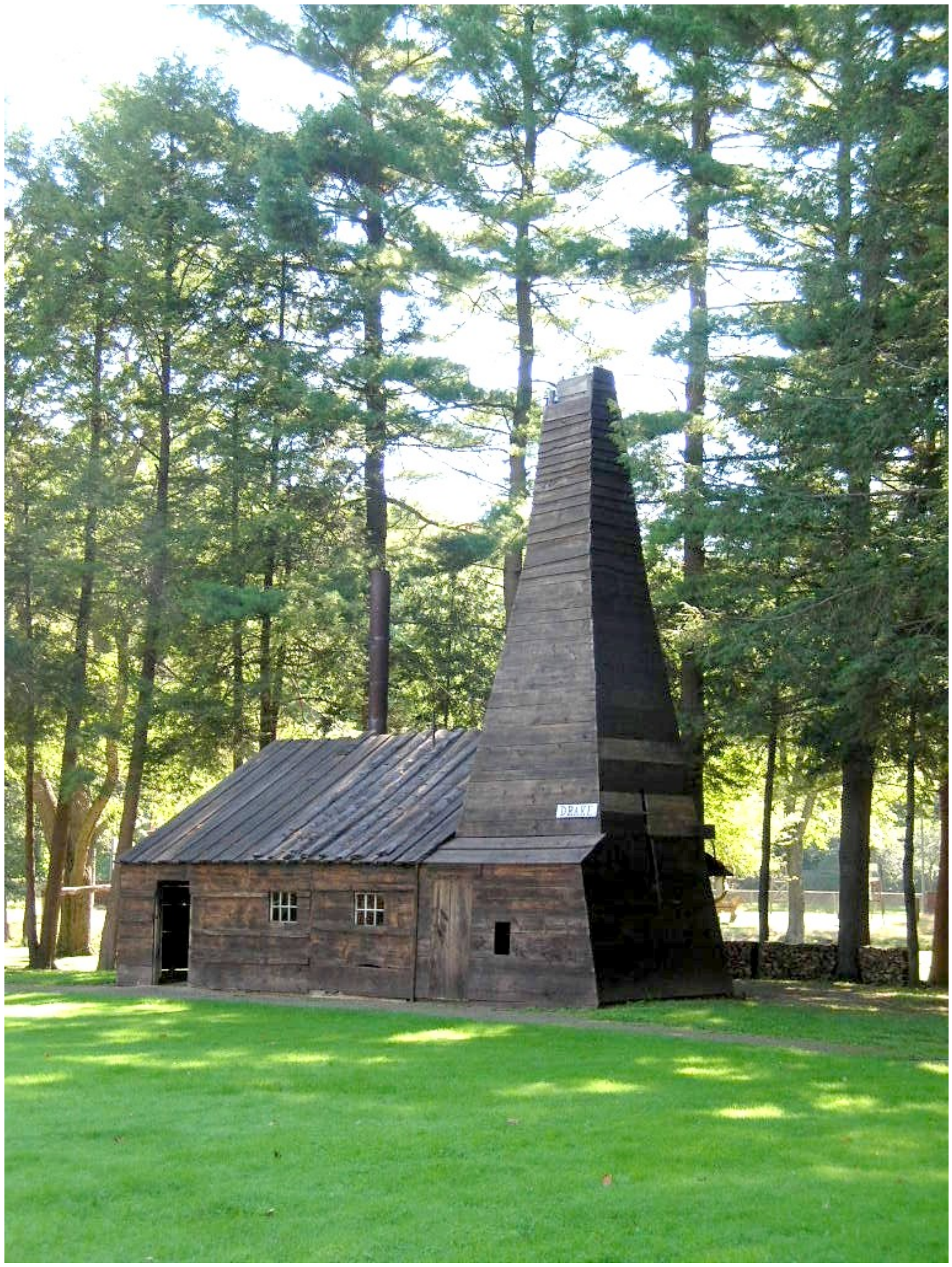


Reproduction of the Drake Well at the Drake Well Museum in Titusville, Pennsylvania. The original well, which was drilled along Oil Creek in Venango County, Pennsylvania, about two miles south of Titusville in 1859, ushered in the modern petroleum industry (photo by John A. Harper, 2007).

EDITORIAL

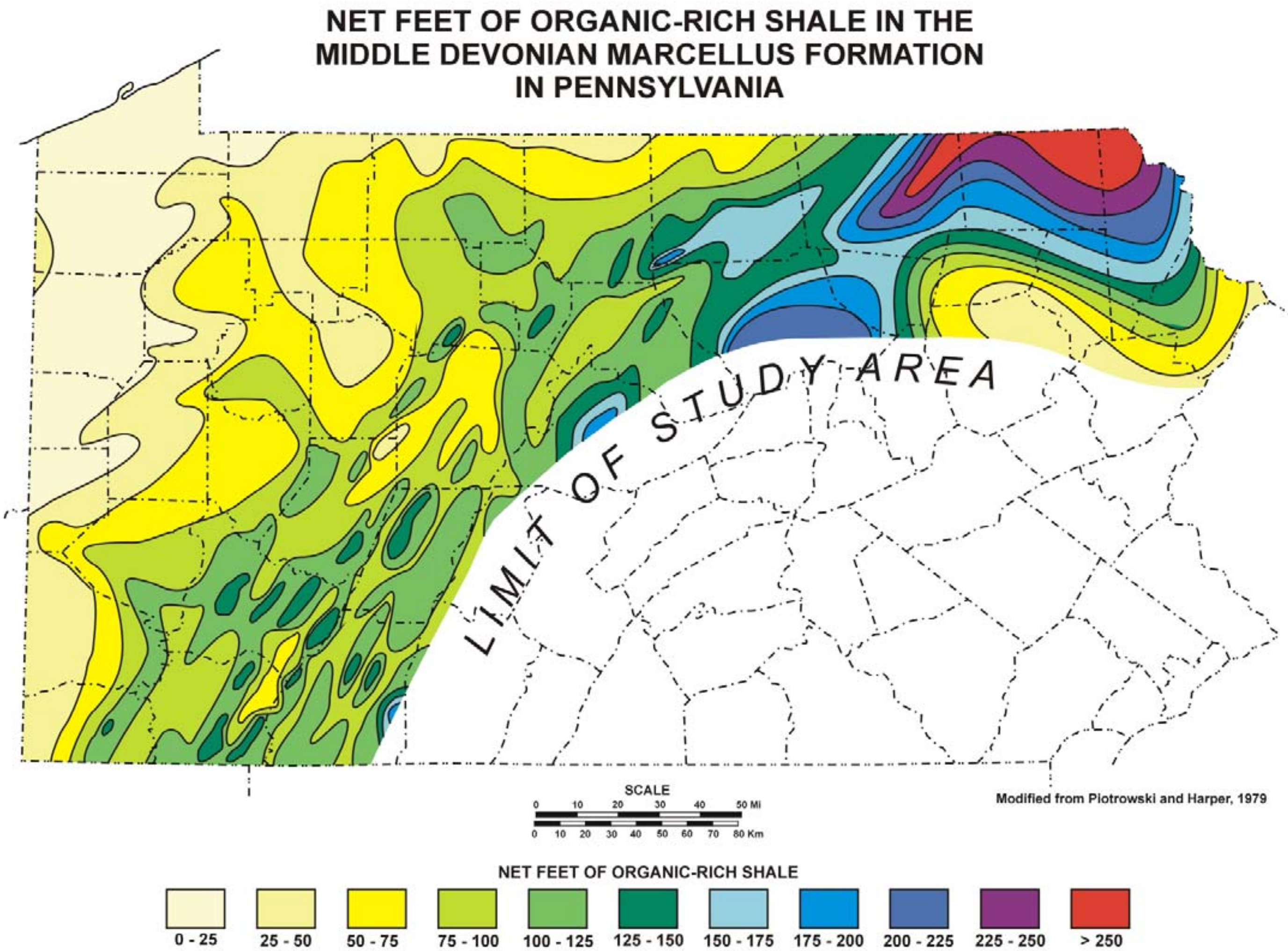
Energy Boom Again!!?

Jay Parrish, State Geologist
Pennsylvania Geological Survey

You'll notice that this issue of **Pennsylvania Geology** has a lot to do with the oil and gas industry. If you've been reading the papers you may also have heard about the "Marcellus shale", considered to be one of the biggest natural gas plays in the world. But you might not know that the Marcellus play was discovered in Washington County, Pennsylvania in 2003 by Range Resources-Appalachia, one of the major players. In any event, energy has long been a dominant force in Pennsylvania history. From the early days of lumbering and coal to the first oil well 150 years ago to the Marcellus, Pennsylvania's fortunes and environment have been tightly tied to energy.

The Survey was first created to map anthracite coal in eastern Pennsylvania in the early 1800s. In the later part of the century it was bituminous coal and oil and gas in western Pennsylvania. Later surveys dealt with environmental and other major issues affecting the citizens of the Commonwealth. Today we face another energy boom with the Marcellus. At a time of declining state budgets and loss of personnel, the demand for information is greater than ever.

Geological and topographical map of anthracite fields of Pennsylvania, constructed from original explorations and instrumental surveys conducted by Henry D. Rogers, State Geologist (Rogers, H. D., 1858, Pennsylvania Geological Survey, 1st ser., 2 sheets, scale approximately 1:115,620. This map is available to download as a pdf from the Survey's website at http://www.dcnr.state.pa.us/topogeo/gismaps/1858mapanthr.pdf .)



Map of the net thickness of organic-rich shale in the Marcellus Formation (modified from Harper, J. A., 2008, The Marcellus shale – An old "new" gas reservoir in Pennsylvania: Pennsylvania Geology, v. 38, no. 1, p. 2-13. This map and other information related to Devonian shales can be accessed from the Survey's website at http://www.dcnr.state.pa.us/topogeo/oilandgas/.)

And much of the interest can be summed up in one map made by Harper showing the thickness of the organic-rich part of the Marcellus Formation. This, in turn, is the result of 174 years of geologists trudging the fields and streams of Pennsylvania looking for outcrops, and 136 years examining well records, drill cuttings and cores, and geophysical logs and seismic surveys looking for oil and natural gas reservoirs.

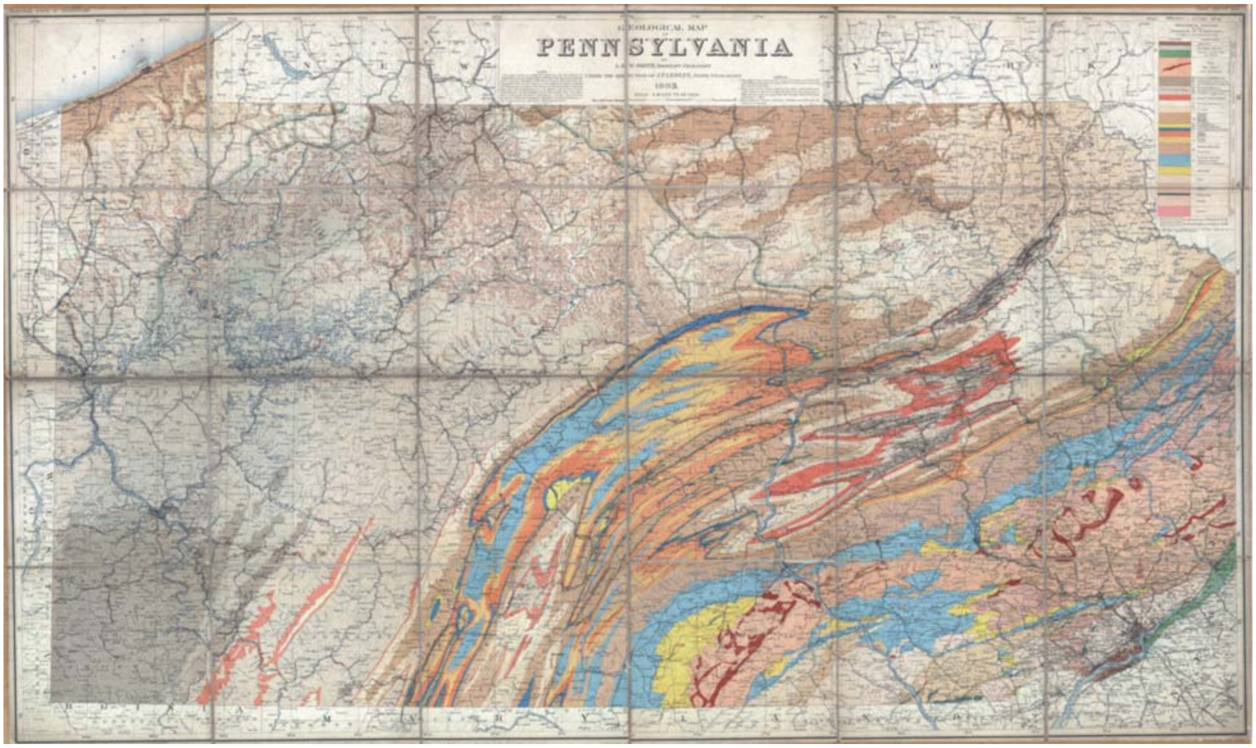
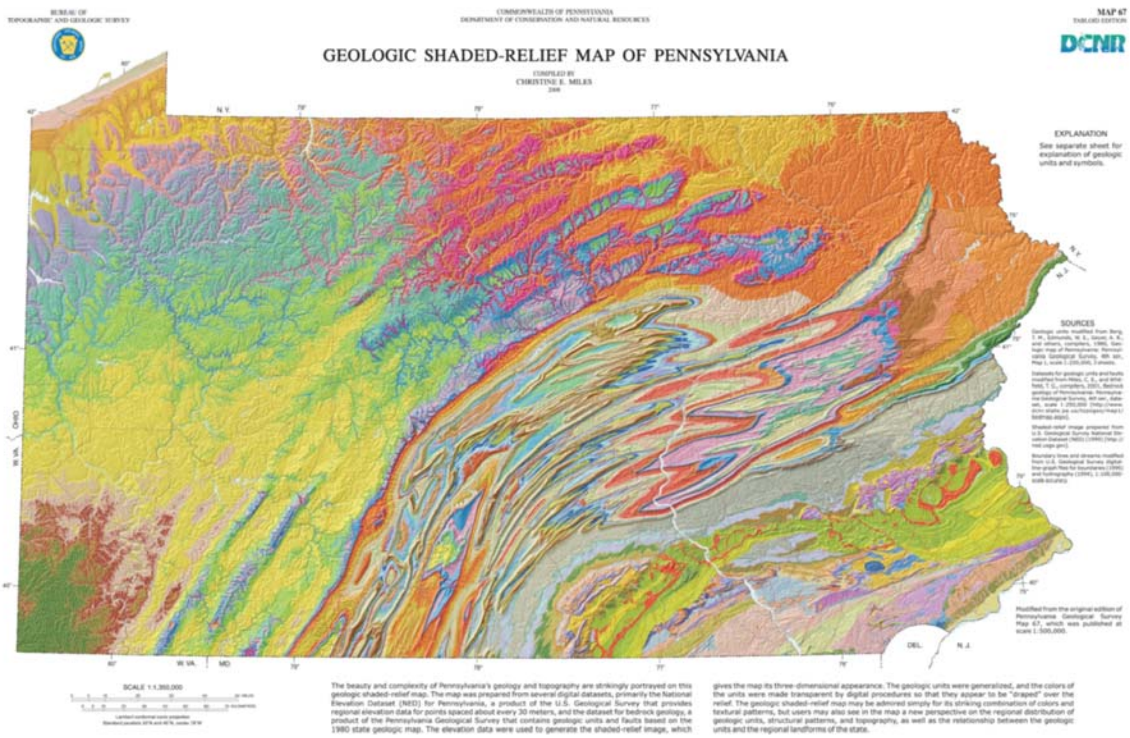


Figure 3. Geologic map of Pennsylvania (Lesley, J. P., 1893,, Pennsylvania Geological Survey, 2nd ser., Atlas, Final Summary Report, 4 sheets, scale 1:380,160. This map is available to download as a pdf from the Survey's website at http://www.dcnr.state.pa.us/topogeo/gismaps/1893geomap.pdf.)

In 1836, 1893, 1931, 1960, and 1980, all years we published wall-size geologic maps, we never dreamed that some day knowing about the Marcellus Formation would be important. But the fact that the Survey collected and maintained the data made it possible to start yet another energy boom.

Our most recent wall-size map (see page 5) is digital and available on-line. Consider what other discoveries remain to be made and may be staring you in the face when you look at a geologic map!



Geologic shaded relief map of Pennsylvania (Miles, C. E., compiler, 2003, Pennsylvania Geological Survey, 4th ser., Map 67, scale 1:500,000.   This map is available to download as a pdf from the Survey's website at http://www.dcnr.state.pa.us/topogeo/pub/map/map067.aspx.)

Practical Uses for Air Pollution, Part 2 – Sulfur Dioxide

John A. Harper, Chief of Geologic Resources
Pennsylvania Geological Survey

Smoke Gets in Your Eyes

In a previous article in this magazine (Harper, 2004), I discussed how carbon dioxide (CO_2) produced during coal combustion in electric power generating plants could be used to enhance the recovery of oil in otherwise depleted reservoirs. This article discusses the uses for another coal-fired power plant air pollutant, sulfur dioxide, that is a major source of acid rain, smog, and respiratory problems when released to the environment.

We are living at a time when our unquenchable thirst for energy has crashed headlong into our ever increasing desire for a clean environment. This raises some very important questions: 1) do we continue to burn fossil fuels that give us a noxious bounty of sulfur and nitrogen oxides, CO_2, ash, and other pollutants and waste products; 2) do we promote the generation of energy through nuclear fission with its by-products that potentially threaten to poison the land for thousands or millions of years; or 3) do we find alternatives to the energy systems, the fuels we use, or to the ways we collect, store, and/or use the resulting waste products? The choice will be crucial to our way of life and to the future of our planetary environment.

Fortunately, there are power companies in this country that have seen the future and are doing something about it. Some are experimenting with renewable energy resources such as wind and solar energy. Some are switching to less polluting fuels such as natural gas. Others are retooling their plants to collect waste products before they can be released to the environment. One company that falls into the latter category is Ohio-based FirstEnergy Corporation, which operates the Bruce Mansfield Power Plant at Shippingport, Beaver County in western Pennsylvania (Figure 1). Bruce Mansfield is the fourth largest fossil fuel plant in the country and the largest east of the Mississippi River. It includes three coal-fired units that produce a total of 2,490 megawatts (MW) of electricity. At full capacity, the plant is capable of

Figure 1. Aerial photograph of the Bruce Mansfield power plant and the National Gypsum Company (NGC) plant in Shippingport, Beaver County, PA.

producing 56 million kilowatt-hours daily (Harper, 2000). But Bruce Mansfield isn't just a coal-fired electric plant. It is also a showcase for an exciting form of environmental technology.

It's Not So Complicated

The combustion of coal in power plants creates flue gases containing sulfur oxides, particularly sulfur dioxide (SO_2), as well as other gases and particulates considered to be contaminants. SO_2 in high concentrations can cause breathing problems and respiratory illness, as well as aggravate existing cardiovascular disease. It is also one of the major causes of acid rain. Many of the coals mined in Pennsylvania, Ohio, and West Virginia have high sulfur contents, enough to cause SO_2 emissions that exceed environmental standards. Rather than transporting cleaner-burning coals from western states or from overseas at great expense, many power plants have had to adopt various clean coal technologies. One of the technologies for reducing SO_2 and particulate emissions is a process called wet flue gas desulfurization (FGD). At Bruce Mansfield the wet FGD process uses a slurry of limestone to remove contaminants, including virtually all particulates and 92 percent of the SO_2 from the boiler flue gases. This is a process called "scrubbing."

Two of the three Bruce Mansfield power-generation units use two-stage scrubber/absorber systems located between the boilers and the 950-foot high smokestack. Scrubber systems use a slurry of finely ground limestone or lime injected into the flue gas as it passes from the burner to the stack. The slurry reacts chemically with the SO_2 in the flue gas to produce calcium sulfite and calcium sulfate precipitates.

The third unit uses a system that consists of electrostatic precipitators, absorbers, fans, and a 600-foot high stack (Figure 2 and Table 1). Electrostatic precipitators remove suspended matter such as dust, fly ash, fumes, or mist from the flue gas stream. They are especially effective in removing very fine particles. As the gas moves through passages within the precipitators, a series of electrodes in the passage centers discharges high-voltage current that ionizes the gases. Ionization charges the suspended particles, causing them to move toward tubes or plates that act as both grounded electrodes and as collectors, which are then rapped to loosen the collected dust. The dust falls into hoppers as fly ash. Liquids are separated out by gravity. All of these waste products can be removed to a holding area or a disposal site, or they can be sold commercially or recycled.

The air quality control system at Bruce Mansfield (number 12 in Figure 2) requires about 515,000 tons of limestone each year, or one ton of limestone for every 11 tons of coal burned. As a result, the plant removes more than 400,000 tons of SO_2 every year. This process helps the company successfully comply with requirements mandated by the US Clean Air Act of 1990.

Making Dollars and Sense of Waste

Wet FGD scrubber sludge generally contains more than 90 percent water, but it can be dewatered using a number of advanced technologies or by simple settling and evaporation in ponds. Dried sludge can be placed in a landfill, or it can be mixed with fly ash to create a fairly impermeable fill material. The construction industry uses fly ash as aggregate or fill, and engineering contractors use it in grouting for mine subsidence remediation. Scrubber sludge, when dewatered, can be used in a variety of agricultural and construction industries.

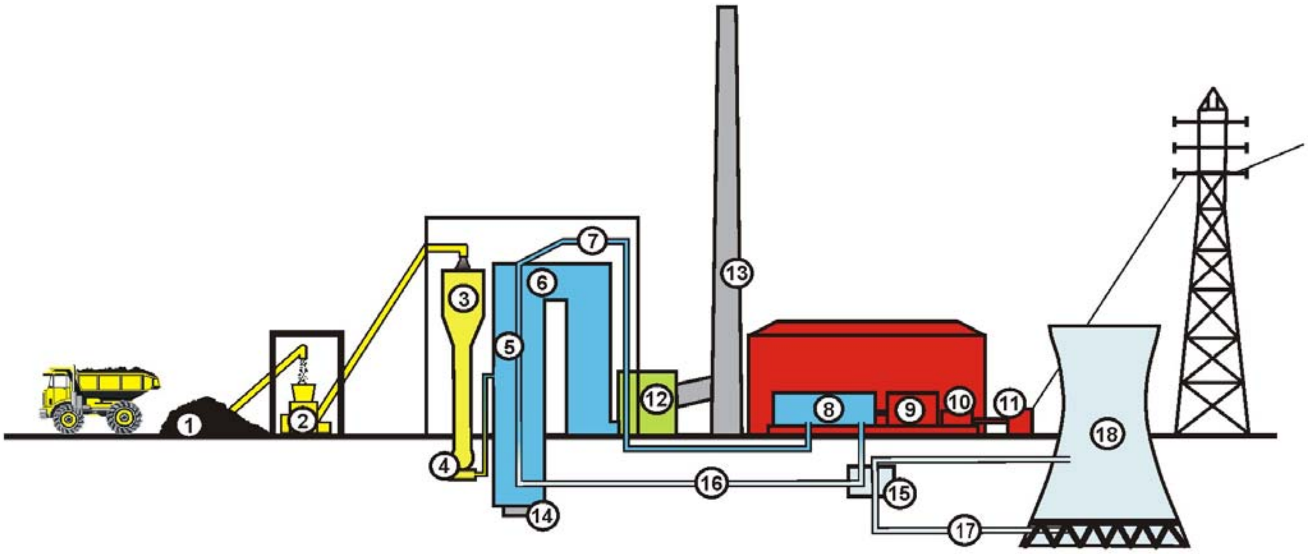


Figure 2. Schematic diagram of a typical coal-fired electrical generation plant with environmental controls (modified from Harper, 2000). Numbered items are described in Table 1. Yellow – fuel source; blue – boiler and heat system; red – electric generation system; light blue – cooling system; gray – disposal system; green – environmental control components.

Table 1. Parts of a Typical Coal-Fired Electrical Generation Plant with Environmental Controls, as Shown in Figure 2. Modified from Harper (2000).

1	**Coal pile**	**Storage of approximately 45-60 days supply**
2	**Crusher house**	**Coal crushed to < 1 in (2.54 cm)**
3	**Coal bunker**	**Storage of 24-48 hour supply**
4	**Coal pulverizer**	**Coal is ground into powder and blown into the furnace**
5	**Boiler**	**Water-filled tubes generate steam**
6	**Steam drum**	**Heat in the boiler produces steam in the top of the drum**
7	**High pressure steam main**	**Steam passes to the turbine**
8	**Turbine**	**Steam causes the turbine blades to rotate**
9	**Generator**	**Produces electricity**
10	**Exciter**	**Produces the electric field of the generator**
11	**Step-up transformer**	**Increases produced voltage to transmission voltage**
12	**Electrostatic precipitators**	**Electronically removes particulates from boiler gases**
13	**Chimney**	**Disperses emissions high into the atmosphere**
14	**Ash hopper**	**Collects heavy ash from the combustion process**
15	**Condenser**	**Cools and condenses steam**
16	**Water recycling**	**Pumps condensed steam back to boiler for reuse**
17	**Cooling water**	**Water for steam condensing from base of cooling tower**
18	**Cooling tower**	**Cools water for steam condensing by evaporation**

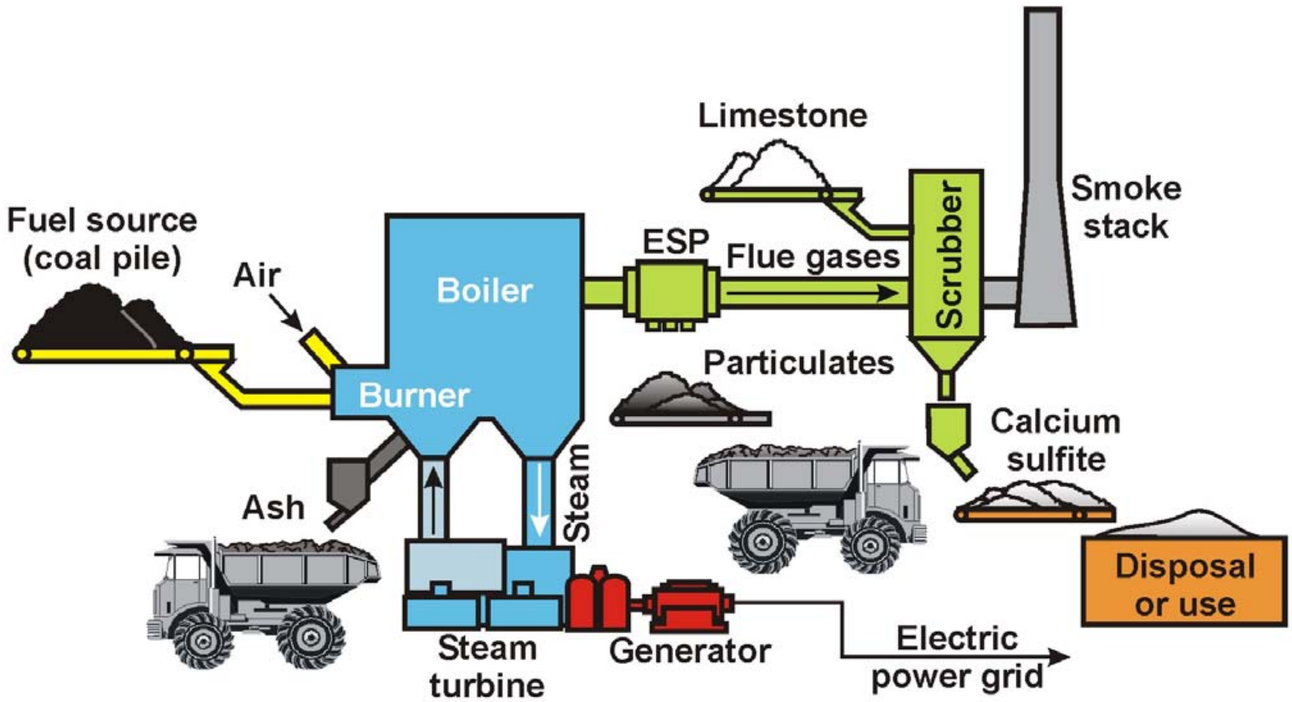


Figure 3. Schematic diagram of a typical wet-flue-gas-desulfurization (FGD) technology. Sulfur products from the scrubber system, such as calcium sulfite, can be disposed of or used commercially. Color scheme as in Figure 2, except orange – calcium sulfite designated for use in gypsum wallboard manufacture.

At full capacity, each of Bruce Mansfield's air quality control systems can produce up to 4,000,000 gallons of scrubber slurry daily. Much of the slurry is pumped through seven miles of underground pipeline into Little Blue Run reservoir, a 1,300-acre disposal site behind the largest earth and rockfill embankment dam in the eastern US. The Little Blue Run reservoir, built in the mid-1970s, originally was supposed to provide the plant with 30 years of disposal capacity (Thiers and others, 1976). With the reservoir nearly at capacity in 2006, FirstEnergy was granted state permission to make the dam higher, allowing its continued use for another 25 years. Still, it is not the best option for disposal of scrubber sludge.

FGD systems frequently are classified according to whether they produce a saleable or a discarded (typically landfilled) by-product. About 70 percent of the FGD technology installed on older power plants in the 1980s produced material that was discarded because saleable by-products were not considered cost effective. More recently, however, regenerable wet FGD systems (Figure 3) have become more attractive as markets for sulfuric acid (H_2SO_4), elemental sulfur (S), or gypsum ($CaSO_4 \cdot 2(H_2O)$) have opened.

The system used at the Bruce Mansfield plant uses forced oxygen technology to treat the slurry. Because of the composition of the wet slurry (calcium sulfite), it can be purified to a commercial grade of gypsum.

In a Fog over Gypsum

The majority of wet FGD waste by-product produced at the Bruce Mansfield plant, after the fly ash has been separated from the slurry, consists of calcium sulfite hemihydrate ($CaSO_3 \cdot ½H_2O$). The plant uses a patented oxidation process called Forced Oxygen to Gypsum (FOG), developed by FirstEnergy and Dravo Lime Company (now part of Carmeuse), to change the calcium sulfite hemihydrate into synthetic gypsum in the form of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) (American Institute of Chemical Engineers, 2000). In this procedure, air is forced (bubbled) through the calcium sulfite hemihydrate, oxidizing it to form a slurry of gypsum ($CaSO_4 \cdot 2H_2O$), which is then dewatered in a device called a hydroseparator. The gypsum solids settle out by gravity, leaving clear water at the top of the hydroseparator that flows to a retention pond for eventual recycling. As a result of their larger particle size, gypsum slurries thicken much more rapidly than normal calcium sulfite sludges. Consequently, hydroseparators may produce 30 to 60 weight-percent of solids, which requires further dewatering. The resultant gypsum product contains about 10% moisture and tends to crust, thereby reducing the likelihood of particle emissions to the environment.

In order to be used as commercial gypsum, the synthetic product needs to be more than 96 percent pure gypsum. In fact, FOG-produced gypsum has higher purity than natural, mined gypsum. The Bruce Mansfield FOG plant, the first full-scale FOG facility, produces up to 70 tons of gypsum per hour (American Institute of Chemical Engineers, 2000). And since there is no compositional difference between synthetic and natural gypsum, whatever you can do with natural gypsum you can do with synthetic gypsum. However, synthetic gypsum provides benefits not found in the natural product – it is cheaper to manufacture and is environmentally friendly. Most synthetic gypsum comes from clean air technology, such as wet FGD. It also makes use of what otherwise would be considered waste material that would take up valuable landfill space. It is non-toxic, has few impurities (mostly minor amounts of fly ash), and can be used by itself or in a mixture with natural gypsum in manufacturing plaster of Paris, gypsum wallboard, roof tiles, cements, fillers for paper, paints, toothpaste, blackboard chalk, lipstick, Epsom salts, and many, many other products.

Wallboard Galore

The FOG plant at Shippingport can produce *at least* 450,000 tons of commercial-grade synthetic gypsum annually, which is then sold to National Gypsum Company (NGC). NGC, based in Charlotte, North Carolina, operates more than 40 facilities, including 19 gypsum wallboard plants, throughout the U.S. and Canada. It is the country’s second largest manufacturer of gypsum wallboard and other construction products. The company built a wallboard manufacturing plant on 118 acres adjacent to the Bruce Mansfield power plant (Figures 1 and 4). When this plant became operational in 1999, it was one of the world's largest single-line gypsum wallboard plants. Two years later, it received the Governor's Award for Environmental Excellence. The plant produces more than 600,000,000 square feet of high-quality gypsum wallboard (dry wall) annually, using only recycled materials. Besides the gypsum from the FOG plant, NGC’s plant also uses recycled paper, produced at the company's subsidiary at Milton (near Williamsport, PA), for the wallboard facing and backing. In fact, most of the products utilized in the manufacturing process are made in Pennsylvania. And 100 percent of the excess material (production waste) is recycled back into manufacturing. In addition, the plant uses natural gas as its primary power source. All combustion sources (kilns) are equipped with ultra low nitrogen-oxide burners and all

Figure 4. Photograph of the National Gypsum wallboard manufacturing plant in Shippingport, PA.

particulate emissions are controlled with state-of-the-art baghouses (large boxes containing numerous bags that remove particulates between 0.01 to 100 microns in diameter).

When it arrives from the FOG plant, the gypsum is milled to a fine powder, which is heated to remove three-quarters of the water in the gypsum lattice. This process produces stucco, a very dry powder that, when mixed with water, will quickly rehydrate and harden. The stucco is fed into large bins, which then feed it into the pin mixer (Figure 5), a machine that blends stucco with water and other ingredients (depending on the type of wallboard being made) to make a paste-like slurry. The mixer then spreads the slurry on a moving stream of cream-colored paper lying on a conveyor system. Another moving roll of gray paper covers this, sandwiching the slurry. The long, continuous sheet of wallboard now travels for about four minutes (to give it time to harden) down moving belts and roller conveyors to the knife, where it is cut into specified lengths. The cut wallboard panels are turned cream-side up and sent into the kiln to dry. Once it leaves the kiln at the "dry end" of the process, the wallboard is sent to a bundler where it is trimmed to exact length, taped in two-panel bundles, stacked and moved to the warehouse to await shipment.

Recycling Hits the Big Time

Fortunately for the world, the Shippingport facilities aren't the only ones turning air pollution into useful products. NGC also has wallboard facilities in Tampa, Florida, and St. Louis, Missouri, that use synthetic gypsum generated from coal-burning power plants. Pragmatic European companies have been using FGD-generated gypsum and other waste products for many years, and several American companies

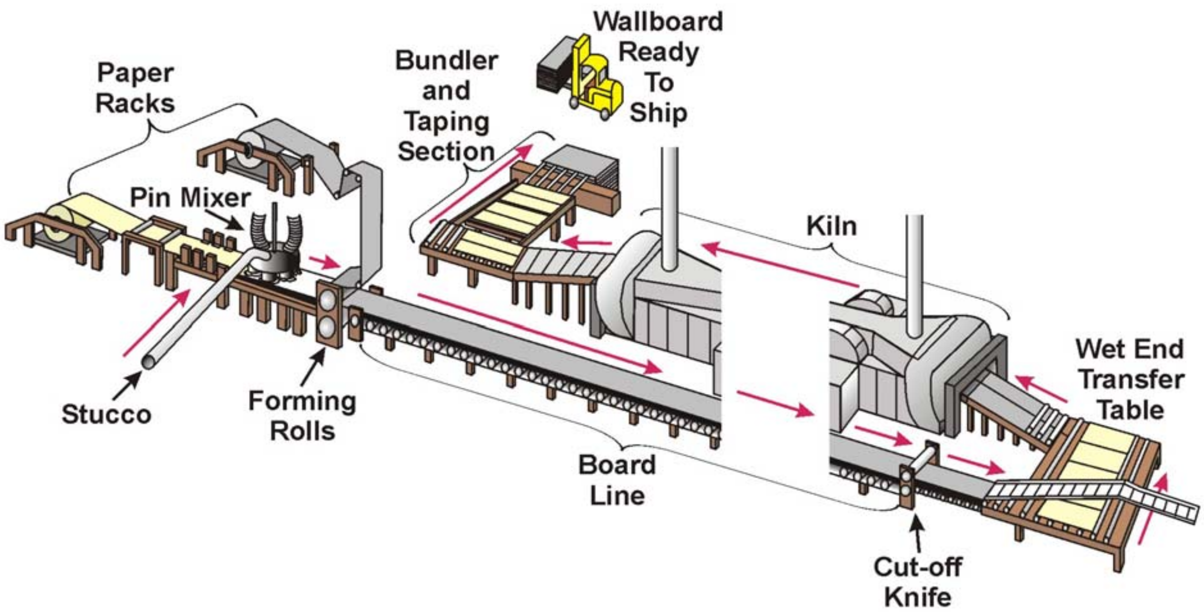


Figure 5. Schematic diagram of a typical gypsum wallboard assembly plant (modified from Harper, 2000). Red arrows indicate direction of movement during the manufacturing process.

have been doing the same since the early 1990s. A quick search of the Internet will find much to read and much to talk about in this exciting aspect of recycling. It is very satisfying to know that many companies, having spent years discharging tons of noxious materials into our air, are now discharging tons of raw materials useful for construction, agriculture, and other industries.

Now, if only they could find a use for nuclear waste!

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IN MEMORIAM

Reginald P. Briggs

1929-2009

The Pennsylvania geological community lost a valued member with the passing of Reginald P. "Pete" Briggs on April 29, 2009. Pete is survived by his wife of 52 years, Rita Ferris Briggs, their three children, and three grandchildren.

Pete was born in Port Chester, New York, and attended public schools in New York, Connecticut, and Arizona. After receiving a BA in geology with a minor in physics from Wesleyan University in 1951, he served two years in the U.S. Army during the Korean War. Pete went to work for the U.S. Geological Survey (USGS) following his military tour, working with coal reserves in eastern Kentucky before spending sixteen years mapping and studying the geology and mineral resources of Puerto Rico. This resulted in numerous reports, maps, and talks on the geology of the Caribbean and its islands. Pete and his family moved to Pittsburgh in 1971 where he headed up the Greater Pittsburgh Regional Geologic Study, a cooperative effort of the USGS, the Pennsylvania Geological Survey, and local geologists from academe and industry. The result of this multi-year study is a huge compendium of maps, reports, and data on the geology, environmental geology, and engineering geology of the six counties surrounding Pittsburgh. When the Pittsburgh area project ended in 1976, Pete chose to leave the USGS and form his own consulting company, Geomega, Inc. Although he spent most of his time working in the greater Pittsburgh area, Pete also found work in the Middle East, Pakistan, and in his old haunts in Puerto Rico.

Pete was very involved in the local (western Pennsylvania), regional, and international geological communities. He was an active member of several professional organizations, including the American Institute of Professional Geologists and the Pennsylvania Council of Professional Geologists. He served as an officer and member of the Board of Directors of the Pittsburgh Geological Society (PGS), most recently as a Counselor where his longevity and wisdom served to provide much good advice to the other Board members. In the early 1980s, he convinced then-State Geologist Art Socolow to involve the Pennsylvania Geological Survey in a project to summarize the geology of the state in a single-volume book. Pete acted as Managing Editor of this project and, with Slippery Rock University professor Chuck Shultz as Editor, saw it through to its final publication after years of struggle with reluctant authors and Survey budget and staffing problems. *The Geology of Pennsylvania*, published by the Pennsylvania Geological Survey in 1999, is a highly regarded and hugely popular book that owes its very existence to Pete's original concept and the tenacity to see it through to the end. He also led field trips for many organizations, including two for PGS - a study of the geology along the light rail transit route in the South Hills of Pittsburgh, and a trek to explore the hardships imposed on General Forbes' army by Pennsylvania's rugged terrain and geology during the French and Indian War.

Pete had a lot of interests outside of his profession. He was a model builder, railroad enthusiast, carpenter, photographer, and world traveler. His interest in history, particularly with respect to 18th to 20th century military and naval history, resulted in a professional paper and several field trip guidebooks examining the engineering geology effort required to get the British army under General John Forbes 217 miles across the Allegheny Mountains from Carlisle to the Ohio River during the French and Indian War. Pete also was a published murder-mystery writer; his novel, *Black Guano*, is set in the Caribbean during the early years of World War I and involves a German guano-mining company, the French security service, and the French Navy.

Pete is sorely missed by those of us who knew him and appreciated his knowledge, hard work, thoroughness, tenacity, and good advice.

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IN MEMORIAM

Samuel T. Pees
1926-2009

Sam Pees, a well known petroleum geologist and oil field historian, passed away on December 27, 2009 in Meadville, Pennsylvania.

Sam was born on November 16, 1926 and raised in Meadville. At an early age he traveled with his father and mother to visit the Drake Well Museum and other areas of oil history in northwestern Pennsylvania. He was fond of telling people that the family used to roll down the windows in their car as they drove by a refinery so they could revel in the odor of crude oil. Thus, it was only natural that, after graduating from Meadville High School in 1944 and serving a stint in the U.S. Army in the Philippines and South Korea during World War II, he attended Allegheny College as a Geology major. He received his BS degree in 1950 and went looking for oil. He later attended Syracuse University in New York and received an MS in Geology in 1959. He did additional studies at Colorado College in Colorado Springs, Colorado, and the University of Tulsa in Tulsa, Oklahoma.

Sam spent most of his professional career as a petroleum geologist, although he also got involved with other mineral resources. While still in college, he worked for the U.S. Geological Survey in Alaska. In 1953 he went to work for the Texas Petroleum Company looking for oil in Venezuela and Peru. In 1962 he was named the South America representative for Skelly International Oil Company, opening offices in both Caracas and Buenos Aires. In the early 1970s he was project leader for a geophysical survey of the islands in the South Pacific. Finally, after 25 years looking for commercial deposits of oil, natural gas, and minerals in 37 countries on five continents, Sam moved back to Meadville in 1978 and organized Samuel T. Pees & Associates. This was an oil-and-gas consulting and advisory company specializing in deep gas exploration in the northern Appalachian basin. Sam and his colleagues studied and mapped the Lower Silurian Medina Group in northwestern Pennsylvania, and contributed significantly to our knowledge of these and other potential hydrocarbon reservoirs through numerous publications and talks at professional society meetings.

Thanks to his early travels with his family, Sam reestablished himself as an avid oil field historian, tirelessly tramping around the historic Oil Creek area studying, photographing, and helping preserve sites, equipment, and artifacts of the early days of oil. He researched and wrote the text for historical markers placed throughout northwestern Pennsylvania commemorating things as diverse as pioneering oil wells and the Mississippian/Devonian-aged sponge, *Titusvillia drakei* Caster. He served as president of the Board of Directors of the Drake Well Foundation for several years, and was the first president of The Colonel, Inc. (now Friends of the Drake Well), an advocacy group for the Drake Well Museum.

Sam retired from active oil and gas work in 1998, but he continued his passion for oil history for several more years. He shared his knowledge, insights, and findings through lectures, field trips, and symposia. He was an engaging speaker and educator, thanks to his passionate interest in his subject.

Sam was a member of numerous professional societies, including attaining the status of Senior Fellow of the Geological Society of America and former chair of the History of Geology Division. He was a member of the American Association of Petroleum Geologists (AAPG), a Certified Petroleum Geologist in its Division of Professional Affairs, and former chair of the History of Petroleum Geology Committee. He was also the recipient of some of AAPG's highest honors, including the national Public Service Award. In 1987 and 1996, he was awarded the George V. Cohee Public Service Award, which recognizes distinguished service and achievement to the Eastern Section AAPG. In 2000, he received the Eastern Section AAPG's prestigious John T. Galey Memorial Award. In 2003, he was awarded the Col. Edwin L. Drake Oilman Award from the Petroleum History Institute in recognition of his lifetime achievement in the oil and gas industry. He was also an Honorary Member of the Pittsburgh Geological Society, and a trustee of the Paleontological Research Institute in Ithaca, New York.

With his passing, oil history has lost a great friend and benefactor.

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The Oriskany Sandstone Updip Permeability Pinchout: A Recipe for Gas Production in Northwestern Pennsylvania?

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and
Kristin M. Carter, Chief of Carbon Sequestration Section
Pennsylvania Geological Survey

Introduction

The Oriskany Sandstone represents a "blanket sand", deposited during Early Devonian time, that is regionally persistent throughout most of the central Appalachian basin, from easternmost Kentucky northward through West Virginia, Pennsylvania, eastern Ohio, and New York (Figure 1). For many oil and gas operators working in this portion of the basin, the Oriskany has been a true workhorse over the past 80 years, having served as a natural gas reservoir, gas storage reservoir, and even fluid waste disposal reservoir in certain situations.

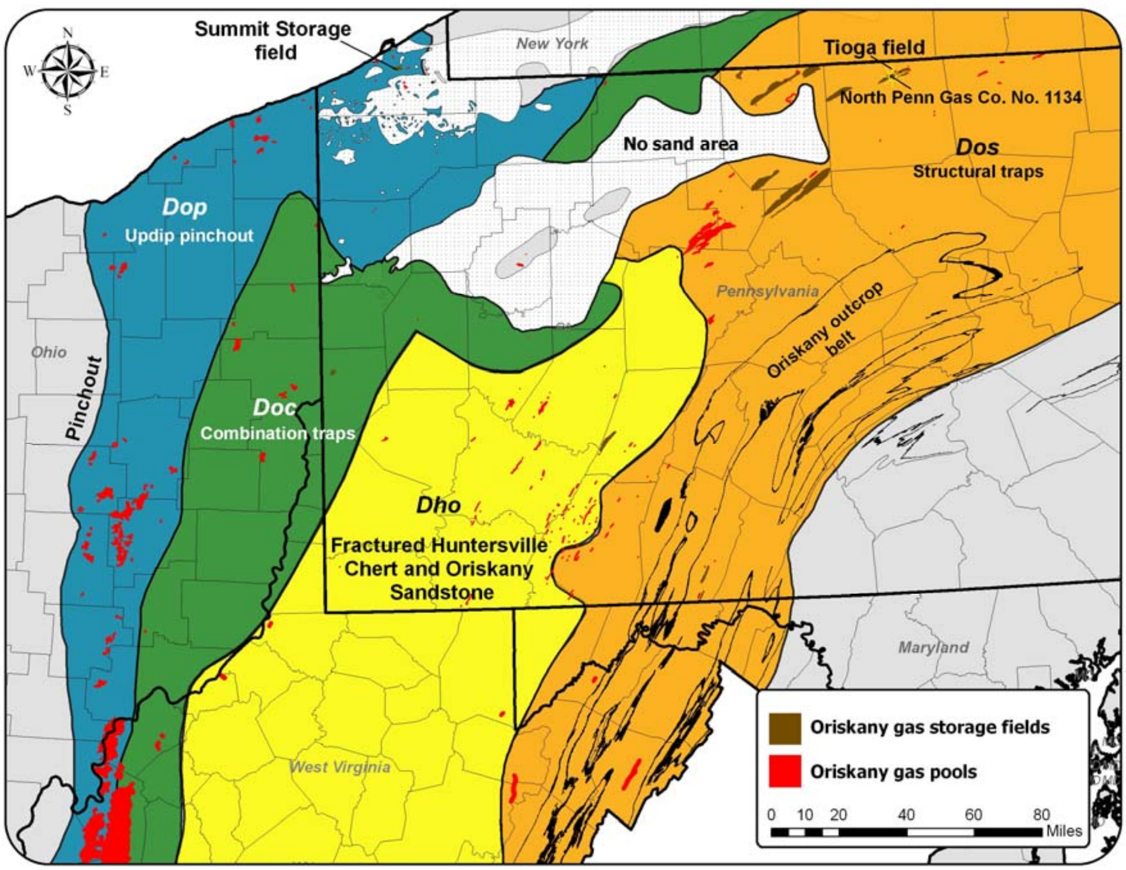

Figure 1. Map of the Oriskany play boundaries in the Appalachian basin (modified from Roen and Walker, 1996). The map also shows all Oriskany gas and gas storage fields and pools. Significant wells, and fields and pools, are labeled.

The Atlas of Major Appalachian Gas Plays (Roen and Walker, 1996), the most comprehensive formal report addressing variations in the Oriskany Sandstone as a natural gas reservoir, divides the unit into four overlapping natural-gas plays in the basin. From east to west these plays include: 1) ***Dos***: Lower Devonian Oriskany Sandstone Structural play; 2) ***Dho***: Fractured Middle Devonian Huntersville Chert and Lower Devonian Oriskany Sandstone play; 3) ***Doc***: Lower Devonian Oriskany Sandstone Combination Traps play; and 4) ***Dop***: Lower Devonian Oriskany Sandstone Updip Permeability Pinchout play (Figure 1). Stratigraphic and structural variations, resulting from a combination of depositional, diagenetic (physical and chemical changes occurring after deposition), and deformational processes, occur throughout the Oriskany Sandstone and are observed on both regional and local scales. This lack of homogeneity complicates the predictability of reservoir quality and makes site-specific characterization a critical step in the exploration and production of natural gas from this unit.

Kostelnik and Carter (2009) provided a detailed evaluation of the Oriskany Sandstone with regard to its geologic carbon dioxide (CO_2) sequestration potential in the Appalachian basin. In this work, the ***Dop*** play was found to have the highest porosity of the four Oriskany plays, averaging between 5 and 6 percent. Because these findings were based on only a limited number of samples from Pennsylvania (our original dataset was based heavily on core and logs from eastern Ohio), we wanted to revisit this play to further evaluate the Oriskany's reservoir properties in the northwestern portion of the state.

Thin sections, rock core, and geophysical well logs are indispensable tools for sorting out variations in Oriskany Sandstone reservoir quality. We used these types of data, obtained from gas wells drilled in Pennsylvania, and combined them with data from eastern Ohio to characterize the Oriskany in the area of the updip permeability pinchout play (herein referred to as the ***Dop*** play; see Figure 1). In this play, natural gas deposits are stratigraphically trapped by a loss of permeability in an updip direction moving toward pinchout boundaries of the Oriskany Sandstone. This pinchout boundary defines the western limit of the play in eastern Ohio; the eastern play boundary occurs in Pennsylvania where structural changes in the rock begin influencing natural gas production. Oriskany Sandstone reservoir data indicate a "sweet spot" throughout the ***Dop*** play and particularly in the Lake Erie region of Pennsylvania. This "sweet spot" is defined by consistently high porosity and permeability measurements and lacks the unpredictability seen in fracture-controlled plays located to the south and east.

Production History

The Oriskany Sandstone was first recognized as a viable natural gas exploration target in Pennsylvania on September 11, 1930 with the completion of the North Penn Gas Company No. 1143 well, which discovered the Tioga gas field in Tioga County (Figure 1). Like Tioga field, the majority of Oriskany and combined Oriskany Sandstone-Huntersville Chert gas fields and pools in Pennsylvania occur in the ***Dho*** and ***Dos*** plays. These fields are elongate, trending from the southwest to the northeast and paralleling the structural grain of the Appalachians.

Since the drilling of that first Tioga gas field well, there have been more than 1,700 wells completed in the Oriskany Sandstone or the combined Oriskany Sandstone-Huntersville Chert interval in Pennsylvania. Of the active wells, 827 produce gas, 239 were converted to service wells in the operation of natural gas storage fields, and 16 are observation wells associated with natural gas storage operations. In addition, there are two brine disposal wells located in Somerset County. Table 1 provides a summary of

Table 1. Well Type Distribution and Cumulative Production from the Oriskany Sandstone in the *Dop* Play of Pennsylvania.

Product	Number of Wells	Total Cumulative Production (through 2007)
Gas	51	168.5 BCF (billion cubic feet)
Storage	22	N/A
Dry	2	N/A
Plugged and abandoned wells	21	N/A

Oriskany Sandstone well types and cumulative production specific to the ***Dop*** play in northwestern Pennsylvania.

Lithology and Depositional History

At the Oriskany type section in Oriskany Falls, Oneida County, New York, the sandstone is a pure white, fossiliferous, quartz arenite that occurs between underlying and overlying Helderberg and Onondaga carbonates, respectively (Vanuxem, 1839) (Figure 2). In Pennsylvania, Oriskany Sandstone varies from relatively pure quartz arenite to calcarenaceous sandstone and sandy limestone (Basan and others, 1980). Calcarenaceous sandstones are usually dominated by quartz but can contain up to 50% carbonate grains. Carbonate grains and cements are the dominant components of sandy limestones, but they also contain quartz sand. The amount of carbonate material in the rock varies as a function of the depositional environment (for example, higher-energy environments produce sandstone that lacks significantly more fossiliferous and finer grained material than lower-energy depositional environments).

Environments of deposition for this unit were variable, ranging from a wave/tide-dominated deltaic system to a shallow-marine shelf system (Basan and others, 1980). Consequently, several different depositional facies developed depending on water depth and position relative to the basin margin at the time of deposition. Oriskany Sandstone lithofacies associated with these depositional facies in

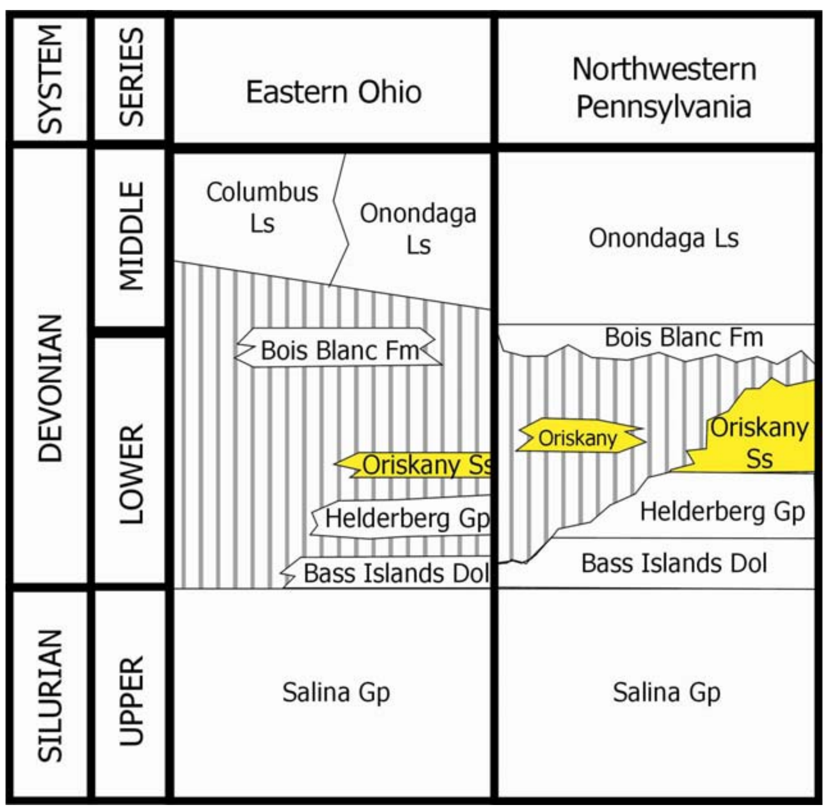

Figure 2. Generalized stratigraphic column of the Lower Devonian and Upper Silurian in western Pennsylvania and eastern Ohio.

Pennsylvania include: 1) conglomerate; 2) shale; 3) sandy quartzose limestone; 4) calcite-cemented, very fine- to medium-grained sandstone; and 5) silica-cemented, fine- to coarse-grained sandstone (Basan and others, 1980). Conglomerate originated as delta-front and shallow-marine bar-sand facies located in eastern Pennsylvania, eastern West Virginia, and Virginia. Deeper-water shale lithofacies, deposited as offshore muds, are recognized in northeastern Pennsylvania and New York. Lime mud containing quartz sand, deposited in the lower shoreface facies located in eastern New York and across Pennsylvania, became sandy quartzose limestone. Upper and middle shoreface deposits observed in western Pennsylvania, western West Virginia, Ohio, and New York include calcite-cemented, very fine- to medium-grained sandstone lithofacies.

Dop **Play**

The ***Dop*** play extends linearly from Ashtabula County, Ohio in the northern Appalachian basin to Jackson County, West Virginia in the south (Opritza, 1996), and includes portions of Ohio, West Virginia, Pennsylvania, and New York (Figure 1). In northwestern Pennsylvania, the play occurs adjacent to Oriskany "no sand" areas, and includes all of Crawford County and portions of Erie, Warren, Venango, Mercer, and McKean counties (Figure 1). The Oriskany "no sand" area corresponds to places where the Oriskany was not originally deposited or was deposited on paleogeographic highs and subsequently eroded. These areas in northwestern Pennsylvania were originally studied by Fettke (1931, 1935). Pools producing from the ***Dop*** play are focused along the northern and western margin of the play boundaries. In Pennsylvania, this includes areas in Erie, Crawford, and Mercer counties adjacent to the Oriskany Sandstone "no sand" areas (Figure 1). The largest pool producing from the ***Dop*** play in Pennsylvania is the former Meade pool in Erie County. This pool, discovered in 1946, included 105 wells targeting the Oriskany Sandstone. Sixty-seven of the wells were successfully completed, and the field produced 5 billion cubic feet (BCF) of natural gas before it was converted to storage in 1959 and renamed the Summit Storage pool (Figure 1).

Within the ***Dop*** play, the Oriskany Sandstone ranges from a pure quartz arenite to a calcareous sandstone. The Oriskany Sandstone is more carbonate-rich in the Ohio portion of the play. The ***Dop*** represents northern basin-margin sediments that accumulated in upper shoreface and beach environments and corresponds to the silica-cemented, fine- to coarse-grained sandstone lithofacies. This lithofacies was deposited as shallow-marine bar sands, delta-front sands, and shoreface and beach sediments in western Pennsylvania, New York, and Ohio. The beach deposits formed in a semicircular pattern from New York around the Appalachian basin's western margin, including parts of northwestern and north-central Pennsylvania and eastern Ohio. (Basan and others, 1980). This lithofacies contains clean quartz arenites cemented with silica. All finer-grained material was washed away by currents during deposition. The lower portion of the Oriskany has some carbonate cement that has reduced the porosity (open space in the rock) and permeability (interconnectivity of the pore space) in this part of the unit (Basan and others, 1980).

The Oriskany Sandstone becomes deeper and thicker to the southeast in the Pennsylvania ***Dop*** play. It is approximately 900 feet (ft) deep along the Lake Erie shoreline and deepens to 3,000 ft in Mercer and Venango counties, adjacent to the "no sand" area at the southeastern edge of the play.

Where present, the Oriskany Sandstone ranges from 1 to about 100 ft thick. In Erie and Crawford counties, the Oriskany averages 10.3 and 10.8 ft thick, respectively. The average thickness in Warren County is a bit higher - 13.6 ft. The greatest average thicknesses occur at the southern limit of the play in

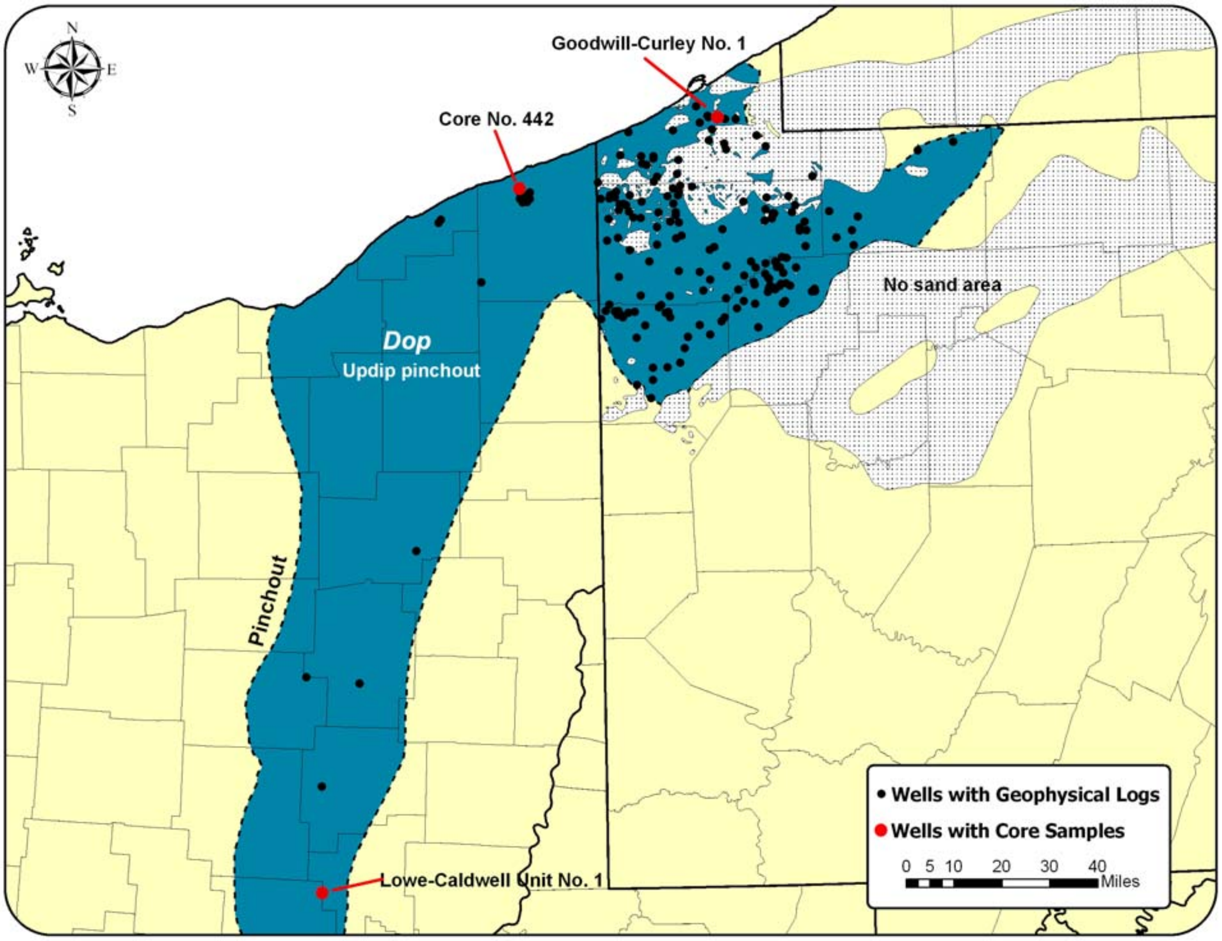

Figure 3. Map of the Oriskany Sandstone updip permeability pinchout play in Pennsylvania and part of Ohio, showing locations of wells with core samples and/or geophysical logs used in evaluating the Oriskany in this study.

Pennsylvania, with averages of 16 and 26 ft in Mercer and Venango counties, respectively. Most of the productive Oriskany wells in the ***Dop*** play occur in Erie County where measured depths vary from 1,702 to 3,170 ft, subsea elevations range from 1,100 to 1,300 ft, and the sandstone averages 10 ft in thickness.

Petrology and Reservoir Characteristics

Oriskany Sandstone reservoir characteristics are related to both depositional and diagenetic history. Unraveling the history of the physical and chemical changes that take place after sediment is deposited is crucial to understanding the variations in reservoir quality that occur within this mostly stratigraphic play (there is a minor structural component to it, the result of salt mobilization in the underlying Salina Group – see Kelley and McGlade, 1969). In order to thoroughly evaluate the ***Dop*** play, we analyzed these features using thin sections from the Fred C. Gerald No. 1 well in Ashtabula County, Ohio, and the Goodwill-Curley No. 1 well in Erie County, Pennsylvania. We also evaluated porosity and permeability using an existing core and geophysical log data from the Lowe Caldwell No. 1 well, located in Noble County, Ohio. Porosity values were calculated using geophysical logs from numerous wells located within the ***Dop*** play (Figure 3).

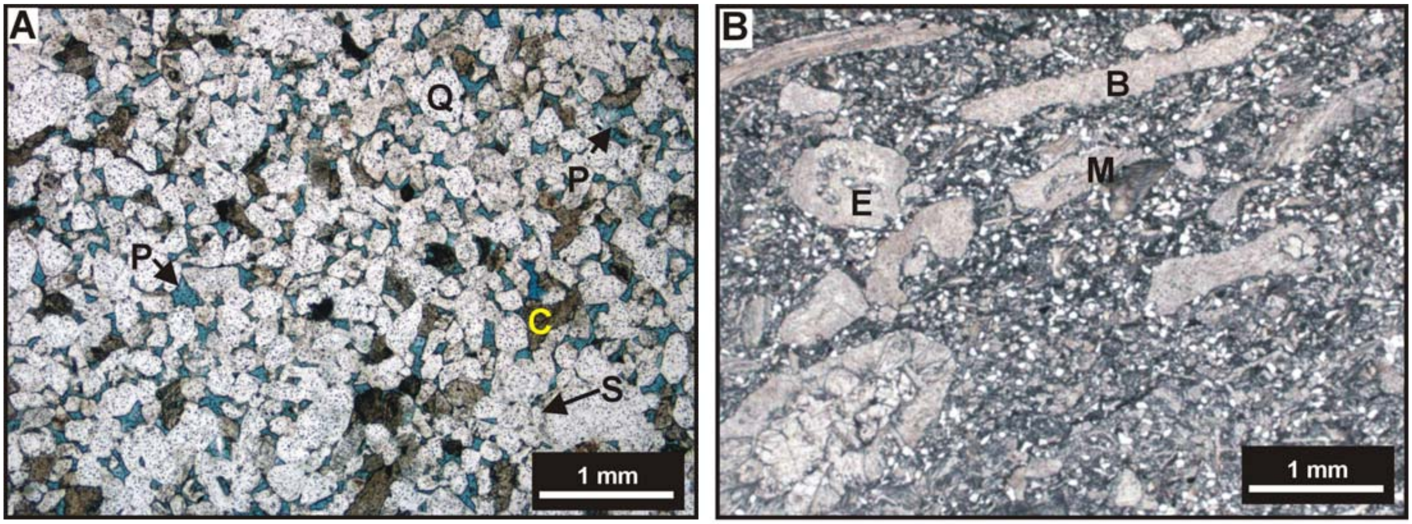

*Figure 4. Thin section photomicrographs of Oriskany Sandstone in the **Dop** play displaying typical lithologic characteristics. The blue color in this, and subsequent thin section photomicrographs, indicates porosity, as does the P in A . A – Quartz arenite from the Goodwill-Curley No. 1 well, Erie County, Pennsylvania, depth 2,358 feet. The rock is composed of subangular to subrounded monocrystalline quartz grains (Q), little or no matrix, and less than 10 percent carbonate material (C). It is cemented with silica (S) and a very minor amount of calcite cement. B – Sandy limestone from Guernsey County, Ohio, representing the most carbonate-rich section of the play. Mollusc (M), brachiopod (B), and echinoderm (E) fragments are the dominant rock constituents. The rock also contains a considerable amount of carbonate cement and matrix.*

Adjacent to Lake Erie in both Pennsylvania and Ohio, near the northern boundary of the play, the Oriskany is a quartz arenite containing only minor amounts of carbonate material, present as both grains and cement (Figure 4A). Clastic rock components include 95 percent monocrystalline quartz, rock fragments, and minor amounts of trace materials (glauconite, feldspar, rutile, and zircon). Quartz grains are rounded to subangular, and boundaries between adjacent grains are mostly long or concavo-convex. Interlocking grain boundaries are observed in some of the thin sections. Some Ohio samples taken from near the southern and central portion of the play contain up to 30 percent carbonate material and are classified as calcareous sandstone (Figure 4B).

Diagenetic processes observed in the ***Dop*** play include cementation, dissolution of grains and cement, replacement of carbonate grains by micrite (lime mud), and compaction. Dissolution and cementation are the most important of these processes because they have the most direct impact on the creation and reduction of porosity and permeability. Cement observed throughout the play includes quartz, calcite, and, to a lesser extent, dolomite. Precipitation of cement was a major process, both early in the diagenetic history of these rocks, shortly following deposition, and later during burial. Quartz overgrowth cement formed on detrital grains (Figure 5A). Variable calcite cementation followed. The calcite cement ranges from coarse crystals having approximately equal dimensions to micrite (Figure 5B). Cementation reduced the primary intergranular porosity in these rocks and the connectivity of the remaining pore space (permeability), but where carbonate material is absent, primary porosity has been preserved.

Dissolution was an important process responsible for the creation of secondary porosity in the ***Dop*** play. Carbonate cement, carbonate grains, and plastic grains such as feldspar have been dissolved from these quartz arenites, as evidenced by carbonate grain and cement remnants lining pores, corroded quartz grains, and enlarged or irregular pore shapes (Figure 6). In some cases, we observed porosity textures

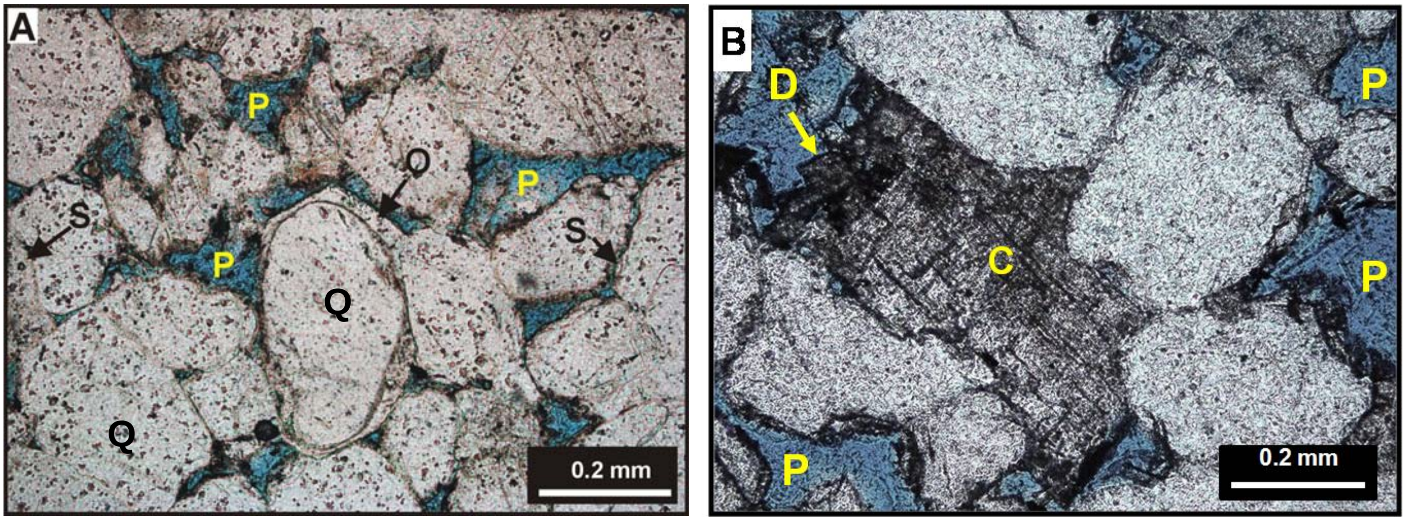

Figure 5. Thin section photomicrographs of Oriskany Sandstone in the ***Dop*** *play. A – Silica cement occurs as overgrowths (O) on quartz grains (Q). The occurrence of dust rims and sutured grain contacts (S) between the overgrowths and the original quartz grain make this cement easy to discern. B. A sparry calcite crystal (C) fills primary pore space between quartz grains. The top of the calcite crystal has been partially dissolved (D). P in both figures indicates porosity.*

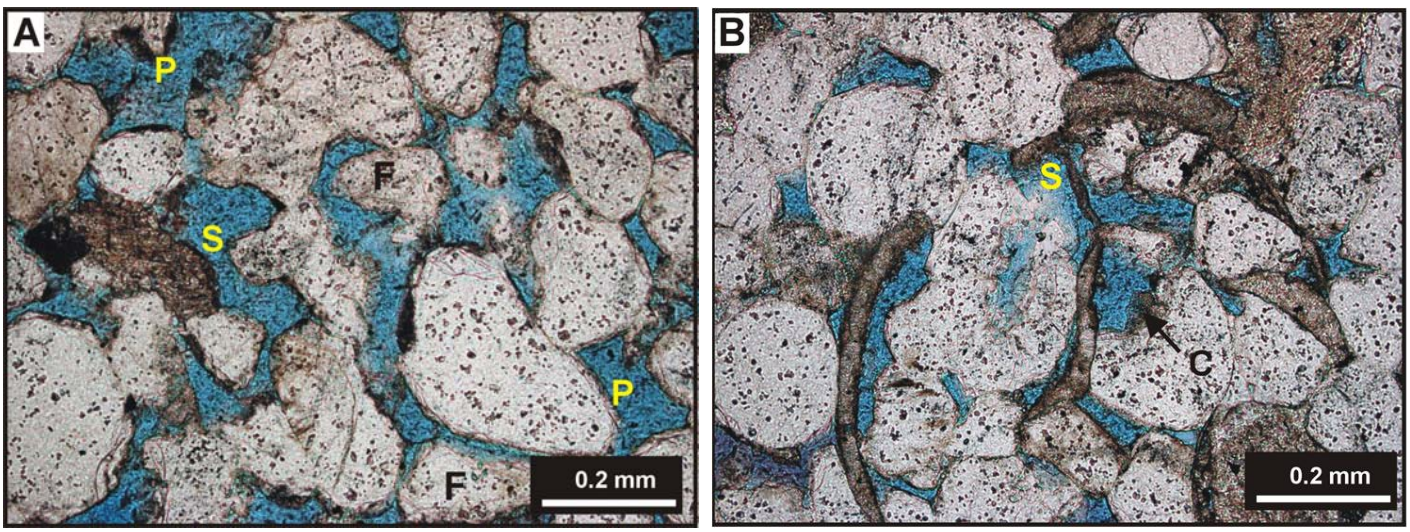

Figure 6. Thin section photomicrographs of Oriskany Sandstone in the ***Dop*** *play showing enhanced primary (P) and secondary (S) porosity from dissolution of grains and cement in quartz arenite from the Goodwill-Curley No. 1 well, Erie County, Pennsylvania. A – Floating grains (F) indicate that original cement has been dissolved. Irregularly-shaped pores also suggest that carbonate or feldspar grains have dissolved out. B – Some original carbonate grains and cement remain, but oversized pores lined with calcite remnants (C) suggest that dissolution has enhanced primary porosity and created secondary porosity.*

resulting from the complete dissolution of grains. Dissolution is most apparent in the upper portion of the Oriskany Sandstone interval, where leaching of carbonate material occurred, as was documented in the Leidy field in Clinton and Potter counties (Harper, 1990). This pore system is well connected, enhancing the permeability of the rocks. Deeper in the subsurface, the Oriskany tends to be more tightly cemented, thus less porous and permeable.

Compaction is a physical process that leads to porosity reduction through a change in packing, orientation, fracturing, and plastic deformation of detrital grains (Pettijohn and others, 1987). In our deepest Oriskany samples, compaction is revealed by the presence of stylolites (pressure solution surfaces) observed in cores and thin sections. Pressure solution as a result of compaction occurs at point contacts between quartz grains, increasing solubility and causing the grains to preferentially dissolve and eventually reprecipitate as quartz overgrowth cement. Sutured grain contacts and concavo-convex grain boundaries also result from pressure solution (Figure 5A). This is a late-stage diagenetic process associated with burial (Pettijohn and others, 1987).

The only available core analysis for the ***Dop*** play is from the Lowe-Caldwell Unit No. 1, located in Noble County, Ohio (Figure 3). This well was drilled to a depth of 5,510 ft and penetrated the entire Oriskany interval from 3,961 to 3,972 ft. The Oriskany in this well is a white-gray calcareous sandstone with abundant brachiopod fragments. Permeability ranges from <0.1 millidarcy (md) to 185 md. The average permeability is 42.7 md. The highest permeability zone occurs at 3,864.1 ft to 3,865.6 ft. Average porosity is 5.7 percent.

Table 2 summarizes the salient reservoir properties of the Oriskany Sandstone in the ***Dop*** play of Pennsylvania, based on the evaluation of geophysical logs from 178 wells. In the study area, the measured depth to the Oriskany ranges from 1,702 to 4,640 ft, and averages 3,367 ft. Where present, the gross thickness of the unit varies from 1 to 41 ft, averaging 14 ft. We calculated reservoir porosity using available density porosity and neutron porosity logs and all values are reported in Table 2.

Table 2. *Dop* Play Reservoir Quality in Pennsylvania.

	Measured Depth to Reservoir (ft below ground surface)	Gross Thickness (ft) (178 samples)	Average Density Porosity (%) (135 samples)	Average Neutron Porosity (%) (68 samples)
Minimum	1,702	1	0.7	0.8
Maximum	4,640	41	16.9	17.0
Average	3,367	14	8.3	5.0

SUMMARY AND CONCLUSIONS

The Oriskany Sandstone of the ***Dop*** play has some of the most prospective reservoir characteristics observed in the Appalachian basin, recording average porosities of 5 to 8 percent and permeabilities of 43 md, based on the current study. Maximum porosity and permeability values of 17 percent and 185 md are also very impressive. Although the Oriskany of the ***Dop*** play tends to be thinner than that of other Oriskany plays, its depositional and diagenetic history is well understood, making the Oriskany's reservoir characteristics more predictable here than in other areas of the basin. Even though a majority of the deep penetrations in northwestern Pennsylvania have targeted the "tight" reservoir sands of the Lower Silurian Medina Group, the geophysical and petrographic evidence presented herein suggest that the Oriskany Sandstone may not always be the best natural gas reservoir, but definitely has the right mix of porosity and permeability to be seriously considered for carbon sequestration or wastewater disposal.

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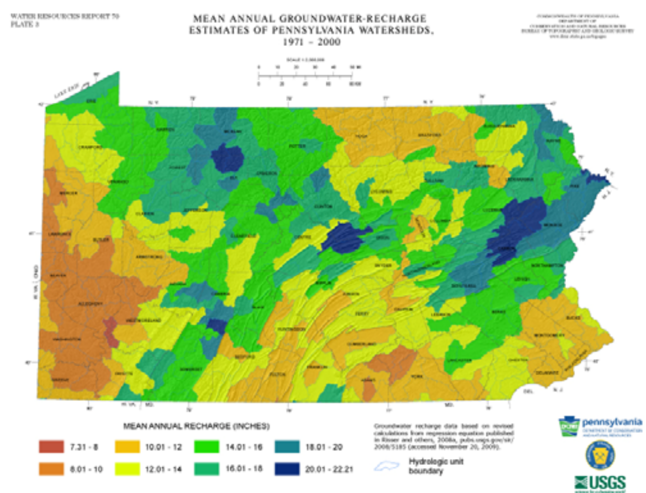
NEW RELEASE

Pennsylvania Groundwater-Recharge Study



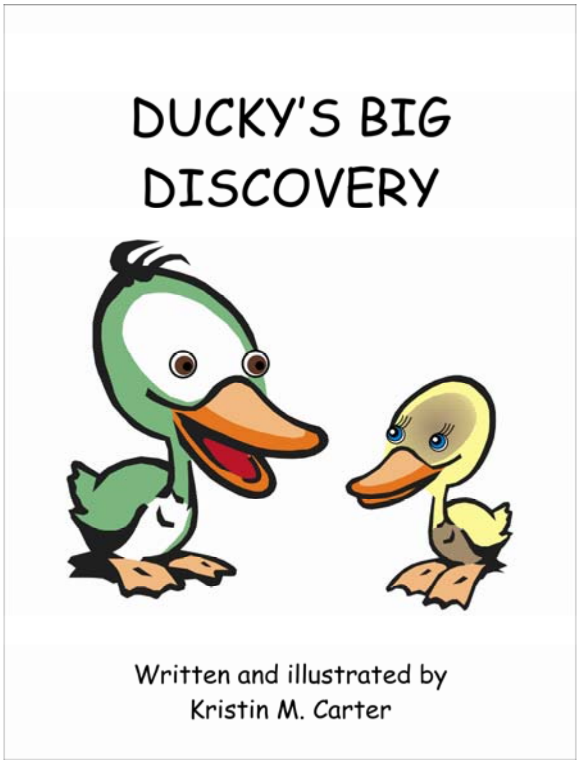
The Pennsylvania Geological Survey, in cooperation with the U. S. Geological Survey (USGS), has released Water Resource Report 70, **Summary of groundwater-recharge estimates for Pennsylvania**. The report is 18 pages long and includes 6 page-sized plates. It is available online as Portable Document Format (PDF) file at http://www.dcnr.state.pa.us/topogeo/pub/water/w070.aspx.

This report, written by Stuart Reese (Pennsylvania Geological Survey) and Dennis Risser (USGS), provides an overview of processes affecting recharge in Pennsylvania and summarizes estimates of recharge rates from studies at various scales. Included maps show the main factors that affect recharge and provide additional information about the spatial distribution of recharge across the state. The maps present the patterns of precipitation, temperature, and winds across the state, and show the spatial variability of recharge as a percent of precipitation. National, statewide, regional, and local values of recharge, based on numerous studies, were compiled to allow comparison of estimates from various sources. Together these plates provide a synopsis of groundwater-recharge estimations and factors in Pennsylvania.

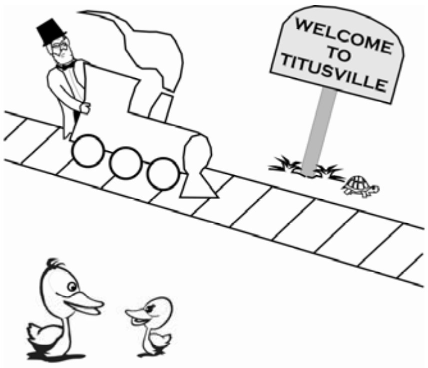
ANNOUNCEMENT

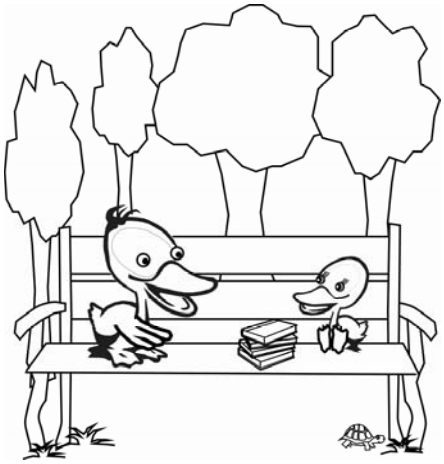
New Coloring/Activities Book Makes Oil History Fun

Released in honor of the Drake Well's 150th anniversary in 2009, **Ducky's Big Discovery** takes a look at oil history through the eyes of two young ducklings, Drake and Ducky. Drake and Ducky visit the Oil Creek Valley to learn about "Colonel" Edwin Drake's well, petroleum geology, energy resources, and different aspects of the early oil industry in northwestern Pennsylvania.

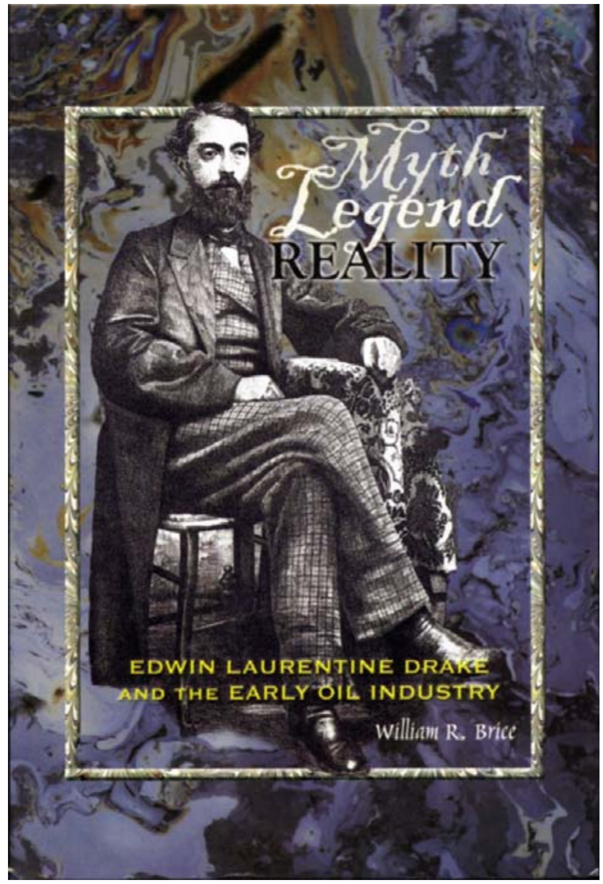


Ducky's Big Discovery was authored and illustrated by Kristin M. Carter, Chief of the Carbon Sequestration Section in the Survey's Pittsburgh office. The book can be purchased for $5.00 from the Drake Well Museum, Titusville, PA by calling 814-827-2797 or ordering on-line at http://www.drakewell.org. All proceeds from the sale of this book benefit The Friends of Drake Well, Inc.





BOOK REVIEW



Myth, Legend, Reality: Edwin Laurentine Drake and the Early Oil Industry
by William R. Brice

Much has been written over the years about how the modern petroleum industry originated in Titusville, Pennsylvania, on August 27, 1859 when “Colonel” Edwin L. Drake completed the first commercially successful oil well drilled specifically to find oil. So, of course, 2009 was the sesquicentennial of the Drake Well, with a year-long celebration throughout the oil region of northwestern Pennsylvania.

One aspect of this celebration was publication of a new book, **Myth, Legend, Reality: Edwin Laurentine Drake and the Early Oil Industry**, a comprehensive look at the drilling of the Drake Well. The author, Dr. William R. Brice, Emeritus Professor of Geology at the University of Pittsburgh at Johnstown, is a long-time advocate of the history of geology and the history of petroleum. His research on the subject of Drake has resulted in a very compelling story of the history of oil and the founding of the modern petroleum industry.

The book begins with a recounting of the history of petroleum, starting with ancient civilizations using materials such as bitumen for mortar around 3,000 BCE. The ancient Greeks, Romans, and Carthaginians used distilled crude oil for a variety of purposes, including hurling fireballs at their enemies with catapults, or spreading oil on the sea and setting fire to it to burn enemy boats. The Chinese had a complete petroleum industry by 100 BCE, having found both oil and natural gas while drilling wells to obtain brine for salt. From the Dark Ages of Europe, through the Middle Ages, Renaissance, and into the time of the Industrial Revolution, we learn of the discoveries and uses of oil. Even in North America, crude oil and other petroleum materials had been known and used for thousands of years. Once Europeans settled in the Appalachian region, they began finding oil seeps along creeks and inadvertently producing oil along with brine in salt wells. Many readers will be surprised to learn that liquid crude oil had been produced from dug and drilled wells for thousands of years before Drake was born!

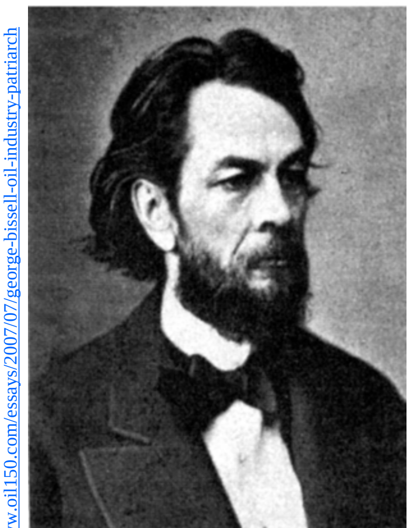
The story of “Colonel” Drake and the drilling of the Drake Well begins at Chapter 3 with Drake’s birth 1819 and continues through Chapter 9 with Drake’s death in 1880. Over the course of the narrative we learn that the supply of whale oil, the primary source of fuel used for lighting in the first half of the 19th century, was very expensive and in short supply. Alternative fuels such as kerosene refined from coal also were expensive, and were being produced in limited quantities. Samuel M. Kier, a Pittsburgh businessman


http://www.oil150.com/essays/2007/02/samual-kier

Samuel M. Kier

and the salt-well operator, invented a process to refine crude oil from salt wells into kerosene as early as 1848, but still the supply was small and would not satisfy the demand for lighting across the nation.

Then in 1854, a sample of crude oil from a seep on Oil Creek near the small lumbering village of Titusville came to the attention of a New York lawyer and businessman named George H. Bissell. Bissell and his partner, Jonathan Eveleth, organized the Pennsylvania Rock Oil Company. They leased the land where the oil seep occurred and hired Benjamin Silliman, Jr., a prominent chemistry professor at Yale University, to analyze the oil. He found a way to distill crude oil into many useful products, and Bissell and Eveleth published his report to show potential investors the value of investing in their new business. They eventually interested a group of New Haven, Connecticut, businessmen in the venture. However, it didn't take long for things to turn sour. Brice tells of the trials and tribulations of Bissell and Eveleth's endeavor in surprising detail, relating how the venture almost failed as the result of some rather underhanded dealings in New Haven. First, the New Haven group took control of the Pennsylvania Rock Oil Company. Then, in 1858, they organized the Seneca Oil Company and leased the oil seep land from the Pennsylvania Rock Oil Company, essentially cutting off Bissell and Eveleth from the business they started. Edwin L. Drake was named General Agent of the new company, and he went to Titusville in the spring of 1858 to produce oil for the Seneca Oil Company.


http://www.oil150.com/essays/2007/07/george-bissell-oil-industry-patriarch

George H. Bissell

Drake, being somewhat familiar with salt-well drilling, conceived of the idea of drilling for oil instead of just bailing it from pits dug in the sand and gravel of Oil Creek Valley. He bought a steam engine and other equipment, designed an engine house and derrick, and hired a salt well driller to man the drilling. As a result, on August 27, 1859, although Drake's well came in at a paltry 69½ feet, it produced enough oil to get a lot of people excited. The world has not been the same since.


http://explorepahistory.com/displayimage.php?imgId=184

"Colonel" Edwin L. Drake

There are many places in North America and Europe that CLAIM to have started the modern oil industry, but close scrutiny shows that the claim is made on the basis of oil from a salt well, an oil seep, or oil distilled from coal. The closest legitimate claim comes from Enniskillen, Ontario, on the basis of a well **dug** with pick and shovel by James Wilson a year before the Drake Well came in. The point, however, is not about who first discovered oil, who was the first to drill a well and produce oil, nor who had the first commercial oil well. Those claims belong to the ancients. The point is about who started the modern petroleum revolution. That claim goes to Edwin L. Drake, a man with a vision who obtained oil in commercial quantities by using technology that, in modified form, is still used today to recover untold billions of barrels of oil and trillions of cubic feet of gas.

The story of "Colonel" Drake goes beyond the Drake Well. Brice provides a heart-rending story of how this American hero was treated badly by his so-called friends back in New Haven who provided little support, financial or otherwise, for the pioneering endeavor in Titusville. Drake was often forced to rely on the good hearts of the town's merchants and his friends for credit and support. In addition, Drake suffered from an extremely painful and debilitating disease that eventually confined him to a chair for the remainder of his life. As a result of his affliction, and a spate of bad investments, the Drake family became destitute. In 1873, by official Act, the Pennsylvania legislature voted to give Drake and his wife a $1,500 per year pension for the remaining years of their lives in appreciation of the millions of dollars the oil industry gave to the state coffers in the way of taxes. Brice witheringly notes that, "this Act [eventually] cost the Commonwealth of Pennsylvania approximately $65,000, or 6.5% of the total revenue collected up to 1873, the year the Act was passed . . . but it seemed to be in poor taste to have included the section about the million dollar revenues that the Commonwealth had received when the Act then provided only $1,500 per year."

This book is thoroughly researched, with 430 pages of narrative, quotations, and numerous illustrations, a very useful index, and 65 pages of end notes and extensive references for anyone wanting to delve deeper into the subject. It has 137 pages of appendices ranging from the articles of incorporation for the Pennsylvania Rock Oil Company to complete texts of letters by the story's participants, the complete text of Benjamin Silliman's crude oil analysis, and general information on the oil industry.

As wonderful as this book is, it is not without its flaws. First of all, there is a lot of wasted space due to wide margins, especially at the bottom of the page. The block of text generally is about 4.5 X 6.5 inches printed on 7 X 10 inch paper, which seems like an excessive waste in this age of environmental concerns. There are many illustrations, but some have text printed over them that distracts from both the illustration and the text. Typos and proofing errors are relatively few, but I found them distracting nonetheless. What annoyed me the most, however, is the author's use of repetition. Brice tends to repeat information from numerous quotations in the narrative, apparently to explain what has been said in, to me, very plain language in the quotes. There are also a few cases where information is repeated in succeeding paragraphs as though the author had written a paragraph twice and, unable to decide which paragraph he liked better, included them both.

Still, **Myth, Legend, Reality: Edwin Laurentine Drake and the Early Oil Industry** is a truly entertaining, enjoyable, and educational read, and a wonderful addition to any historian's or oil buff's library. It is available from the Oil Region Alliance of Business, Industry & Tourism in Oil City, Pennsylvania for $40.00 plus a $5.00 shipping and handling fee, a very reasonable price for a hard-bound book of 660 pages. Information for ordering can be found on-line at http://www.oilregion.org/Store/, and you can call to order at 814-677-3152. If you are in the Oil City-Titusville area, you can stop in at the Oil Region Alliance's offices at 217 Elm Street, Oil City and pick up a copy (and save shipping and handling fees). The Alliance has many other book titles and items of oil history in stock. Be sure to check out all of their products.

—John A. Harper
Pennsylvania Geological Survey

Recent Publications

Water Resource Report **(March 2010)**

- W 70—Summary of Groundwater-Recharge Estimates for Pennsylvania

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

- Bedrock Geologic Map of the McVeytown 7.5-Minute Quadrangle, Juniata and Mifflin Counties, Pennsylvania

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

- Surficial Geology of the Lehighton 7.5-Minute Quadrangle, Carbon and Lehigh Counties, Pennsylvania
- Surficial Geology of the Pohopoco Mountain 7.5-Minute Quadrangle, Carbon and Monroe Counties, Pennsylvania

Park Guide Addendum **(January 2010)**

- Addendum to PG 4—Muddy Creek Oil Field

Surficial geology open-file reports: **(December 2009)**

- Surficial Geology of the Jackson Summit 7.5-Minute Quadrangle, Tioga County, Pennsylvania, and Steuben County, New York
- Surficial Geology of the Mansfield 7.5-Minute Quadrangle, Tioga County, Pennsylvania

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Contributed articles are welcome. Guidelines for manuscript preparation may be obtained at www.dcnr.state.pa.us/topogeo/pub/pageolmag/pageolguide.aspx or by contacting the editor at the address listed above. To subscribe, send an email to RA-pageology@state.pa.us.

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