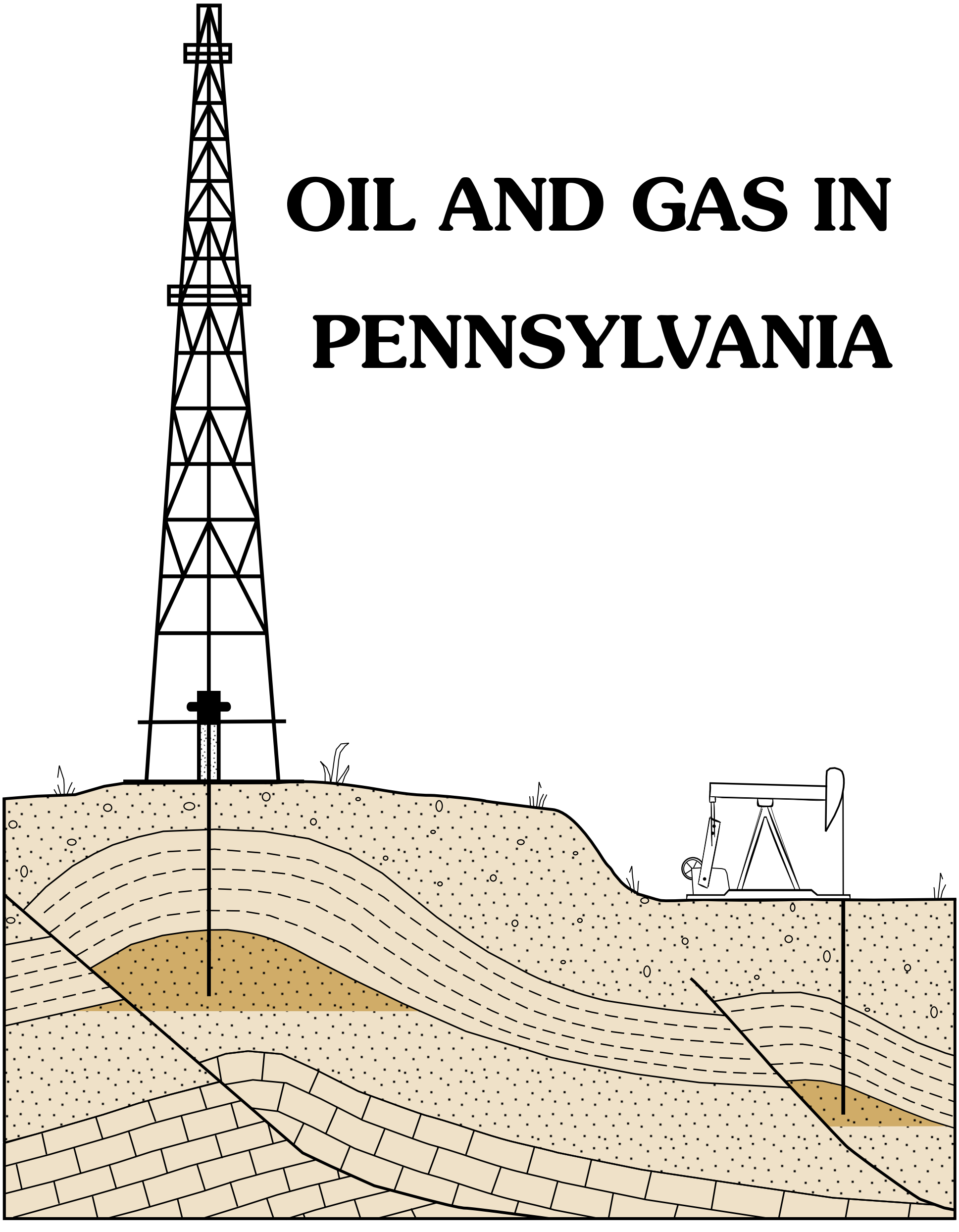
Educational Series 8

OIL AND GAS IN PENNSYLVANIA



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Educational Series 8

Oil and Gas in Pennsylvania

by Kathy J. Flaherty
Abarta Oil and Gas Company
and Thomas Flaherty, III
Department of Environmental Protection

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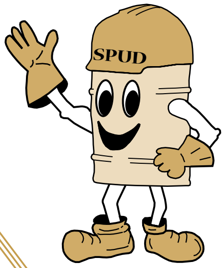
Hi! I'm Spud. "Spud" is a word used by oil and gas drillers. It means "to begin to drill a well." I'll be taking you on a tour of the oil and gas, or petroleum, industry. We'll look at many aspects of oil and gas, such as how they are found and produced, and how they are used.



Turn to the back cover of this booklet. Take a few minutes to look at the chart, which shows the kinds of rocks that lie underground in Pennsylvania. The symbols for the different rock types are also used in other figures in this booklet. This figure will be a handy reference as you read about oil and gas in Pennsylvania. Let's get started!

OIL AND GAS IN PENNSYLVANIA

by Kathy J. Flaherty[1] and Thomas Flaherty, III[2]

WELCOME TO THE OIL AND GAS PATCH!

Think fast! Paint, acrylic carpets, and deodorant have something in common. Do you know what it is? Suppose we add gasoline and WD–40 to the list? Got it now? They are all by-products of oil and gas, or petroleum. You may not realize just how much your life is affected by petroleum.

Let's take an example from part of your typical day. You woke up this morning and stepped onto the *acrylic carpet.* You reached for your *eyeglasses* and *toothpaste tube,* then headed down the freshly *painted* hallway. You popped a *CD* or a *cassette tape* into your stereo to sing along with as you closed the *shower curtain* and reached for a *plastic bottle* of shampoo. After a refreshing shower of *hot* water brought to you through *plastic water pipes,* you applied your *deodorant,* a dab of *perfume* or *aftershave,* and dressed in *synthetic running shoes* and a *sweater.* You used a *hair dryer, comb, brush,* and *lip balm,* and headed for the kitchen. You put your sandwich in *plastic wrap* and some soup in a *thermos bottle.* You pulled up a *vinyl* chair to the *Plexiglas®* table, ate your breakfast, and sipped orange juice from a *plastic cup.* On your way out the door, you swished your dishes in *dishwashing liquid* and unwrapped a piece of *bubble gum.* You put your *pen* and *tennis racket* in your *backpack* and grabbed your *boots, umbrella,* and *waxed-paper-bag* lunch. After placing a quick *telephone* call, you started your *car* or jumped onto the *bus,* all set for the day, thanks to petroleum!

Oil goes into nearly everything. It is a key ingredient in a wide variety of products essential to modern everyday life. Look around your home, school, or office, and imagine life without the benefits of petroleum.

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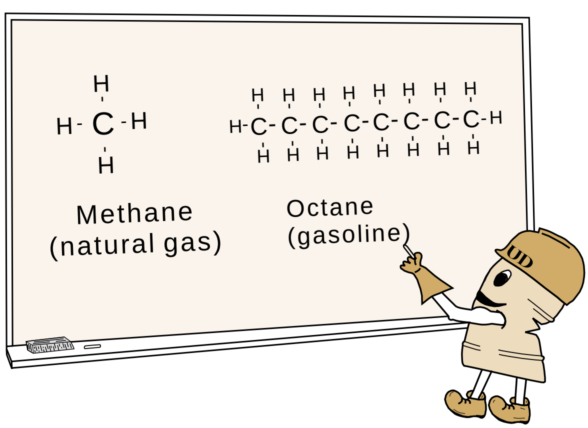
WHAT IS PETROLEUM?

So what is this substance called petroleum that seems to be everywhere in our daily lives? To answer that question, we need to start at the beginning. The basic building blocks of the world are tiny particles known as ***atoms.*** Everything is made of atoms. Each atom has a nucleus that is surrounded by at least one electron. The number and arrangement of the electrons around the nucleus are different for each element. Clusters of two or more atoms are called ***molecules.*** The elements hydrogen and oxygen, for example, combine to form water molecules. Petroleum molecules are made mostly of the elements hydrogen and carbon. Hydrogen and carbon can combine in many different ways to form these ***hydrocarbon*** molecules, which vary greatly in size and shape. Carbon atoms can connect with up to four other atoms, and hydrogen atoms can connect to only one. Therefore, hydrocarbons usually form as carbon chains surrounded by hydrogen atoms.

Hydrocarbons make up petroleum, which occurs naturally. Petroleum is found in two forms: oil, commonly called crude oil, and gas, commonly referred to as natural gas. Typical crude oil consists of 85 percent (by weight) carbon, 13 percent hydrogen, 1 percent sulfur, 0.5 percent nitrogen, and 0.5 percent oxygen. Natural gas may consist of 75 percent carbon, 20 percent hydrogen, 0.1 percent sulfur, and 4.9 percent nitrogen. However, crude oil or natural gas from different locations are never exactly the same.

HOW DOES PETROLEUM FORM?

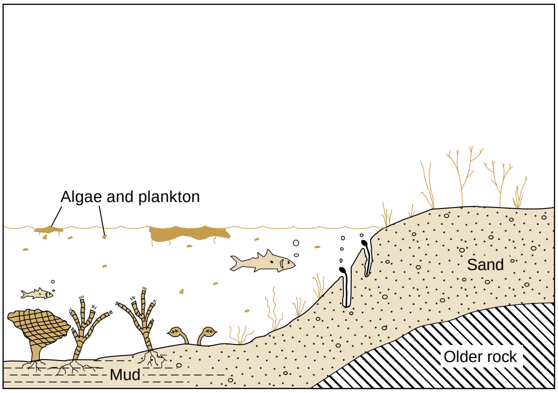
Variability in the composition of petroleum is related to how



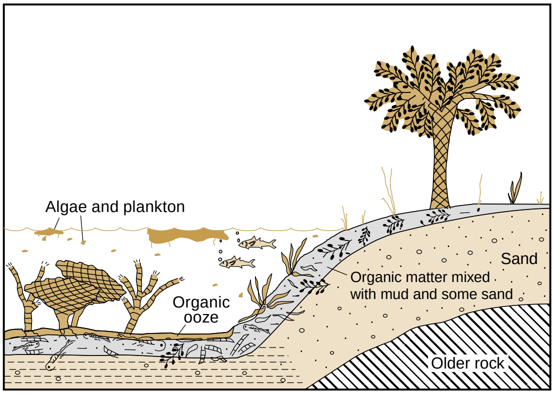
Here a hydrocarbon molecule, there a hydrocarbon molecule. Slight differences in organization result in totally different substances.

it was formed. Geologists believe that petroleum is produced from organic matter found in rocks.

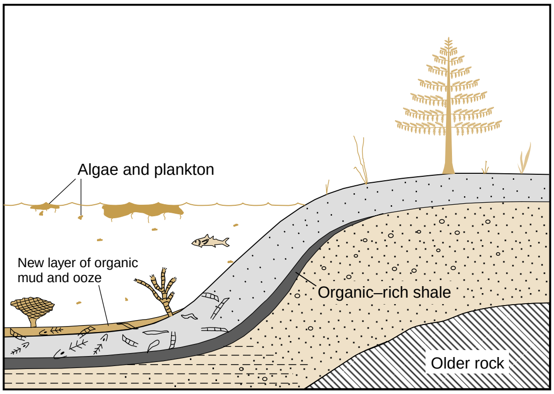
Many sedimentary rocks contain organic matter formed from the remains of dead plants and animals. Most of the rocks under Pennsylvania are sedimentary rocks. The climate at the time these rocks were formed was very different than it is today. The air was warm, and a shallow sea covered much of the region in an elongated basin (the Appalachian basin) that stretched from Newfoundland to Alabama. Mountains bordered the eastern section of what is now New Jersey. Plankton, fish, corals, marine plants, algae, and shellfish were abundant in the sea. At times, evaporation caused portions of the sea to dry up, leaving shallow, isolated ponds. Plants grew on the land surface between the ponds. The mountains eroded very slowly. Streams flowing toward the sea carried grains, pebbles, and gravel broken away from the eroding mountains. These were deposited and became sandbars, beaches, and soil. They were then covered with more and more material eroding from the mountains. Meanwhile, plants dropped leaves and branches onto the land and into the sea. They were covered with sand and



Living things became organic debris that accumulated over time.



The accumulating organic materials were covered with mud, sand, and gravel and still more organic material.



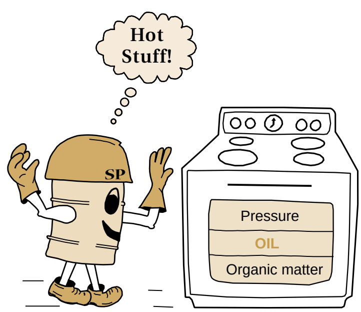
The muddy organic layer was compressed and hardened to form shale.

gravel. Dead creatures and masses of dead algae and plankton sank to the muddy bottoms of the ponds and sea, and were slowly buried and pressed down by more layers of mud, sand, and gravel. The muddy bottoms of the ponds and sea hardened and became shale. Grains, gravel, and pebble layers hardened into sandstone and conglomerate.

You see now that various processes form sedimentary rocks, including the deposition of sediments that have been moved from other places by wind or water. Chemistry plays a role in the decaying of plants and animals. Some sedimentary rocks contain abundant organic material—the hydrogen and carbon that will become petroleum. These are called ***source rocks,*** and they occur at various depths below the earth's surface.

When a source rock is buried beneath the earth's surface, the organic material is subjected to heat and pressure. These forces transform the organic material into hydrocarbon. The chemical composition of the hydrocarbon depends on several factors: the nature of the original organic material, the amount of pressure (deeper burial means higher pressure), the temperature (deeper burial means higher temperature), and the length of time the rock is buried (usually measured in millions of years).

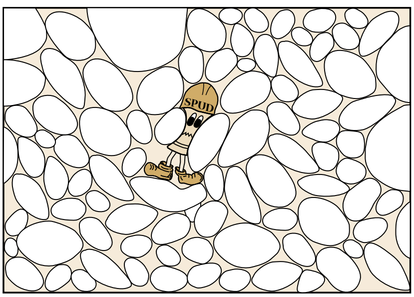
Want to cook up some petroleum? The recipe is simple: just combine a few tons of organic matter, a few thousand pounds per square inch of pressure, and set temperatures between 140°F and 320°F (60°C and 160°C) for a few million years to make oil. Natural gas requires a slightly higher temperature: 212°F to 392°F (100°C to 200°C).



FINDING PETROLEUM

Where do you find oil and gas?

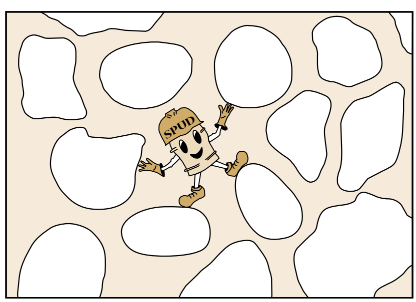
Petroleum (both oil and gas) moves through open spaces between grains in the rocks. It migrates upward into places that have lower pressure and temperature (closer to the surface of the earth). The petroleum collects within a ***reservoir.*** A reservoir is a rock layer, such as sandstone, that serves as a container to hold the petroleum. Open spaces in the rock are called ***pores.*** Rocks having lots of pore space are high in ***porosity***—an important characteristic of oil and gas reservoirs. A reservoir having high porosity can hold a greater amount of petroleum. Porosity can be high if the particles do not fit together perfectly; it can also be high because of openings that are formed either when a rock is fractured or when minerals in the cement holding the grains together are dissolved. In Pennsylvania, the porosity of oil and gas reservoir rocks ranges from none at all to more than 50 percent, and averages 12 percent. This means that 12 percent of the rock is open space.



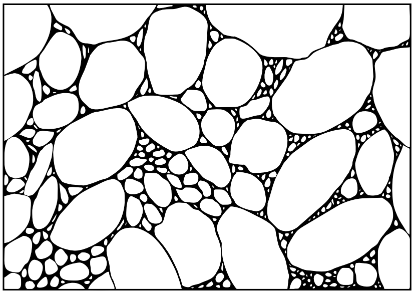
Porosity is a measure of the amount of space between the particles that make up a rock. Here, grains of similar sizes allow for pore spaces between them.

The ease with which petroleum moves from one pore to another is called ***permeability*** and is determined by the size of the openings that connect the pores. If permeability is high, petroleum has the ability to move relatively easily. Petroleum is slow to move through a rock that has low permeability.

In addition to high porosity, high permeability is also key to a good petroleum reservoir. High permeability is desirable because petro-

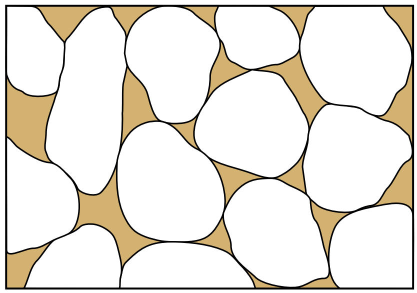


Permeability is a measure of the ease of movement between pore spaces in a rock.



In a rock having a mixture of grain sizes, the smaller grains can clog the pores between the larger grains. This is one of many ways a rock can have low porosity and permeability.

leum that can move throughout a rock can be removed easily from the reservoir. ***Impermeable*** rocks, or those with no communication between pore spaces, serve as good ***cap rocks*** to seal the petroleum within the reservoir. Cap rocks function much like caps on bottles. Shale is a great cap rock due to its low permeability.



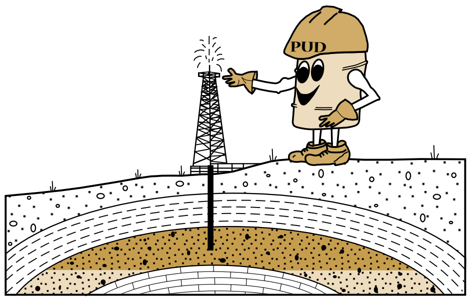
Lack of communication between pore spaces makes this porous sandstone impermeable. Any petroleum present is locked within the pores.

There is nothing like a good trap!

Oil and gas migrate until they become blocked by a cap rock. Because they cannot move any farther, they become trapped. Two common types of traps known to geologists are ***structural traps*** and ***stratigraphic traps.*** In Pennsylvania, petroleum is found in both types of traps.

A geologic ***structure*** is formed when the rock layers become folded (bent) or faulted (broken) by pressure from shifting landmasses. Structural traps occur where the rock holding the oil or gas is isolated from other porous and permeable rocks by folds or faults that prevent the petroleum from escaping. Looking for oil and gas means looking for the kinds of structures that may trap them. Understanding how geological structures are formed and where they can be found is important to petroleum exploration.

Stratigraphy is the study of strata, or layers of rock. Sediment, such as sand and small stones, and organic matter are deposited in layers, or beds. Variations in the type of materials, as well as processes such as cementation that harden the sediment to rock, result in beds of rock



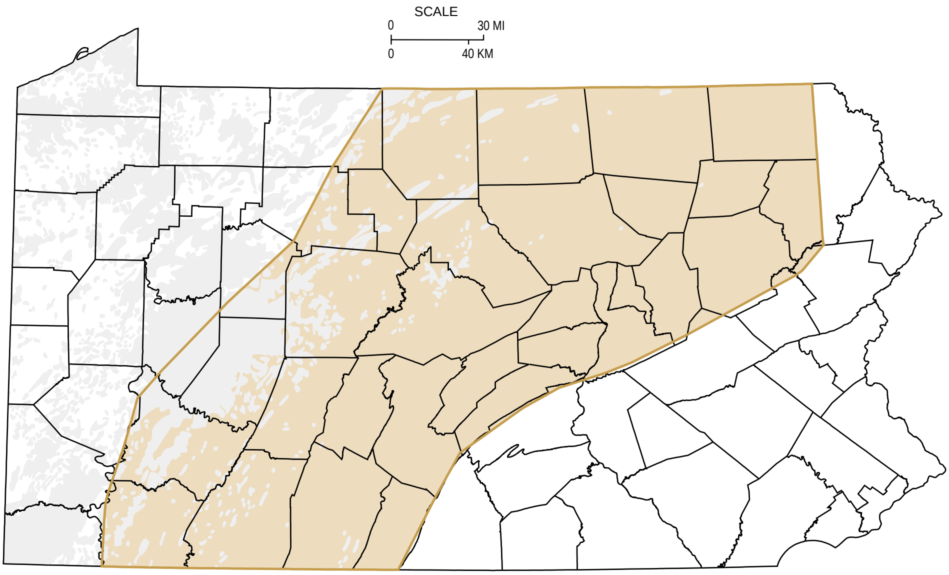
This structural trap, shaped like an arch, is called an anticline. The petroleum cannot escape from the sandstone because the rocks above and below the sandstone are impermeable. The sandstone and petroleum are sandwiched between them. Having migrated through the sandstone to this location, the hydrocarbon fluids separate out in the reservoir; gas rises to the top, water (which was present within the sediments) sinks to the bottom, and oil, where it occurs, remains above the water and below the gas.

that change character both laterally and vertically. Even slight changes in the characteristics of rock can be enough of a barrier to cause it to behave like a trap to the migrating petroleum. A stratigraphic trap occurs where oil and gas collect in the more porous rocks, like sandstone, and are sandwiched in place by the less permeable shale. Of course, it's possible in nature to have a ***combination*** trap, which is a mixture of the features from both structural and stratigraphic traps.

Why is it important to know all of this? Petroleum occurs beneath the earth's surface at depths anywhere from a few hundred feet to several miles. We obtain that petroleum by drilling a hole through the rocks until a reservoir is encountered. Therefore, it makes sense to have a good idea about where reservoirs may be found before starting to drill.

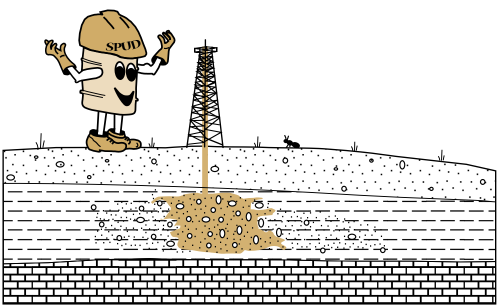
Let's go on a hunt!

We know that petroleum is trapped within a reservoir, and therefore the search for petroleum involves using ***subsurface*** information to go on a hunt for reservoirs and traps. This process is known to geologists as ***prospecting.*** Much modern petroleum prospecting is done indoors on paper or with the aid of computers. This usually means combining art with science. To be a good prospector, it is necessary to think in terms of three-dimensional space. The idea is to conceive and build a three-dimensional picture or model that shows the lateral and vertical dimensions of the target reservoir. Then the prospector knows where to begin drilling on the surface in order to intersect the reservoir.



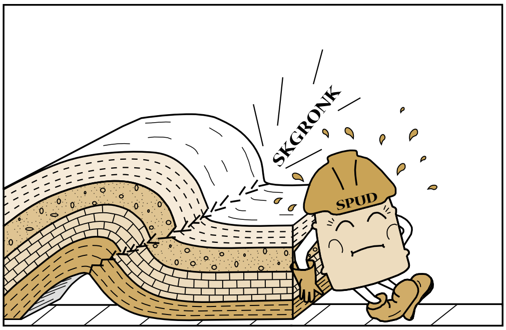
The area enclosed by the heavy colored line is that part of Pennsylvania most likely to produce natural gas from structural traps. The gray areas indicate where oil or gas is already being produced.

To create a three-dimensional image of a target reservoir, a geologist needs information. This information comes from many sources. First, the rocks on the earth's surface are studied. If there are existing holes drilled in the prospect area, information from these holes is studied. Subsurface data can be obtained by remote-sensing processes such as ***seismic reflection.*** In seismic reflection, a large number of sensors are placed on the ground in a long line leading away from a noise-making device. Sometimes the device is an in-ground explosion, and sometimes it is a large truck that has a vibrator attached, called a "thumper truck." When all of the sensors are lined up, workers generate

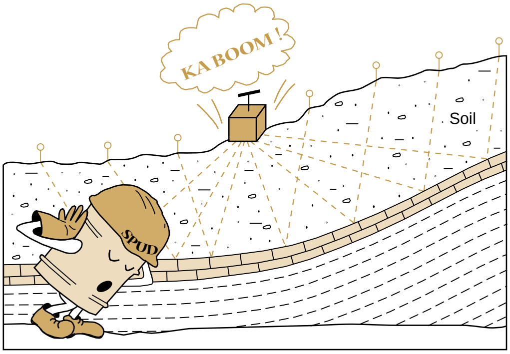


A stratigraphic trap holds petroleum within the more porous rock. The petroleum cannot migrate into the less porous and less permeable rocks that surround it.

Geologists construct models to help understand earth processes, such as the formation of this fold and fault. A simple three-dimensional sketch or computer model usually serves the purpose quite nicely.



the noise. Sound waves created by the noise travel downward and horizontally. As the sound waves travel downward, they encounter the different types of rocks and are reflected back to the surface, where they are "heard" by the sensors. Different rock types reflect the waves differently. Some rocks, such as limestone, return a very firm sound wave. The sensors record this information. A sketch that represents the way the rocks are lying deep below the surface of the earth can be created. Interpretations of the recorded data enable the geologist to learn more about the rocks too deep to be seen.

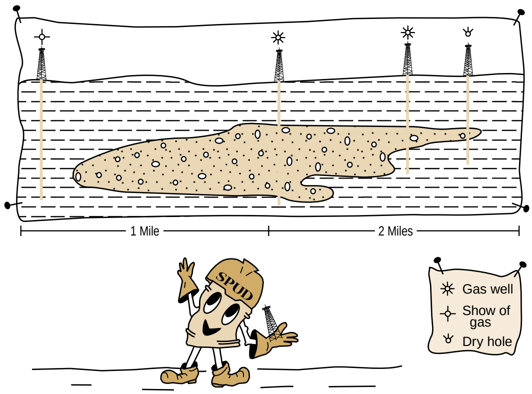


Seismic sound waves are induced by a small explosion. Receivers collect the echoes of these vibrations, and scientists compile the information, which may give clues about the deeper rock units.

Geologists may begin interpretation by drawing ***cross sections*** of the oil- and gas-bearing rocks. Cross sections show side views of how the reservoir changes in depth, rock type, and thickness in a given direction.

Next, the geologist may draw ***isopach,*** or thickness, maps to show where the reservoir is thickest. This is important because the thicker the reservoir, the more petroleum it may hold.

Structure maps can be constructed to show the geologist how the layers of the earth have been folded, faulted, or otherwise distorted un-



Spud uses a cross-section diagram to select a good spot in the thick part of the reservoir to drill a new well.

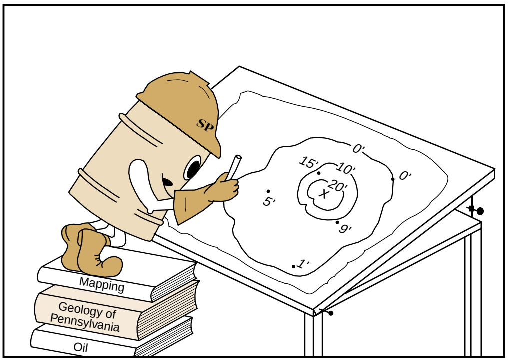
derground. Geologists can use the structure map to target the higher portions of a fold or the side of a faulted sequence of rocks where oil and natural gas have accumulated.

By using tools such as isopach maps, cross sections, structure maps, and results from seismic or other remote-sensing surveys, a geologist constructs a three-dimensional view or model of the geometry and characteristics of the rock reservoir before drilling for petroleum. The model helps the geologist to determine where to drill a well. The goal is to find the most ideal spot in the oil and gas reservoir, where it is thickest, is the most porous and permeable, has a good trap, and is structurally desirable.

DRILLING FOR OIL AND GAS

Let's drill here!

Once the geologist has determined the best location on the surface for a well, the next step is to plan for and obtain a permit to drill the well. In Pennsylvania, the Department of Environmental Protection, Bureau of Oil and Gas Management, issues such permits. To qualify for a permit, the well must be planned in an environmentally responsible manner. It may be necessary to shift the exact position of the proposed well location in order to accommodate en-



"X" marks the spot! An isopach map shows where the reservoir rock is at its thickest, and therefore where it may be the most productive.

vironmentally sensitive natural resources such as streams and wetlands or endangered and protected wildlife areas.

The distance from other producing wells can also be a consideration, because it is important not to position existing oil and gas wells too closely. Crowding might decrease the production of existing wells. The placement of the access road that leads from the paved highway to the proposed well location is important. Care must be taken to minimize the impact on the surface landowner by avoiding croplands and pastures as much as possible. Because construction of the access road and well site usually involves moving considerable amounts of earth around with a bulldozer, all plans should be designed to prevent any erosion and sedimentation.

Sometimes it is a challenge to find an environmentally acceptable drill site in a geologically favorable area. It is the job of the well operator to conduct business in a responsible way with as little environmental disturbance as possible.

Turning to the right

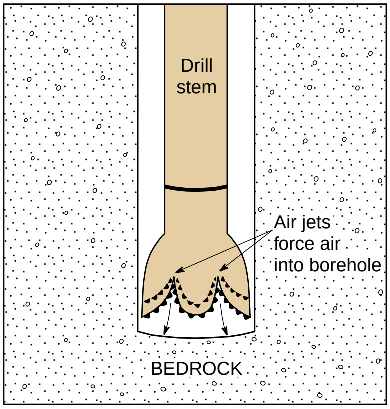
After the location has been prepared, the driller sets up a drilling rig over the permitted well location and makes preparations to drill, known as ***rigging up.*** Most modern wells are drilled using an ***air rotary drilling rig*** that typically operates 24 hours a day in three shifts, or tours (pronounced "towers"), of 8 hours each.

In air rotary drilling, a ***drilling bit*** is attached to the end of a length of hollow drill pipe. The drilling bit and drill pipe are referred to collectively as the ***drill string.*** The drill string, powered by diesel engines, is lowered to the ground and begins drilling by rotating to the right, or clockwise. As the bit rotates, it cuts away small pieces of rock. The cutting action plus the weight of the drill string forces the drill bit deeper into the rock and causes a continuous borehole to form.

While the drill string is turning, a powerful flow of air is pumped down the center of the hollow drill pipe; it exits at the bottom of the pipe through openings in the drill bit. The air rushes back up the hole

An example of a drilling rig. For an average gas well in Pennsylvania, the workings take up approximately one acre of land during the drilling period. When the well is completed, all that remains on a well site is a gas meter that has control valves and charts for recording the quantity of gas going into the pipeline. A tank to collect water and oil produced with the gas may be placed at the well location.

along the outside of the drill pipe where it is vented at the surface through the ***flow line*** into a ***drilling pit.*** The air flow carries the pulverized rock pieces upward and out of the hole. Removal of these particles keeps the hole clean and enables drilling to progress faster and easier. Geologists present during drilling may take samples of the drill cuttings. They look at the cuttings through a microscope to determine the type of rock and the presence of minerals or fossils. Because the cuttings come from increasing depths as drilling continues, the geologists can also determine preliminary details about the depth of potential reservoir rocks. Cuttings caught in the drilling pits will be disposed of in an environmentally proper manner after the well is completed.



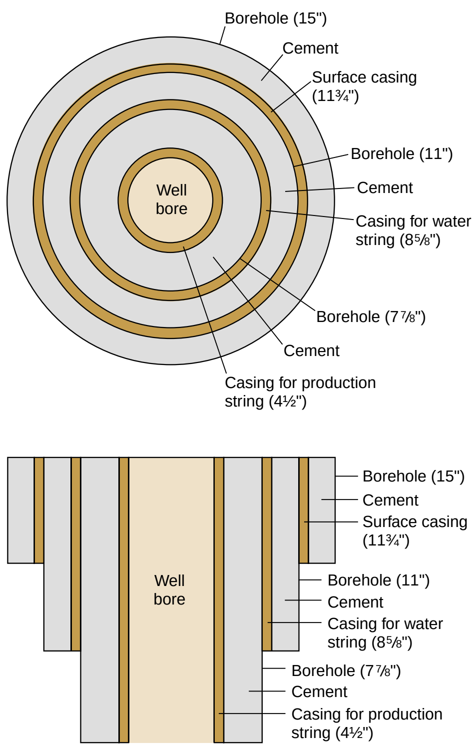
The drill bit rotates as the entire length of drill pipe turns. Teeth on the bit grind through the rocks in the bottom of the hole until the total depth of the well is reached. Air forced through the jets between the rotating gears blows the pulverized rocks to the surface for examination.

As the well is deepened, lengths of drill pipe must be added to continue the drilling. This is known in the petroleum industry as ***making a connection.*** This process continues until the well is a few hundred to, possibly, a few thousand feet deep, and the ***casing point*** is reached. The casing point is the depth at which the drill pipe is removed from the well and replaced with steel pipe called casing. The casing is permanently cemented in place within the well to prevent cave-ins and to protect shallow groundwater or coal seams from contamination by petroleum. Cement is pumped and circulated into place in the same manner that air is circulated: down the center of the hollow casing to the bottom of the well and back up the well alongside the outer surface of the casing. After the cement has hardened, drilling can be resumed by entering the cased drill hole with a drill bit of a smaller diameter. This provides for a "telescoping effect" of successively smaller hole sizes and casing sizes. The well continues to be drilled until the target reservoirs have all been penetrated. The well is now at ***total depth.*** The drill string is removed from the well for the final time, and the next phase, well logging, is about to begin.

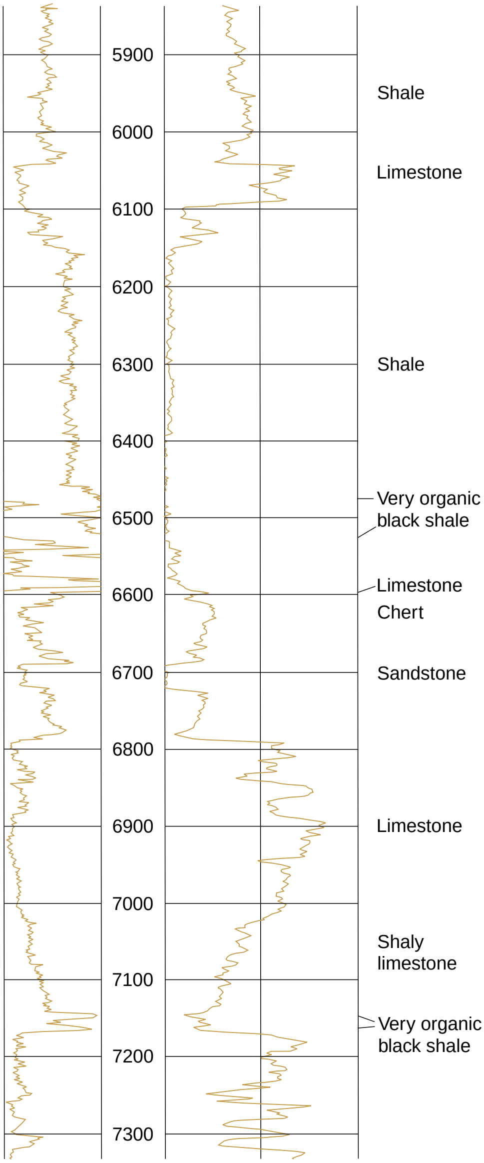
EVALUATING THE WELL

Logging the well

In the petroleum industry, ***logging*** is a technique used to record the characteristics and depths of the rocks penetrated by drilling. Logging a well is important because it provides geologists and engineers with an analytical tool upon which to base their



These horizontal (top) and vertical (bottom) cross-section views show the concentric rings of steel casing pipe and the cement sandwiched between each string of pipe. The numbers are diameter measurements.

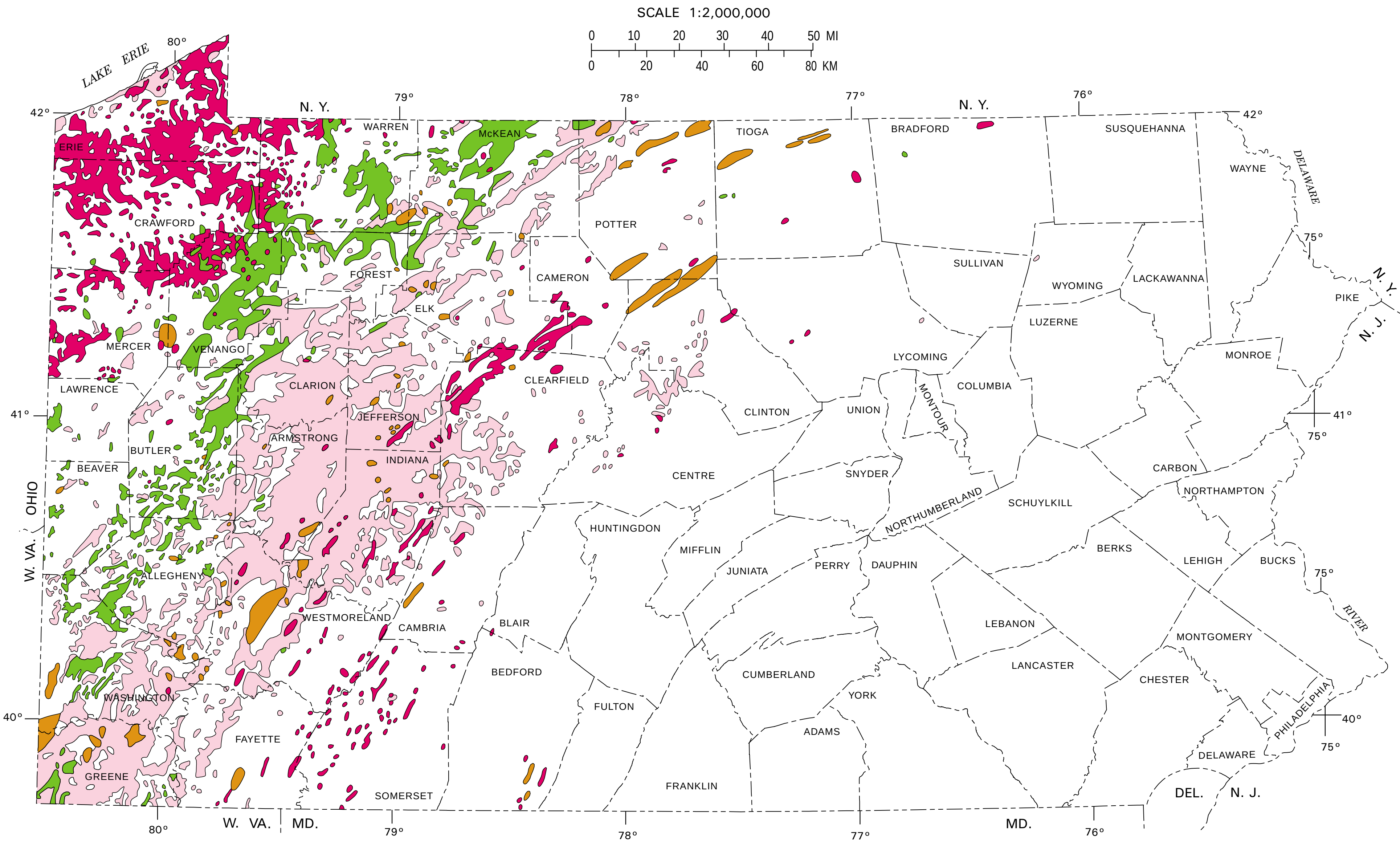


Sensitive gamma-ray logging tools record the small amount of natural radiation emitted from the rocks (left curve). Each rock type has its own gamma-ray characteristics. Sandstone and limestone emit very little radiation, so the curve stays far to the left. Some organic-rich black shales contain concentrated amounts of radioactive elements and emit enough radiation that the graph goes off the scale to the right.

Neutron logs (right curve) measure the porosity in a rock formation by responding to the amount of hydrogen present. The higher the reading, the more hydrogen. Water and petroleum are made partly of hydrogen and can be present in the pore spaces within a rock unit. Therefore, the more hydrogen, the larger the pore spaces must be.

evaluation of whether the hole will be a good well. Cylinder-shaped well-logging tools contain sensors that record important characteristics of the rocks through which the well was drilled, including porosity, rock type, hole diameter, downhole temperature, and electrical resistivity. The tools are attached to the end of a long wire cable and are slowly lowered down the well. As they move down to the bottom and then back up the hole, the sensors take continuous readings and transmit them through the wire cable to recording devices.

OIL AND GAS FIELDS OF PENNSYLVANIA



EXPLANATION

Shallow oil field

Shallow gas field

Deep gas field

Gas storage area

The result is a series of long vertical graphs, one for each of the rock characteristics being evaluated. Geologists and engineers study these graphs and interpret them in order to answer some key questions about the new well. Well logs can indicate whether the well was drilled deep enough to go through the good petroleum reservoirs, whether oil and gas are contained in the rocks in commercial quantities, and whether the porosity and permeability are high enough to recover the petroleum. This is the moment of truth for the geologist who planned the well and selected the well location based on a hypothesis of where the best geological conditions could occur.

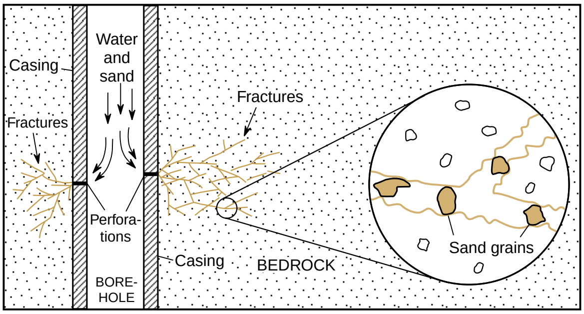
If the well is not going to be productive, it will be filled with cement and ***plugged.*** A well that will produce oil or gas is prepared for completion.

PRODUCING THE WELL

Fracturing the well

Using the well logs as a guideline, the geologist has carefully noted the precise depths where oil and gas occur. However, the vast majority of new wells in Pennsylvania will not produce oil or gas by natural flow. The reservoir rocks usually do not have permeability high enough for the hydrocarbons to flow naturally. Therefore, the reservoir must be stimulated to enhance the porosity and permeability so that the well can produce commercial quantities of oil and gas.

First, the final string of casing, ***the production string,*** which is extended below the deepest target reservoir, is put into the hole and cemented in place. This effectively seals off the entire portion of the well from which production is anticipated. Explosive charges known as shots are lowered down the hole to the precise depth of the deepest reservoir in the well from which production is desired. The shots are detonated, creating ***perforations,*** or holes, in the casing at the level of the deepest reservoir. These perforations provide openings for sand, water, and possibly acid, which will be pumped down the well and through the perforations at high pressures. This causes the rock to break down. The process is known as ***hydraulic fracturing,*** or more simply, ***fracing*** (pronounced "fracking") the well. The goal of fracing is to increase permeability by opening an oil and gas pathway for easier flow into the well. Acid and water are used to dissolve minerals and clean out the newly formed fractures. Sand flows into the fractures to prop them open. The



The reservoir is fractured through the holes created by perforating the production string. The fractures extend out from the well, forming a network of small tunnels. Sand grains pumped down the hole with the water become wedged in the spaces in the tunnels and help prop them open. Now, gas or oil has a way to flow out of the rock and into the well.

acid and water are then permitted to flow back out of the well, and the sand remains in place to keep the fractures open.

If the procedure is successful, the petroleum well responds quickly by flowing with greater pressure and volume than were measured prior to fracing. The process of perforating, fracing, and flowing the well can be repeated for successively shallower reservoirs until all the potentially productive reservoirs have been treated. The result is a well with good pressure and higher volumes of oil and gas than would have been possible without the fracing process. Of course, higher volumes of oil and gas translate into greater economic benefit from the well.

Why many people think that oil and gas just come from a pipeline

Upon completion of fracing activities, the well is ready to produce. If the well is capable of producing commercial quantities of natural gas, a pipeline is constructed to attach the well to the gas-gathering pipelines of the local gas purchaser.

If commercial quantities of oil are found, the oil is either stored in holding tanks near the well or transported to a refinery by pipeline. If it is stored at the well site, an oil tanker truck must regularly collect the oil and transport it to an oil refinery. Some wells produce commercial quantities of both oil and gas, but the more common situation is to have either an oil well or a gas well. A successful oil or gas well may produce for 30 years, and sometimes much longer. The famous McClintock No. 1 well, north of Oil City, Pa., has produced oil continuously since it was drilled in 1861.

The McClintock No. 1 well is still pumped. It produces several barrels of oil per year. The well is now operated by the Drake Well Museum, and the public is welcome to visit the site.

TRANSPORTING GAS

The story does not end after a well has been completed and is producing either oil or gas. Most natural gas requires no treatment. All that is needed is to get the gas to customers, who will use it for fuel, lighting, heating, and/or cooking. This is accomplished by moving gas through pipelines. Today, from the smallest gathering and distribution lines to the large 42-inch-diameter interstate gas-transmission lines, an impressive and efficient pipeline network crisscrosses Pennsylvania. Gas from these pipelines meets the needs of families, factories, and even cities across the state and across the country. Compressor stations situated along the network of pipelines maintain pressure in the system and keep the gas moving. Gas storage pools located throughout the gas-producing region of Pennsylvania help to assure supplies during periods of high demand. Technological advances continue to increase efficiency and cost-effectiveness of delivery of natural gas to customers who may be thousands of miles away from the wellhead. Some recent improvements include computer monitoring of pipeline conditions and robotic inspection in remote areas.

The treatment of oil after production, however, is not the same as it is for natural gas. Most oil that is produced from a well must be taken to a refinery to be prepared before use.

REFINING OIL

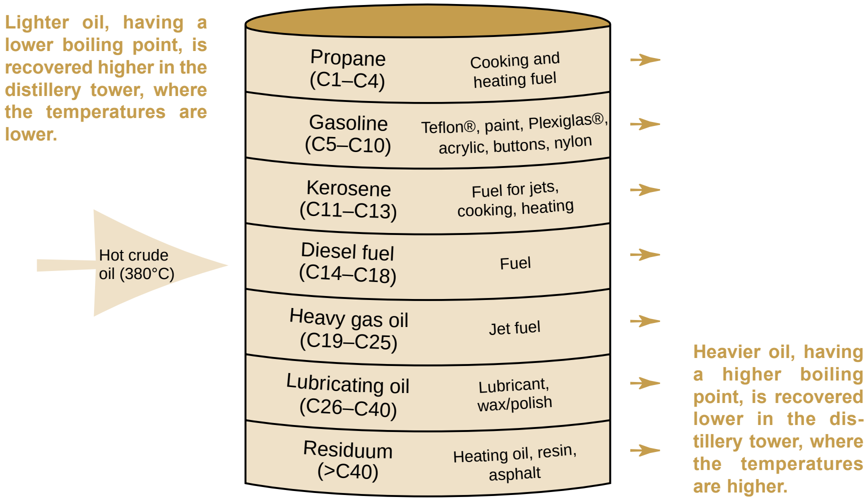
What happens in the refining process?

Petroleum is ***refined*** to clean, break down, and rebuild the hydrocarbons that enter the refining process in the form of crude oil. As previously discussed, the primary elements that make up petroleum molecules are carbon and hydrogen. These hydrocarbon molecules vary in type depending on how carbon and hydrogen atoms are combined. In addition, other elements, such as sulfur, nitrogen, oxygen, and some metals, can also be present. The organization of the molecules is affected by the composition of the original organic matter and by reactions to heat and pressure. Because the hydrogen molecules can be arranged in different ways and can include other elements, there are hundreds of different petroleum compounds. Refining is necessary to make usable products from this variety of complex hydrocarbons that is pumped out of the earth.

At the refinery, crude oil is separated into its components. The process is based on the fact that different compounds have different boiling temperatures. First, the crude oil is heated until it is partially vaporized (between 662°F and 752°F, or 350°C and 400°C). Then it is sent through a distillation tower, which has temperatures that increase from top to bottom, and which has many layers of condensers. The oil *vapor* rises toward the top of the tower, and as it rises and cools, it returns to a liquid state. Some vaporized hydrocarbons become liquid and settle in lower trays, whereas others move higher up before condensing. The *still-liquid* crude oils having higher boiling points move to the bottom of the tower, where the temperature is higher. The result is a series of useful end products generated at each stage of the crude-oil refining process.

At this point, some of the separated components, such as propane, can be removed and packaged as end products. Gas oil and kerosene are removed and are subjected to ***cracking*** (breaking down) to turn them into gasoline. The cracking process involves the use of heat and pressure to crack the hydrocarbon molecules. This results in a chemically different substance. Frequently, other substances are introduced to make specialty fuels like high-octane gasoline and cleaner burning, reformulated mixtures. Sometimes oil contains other elements that have to be removed before the products can be used. Chemicals may be introduced during the process in order to react with the contaminants and make them easier to extract. Other substances, such as clay and acid, may be used to stabilize the end products or break down the tar components.

Not all oil requires this much treatment. The crude oil found in Pennsylvania is referred to as "Pennsylvania Grade Crude." Although some is used as fuel oil, gasoline, and kerosene, Pennsylvania Grade Crude is prized as high-quality lubricating oil. It is especially good as lubricating oil for light machinery, such as sewing machines, because it has a very high boiling point, enabling it to withstand the high temperatures reached by



This is a simple sketch of a refining distillation tower. The temperature in the tower ranges from about 68°F (20°C) at the top to more than 1,112°F (600°C) at the bottom. For the various petroleum compounds, the number of carbon atoms per molecule is indicated by the number following the carbon symbol. Kerosene, for example, has between 11 and 13 atoms of carbon per molecule.

operating machinery. Pennsylvania Grade Crude is also a light, sweet oil (it has only minute quantities of sulfur and nitrogen). This makes it valuable for use in cosmetics and pharmaceuticals. Moreover, it contains wax. These waxy components are ideal for engine oil, gear lubricants, greases, candles, paper coatings, inks, fabrics, and food additives. Pennsylvania Grade Crude is sometimes used without refining it at all. When it needs refining, it requires much less processing than most other crude oils.

Once refined, oil is shipped by pipelines, tank trucks, and ocean-going tankers to destinations where the refined product will be put to many uses. Petroleum helps the world go round in a very real sense.

DEVELOPING AN OIL OR GAS FIELD

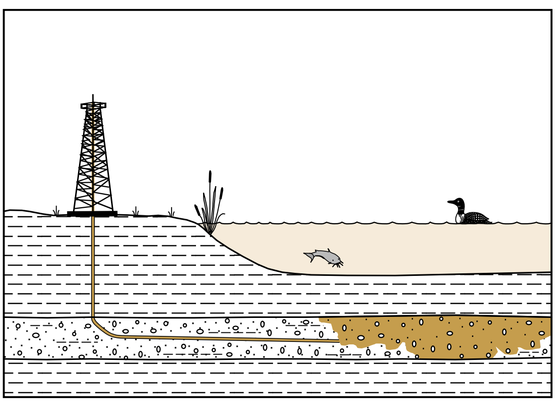
It has been said many times: all the easy-to-find oil and gas has already been discovered. But the truth is that new oil and gas pools are being discovered all the time, even here in Pennsylvania.

There are two types of drilling, ***exploratory*** and ***development.*** Exploratory drilling, also known as ***wildcatting,*** is conducted where there are few, if any, existing wells nearby. Because exploratory wells are drilled in areas where there are little or no subsurface well data, they are very risky endeavors. Although the potential rewards are very high, commercial quantities of petroleum are identified in an average of only 10 percent of wildcat wells. ***Rank wildcats,*** or wells drilled in more remote, totally unproven frontier areas, have a success ratio of only 1 in 40 (2.5 percent).

Development drilling, or infill drilling, as it is sometimes called, involves drilling that takes place in areas where petroleum has already been discovered by drilling exploratory wells. The geographic extent of the production area may have already been defined by the initial exploratory wells. Therefore, development wells that build upon the successes of the exploratory drilling program are more likely to be successful. These lower-risk wells serve to further define the extent of the productive area, usually making it easier to proceed with additional development wells that will produce petroleum.

Directional drilling may be used for either exploratory or development projects. In this type of drilling, the initial portion of the hole is drilled vertically. At a planned depth, the drillers cause the drill string to veer away from the hole and drill at an angle in a selected direction. This technique can be used to drill under environmentally sensitive areas or from an ocean platform, where 20 or more wells can be drilled from a common vertical hole.

Pennsylvania and the entire Appalachian basin in general are referred to as a "mature basin" because there has been more than 100 years of active drilling. So far, drilling activity has occurred primarily within the top 3,000 to 5,000 feet in a basin that contains up to 30,000 feet of sediments. Some gas fields are producing from depths of 8,000 to 9,000 feet. Exploration is ongoing for natural gas at depths upwards of 10,000 feet. More oil and gas are being discovered each year, and additional supplies are waiting to be discovered in the future.



Directional drilling allows access to petroleum reserves that may be under a protected or sensitive environmental area.

The key to success is to become better scientists. Geologists must exercise the scientific method and their technological skill, and use their tools effectively, in order to project extensions to existing fields, identify deeper horizons, and plan viable exploratory prospects in new geographic areas.

What else can be done?

Secondary recovery: getting more energy from "tired" reservoirs

Primary production from an oil reservoir consists of oil recovered by ordinary means, such as natural oil flow or oil being pumped to the surface. However, only one tenth of the oil available in a reservoir can be produced during primary production. Ninety percent of the oil remains tightly held within the reservoir. To produce as much of the oil as possible after primary production has tapered off, ***secondary recovery*** methods are employed. In Pennsylvania, the main secondary recovery techniques attempted are vacuum, water flooding, and gas drive.

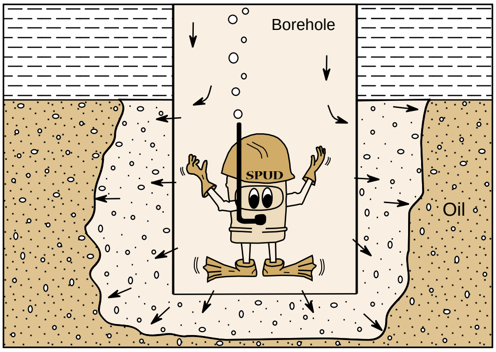
Secondary recovery by vacuum

Reservoirs were "vacuumed" in Pennsylvania as early as 1869. But vacuum techniques were used mostly in the early 1900s. Vacuuming involved pumping wells so thoroughly that the pressure in the well bore was less than natural air pressure. If a new well was drilled nearby through a reservoir being vacuumed, air could be heard whistling down the new well bore because of the great amount of suction being used to try to withdraw oil from the permeable reservoir in the neighboring well. Even with this amount of suction applied to the reservoir, the quantity of additional oil recovered by vacuum was relatively small. Moreover, the vacuum process removed the thinner, less viscous oil components. The heavier oil remained in the reservoir and was more difficult to produce.

Secondary recovery by water flooding

The initial secondary recovery by water flooding was unintentional. In the 1870s, oil producers in Venango County, Pa., noticed that wells that had been abandoned and left open to the weather accumulated water from groundwater reservoirs and runoff from rainstorms. The pressure created from tall columns of water in the bores of the abandoned wells forced the water into the reservoirs, and the water pushed oil toward wells that were still producing.

Oil companies realized that if they were able to select wells to plug and flood to produce oil, the results would become more predictable. The field would no longer be subjected to haphazard production. Eventually, the **circle flood** method was used. In a circle flood, water is injected into one well (the injection well) in the center of a cluster of producing oil wells. The water fans out from the injection well in a circle and pushes the oil toward the producing wells.



Fresh water invades the reservoir under pressure from the weight of the water column in the borehole. Oil left after primary production is forced away from the well and toward other nearby producing wells.

In 1922, companies started drilling one row of water-injection wells between two rows of oil wells. In this type of recovery, called **line flood,** water injected into the wells pushed the oil in the direction of the oil wells. As the oil was depleted, the producing wells were converted to water-injection wells, and the oil was pushed out toward a new line of producing wells. It took 2 to 3 years for the water from the injection wells to reach the oil wells! This was the style of secondary recovery that was used with some success in the famous Bradford oil field in McKean County, Pa.

The **five-spot** method was introduced in 1928. One producing oil well was centered among four water-injection wells. Five-spot, which proved to be very effective, was later combined with **pressure flooding** techniques. In pressure flooding, hydraulic pressure was added to the column of water in the injection well, forcing the water into the reservoir formation. The combination of five-spot and pressure proved so successful that it is still commonly used today. It takes 10 to 25 barrels of floodwater at pressures of 1,800 to 2,000 pounds per square inch, at a distance of 200 to 300 feet between the water-injection and producing oil wells, to produce one barrel of oil.

While pressure flooding is not effective in many of the Pennsylvania oil fields due to the characteristics of the rock reservoirs, some parts of the Bradford field have produced more than 10,000 barrels per acre through the use of flooding projects.

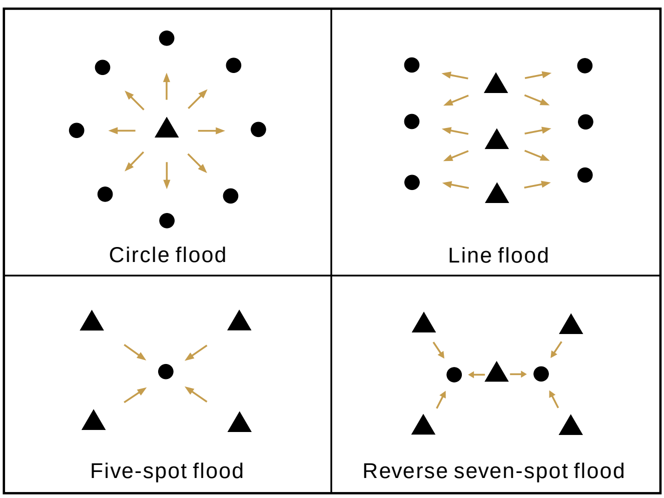
Secondary recovery by gas drive

High-pressure gas was first injected into an oil reservoir in 1890 in Venango County, Pa. A well was intentionally drilled deeper than the oil reservoir, and it reached a natural gas reservoir under high pressure. The operator shut the well in (closed the well), and the pressurized gas was naturally driven into the oil reservoir. All the surrounding oil wells realized an increase in production. Since that time, gas and/or air injection has become a popular method to repressure oil reservoirs to produce additional oil. This method requires approximately 1,000 cubic feet of air or gas per day per vertical foot of reservoir to be injected at pressures from 50 to 400 pounds per square inch. The distance between the injection wells and the producing wells should be 150 to 250 feet in a **reverse seven-spot** arrangement. The expected production is from 10 to 100 barrels of oil per acre for each foot of reservoir thickness.

Tertiary recovery: the third try

Getting even more energy from tired reservoirs

Sometimes the reservoir is subjected to yet another round of petroleum recovery enhancement called tertiary recovery. Some tertiary recov-



Four of the many arrangements of injection and production wells that have been tried throughout history. Dots represent oil wells; triangles represent water-injection wells.

ery techniques used in petroleum-producing areas include injecting steam, chemical solvents, foams, biochemicals, or carbon dioxide, or heating the reservoir. These have been tried in Pennsylvania with limited success.

UNDERGROUND NATURAL GAS STORAGE

Gas supplies are ready when we need them the most

An important activity undertaken by natural gas companies in Pennsylvania is the underground storage of natural gas. Underground storage involves pumping natural gas into the ground where rock reservoirs have porosity, permeability, and a trap so that the gas cannot escape. Frequently, gas reservoirs are used for storage after much of the original natural gas has been produced. One benefit of having underground gas storage is that extra supplies are ready and available during the cold winter months when the gas is in great demand for heating.

Perhaps the most important requirement for suitability for gas storage is that the underground container or reservoir is well defined and has known limits to ensure that gas pumped underground will not escape. Therefore, geologists look for a seal, or trap, around the reservoir. This can be indicated by a "dry hole perimeter," a series of wells encircling the reservoir that were drilled but had no production. The lack of production can signal the presence of a natural barrier, which allows the gas to be contained for storage purposes within the reservoir.

Historically, natural gas has usually been pumped into the storage reservoir during the late spring and summer months, when gas supplies are abundant because demand is low. Storage reservoirs are generally filled to capacity by the fall, and gas is available to be withdrawn as needed during the winter months.

When filling the storage reservoirs, the gas storage operator must take precautions not to overfill the reservoir. If the original natural rock pressure of the reservoir is exceeded, fractures may form in the rock reservoir and allow gas to escape.

There are 88 natural gas storage pools that are accessed by 1,675 wells in Pennsylvania. Most people are unaware of the natural gas storage pools because the storage facilities are located underground at depths of 2,000 to 8,000 feet. The only indications on the surface of the earth are compressors, flow meters, valves, and pipelines. Gas storage pools in Pennsylvania vary in size from those requiring single wells to a pool having

The Dice Storage facility near Murrysville, Pa., is operated by Dominion Peoples Natural Gas Company. Natural gas is stored in an Upper Devonian sandstone between 1,900 feet and 2,200 feet underground. Pressure and the flow of gas into and out of the rock formation are controlled from this station.

more than 150 storage wells. Oil and gas law in Pennsylvania allows for the storage of natural gas in any rock type except underground coal seams.

WHAT HAPPENS WHEN THE WELL RUNS DRY?

When a well no longer produces economic quantities of oil or gas, the well operator is required to ***plug*** the well. First, the well is disconnected from the gas or oil pipeline, and any production casing inside the well is removed for scrap value. Then, cement is pumped down the hole to seal off the oil- and gas-bearing rocks. At the surface, a 6-foot-tall vent pipe must be present to prevent pressure build-up from any gas that may still work its way to the borehole. The vent pipe also serves as a marker so that old wells can be located if the land is going to be developed by builders.

THE FUTURE OF OIL AND GAS

What have we taken and what's left?

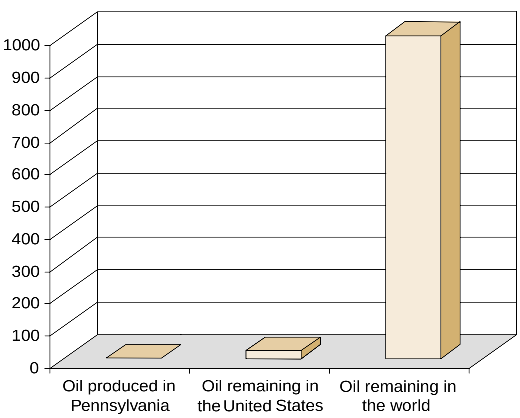
Since Drake's discovery of oil in 1859, Pennsylvania oil fields have produced more than 1.4 billion barrels of crude oil. That's more than enough oil to fill 6.5 million swimming pools 20 feet in diameter and 4 feet deep. Natural gas production has exceeded 1.07 trillion cubic feet, enough to heat all of the homes in Pennsylvania for more than 2,000 years. All of that petroleum came from more than 350,000 wells that have been drilled in Pennsylvania to date. The centerfold map shows the locations of the oil and gas fields of the state.

The amounts of oil and gas that remain to be discovered and retrieved have concerned the energy industry, governments, and many other people since petroleum was discovered. Teams of scientists meet regularly to discuss the petroleum supply that remains. The federal government encourages exploration and evaluation of "unconventional" reservoirs (those not previously known for economical petroleum production) to supplement the known supply.

Of all the oil and gas known in the world today (total resource), only some of it is available to be collected (recoverable) because of economic, environmental, or technological limitations.

Estimates from the U.S. Department of Energy in the late 1990s showed that reserves in the United States (reasonably certain to be in place and retrievable) are nearly 23.5 billion barrels of crude oil. That's enough oil to fill the 15-gallon gas tank in one car three times a day every day for 60 million years. The estimates indicate that natural gas reserves are 175 trillion cubic feet, enough to drive a natural gas powered car to the moon and back 89 billion times. World oil reserves were estimated to be 1,000 billion barrels, and world natural gas reserves were judged to be about 5,100 trillion cubic feet.

The United States is dependent on petroleum imports. More than half of the crude oil we use every day, nearly 11 million barrels, is imported primarily from the Persian Gulf and countries of the Middle East, as well as Venezuela, Canada, Mexico, Nigeria, the United Kingdom, Colombia,



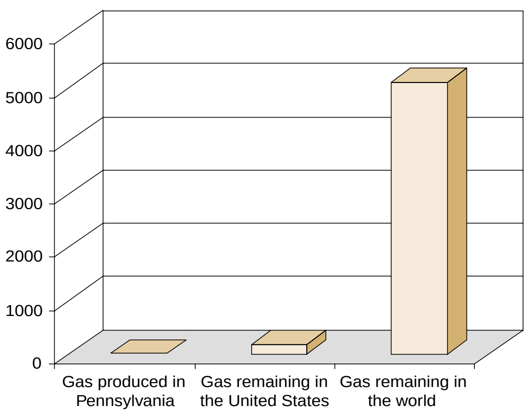
A comparison of the amount of oil produced since its discovery in Pennsylvania with the amount of oil remaining to be produced in the United States and the world. Units are in billion barrels of crude oil.

and Norway. Petroleum supplies have become unpredictable because they are subject to global economic and political influences. Petroleum companies and politicians in the United States are considering the production of vast oil reserves under the environmentally sensitive Arctic National Wildlife Refuge and the outer continental shelf on the east coast of the United States. They are also investigating technology that will be required to reach petroleum under the deeper parts of the Gulf of Mexico and the Great Lakes. Once the technological challenges that will allow us to produce oil and gas safely from sensitive environments and extremely deep waters are met, there is no doubt that these vast reserves will become part of our petroleum supply.

Strong national interest in improving air quality and decreasing our dependence on imported fuels continues to have a positive impact on research and development of viable alternative fuel sources. Two very promising products are ***liquefied natural gas*** and ***compressed natural gas.***

Liquefied natural gas (LNG) is nearly pure, very cold methane (−260°F, or −162°C). It takes up less space and weighs considerably less than the equivalent amount of water. LNG is considered to be environmentally friendly; it burns with little waste, it is economical, and it is an efficient fuel. Difficulty in maintaining the very low temperatures needed to keep this gas from evaporating makes it impractical to use in passenger vehicles at present, although it is used to power long-distance delivery trucks.

Compressed natural gas (CNG) is primarily methane, compressed to 200 to 3,600 pounds per square inch, and stored in tanks designed especially for that purpose. It is becoming more common and available for daily commuter use. CNG is cheaper than gasoline, environmentally friendly, and efficient. This fuel is being used in local delivery trucks and car fleets.



A comparison of the amount of natural gas already produced in Pennsylvania with the estimated amount of gas yet to be produced in the United States and the world. Units are in trillion cubic feet of gas.

LOOKING BACK: HOW IT ALL BEGAN

Petroleum has been used since at least 4,000 B.C. Ancient Egyptians used petroleum in their preparation of mummies for burial. The asphalt mortar used to construct the Tower of Babel in ancient Mesopotamia and the Hanging Gardens and city walls of Babylon rendered those structures virtually indestructible. Hardened asphalt was used for carved ornaments in Jerusalem. Hindu people used oil to treat diseases, treat timber, and cremate corpses. The ancient Chinese drilled for, produced, and marketed natural gas, and transported it to their homes for lighting and heat through bamboo pipelines. Early Europeans also used petroleum for light.

The properties and usefulness of other oils was familiar to many cultures. As early as 800 A.D., Basques hunted whales and used whale oil for light and heat. Through time, many other products, including paint, varnish, soap, candles, medicines, lubricating oil, and leather tanning oils were made from whale oil. The more people used oil, the more they needed oil. During the 1600s, shortages of whales and whale oil led to skirmishes between the Dutch and English. Whales were becoming harder to find, and whalers ventured farther from Europe. Eventually, even the whalers realized that future supplies were to be found in "rock" oil.

The Seneca Indians told early explorers about the oil seeps they found. These Native Americans were the first oil producers in North America. Hundreds of years before Columbus sailed to North American shores, the Seneca were collecting oil by trapping it behind dams and in timber-lined pits near the seeps on the banks of Oil Creek, Pa. The Seneca also skimmed the oily surface of water with blankets, then collected and stored the oil for trading, ceremonial, and medicinal purposes, including treatment of stomach ailments, aching muscles, and dry skin. To this day, Seneca Indians excavate for "Seneca Oil" for medicinal and ceremonial use.

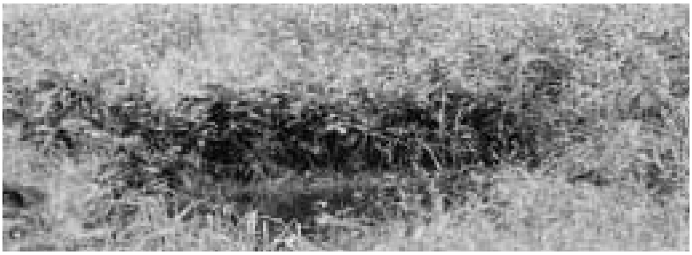
Samuel M. Kier operated a salt well (to obtain salt by evaporating salt water) near Tarentum, Pa. He was also a clever entrepreneur and inventor. In the 1840s, other salt-well operators were discouraged when their wells along the Allegheny River began to produce nasty, greasy crude oil along with the sought-after salt water. Kier saw opportunity. He came up with uses for the "nuisance" oil that was ruining his salt wells, and even got people to pay for these waste products! Kier began by selling crude oil as medicine. This business became so successful that Kier began buying petroleum from salt works operated by others. One of his advertisements was as follows:

> **KIER'S GENUINE PETROLEUM! OR ROCK OIL! A NATURAL REMEDY, Procured from a Well 400 feet deep, and possessing wonderful Curative Powers in diseases of the CHEST, WIND-PIPE AND LUNGS; ALSO, FOR THE CURE OF DIARRHŒA, CHOLERA, PILES, Rheumatism, Gout, Asthma, Bronchitis, Scrofula or King's Evil; BURNS AND SCALDS, Neuralgia, Tetter, Ring-worm, Obstinate Eruptions of the Skin, Blotches and Pimples on the Face; BILES, DEAFNESS, CHRONIC SORE EYES, KRYSIPELAS, Pains in the Bones and Joints and all that class of diseases in which ALTERNATIVE OR PURIFYING MEDICINES are indicated, Put up by S. M. Kier, CANAL BASIN, Pittsburgh, FOR SALE HERE!**

Kier experimented with refining crude oil into kerosene. He also adapted burners from whale-oil lamps to burn the kerosene "rock oil" that he refined from crude oil. Refining decreased the amount of smoke emitted from the burning oil. Improvements in his distillation (refining) process led to increased demands for the oil that he collected. It burned brightly, provided good heat for warmth or cooking, and was considerably cheaper than whale oil and lards, and safer than burning other fluid fuels available at that time. Kier's enterprising distillation and uses of oil caught the attention of East Coast investors. Sensing a business opportunity, they contracted the services of "Colonel" Edwin L. Drake for the purpose of evaluating the oil. Because skimming the oil springs did not collect large amounts of oil, Drake thought of boring a hole into the earth specifically to obtain the crude oil. With the cooperation of William "Uncle Billy" Smith, a blacksmith and an experienced salt-well driller, the tools to drill a well were constructed and brought to Titusville, Pa., near the site of the oil seeps. The first well drilled was a success. Oil was found at 69.5 feet below the surface of the earth in August 1859, and the modern oil industry began.

INFLUENCE OF THE PETROLEUM INDUSTRY ON OTHER INDUSTRIES

Much excitement and opportunity resulted from the discovery and development of the petroleum industry in western Pennsylvania. Many different kinds of people traveled to the oil regions in Pennsylvania soon



This photograph shows a pit on the grounds of the Drake Well Museum that may have been one of the seeps used by the Seneca to skim oil. The Drake Well Museum grounds are situated on Oil Creek.

after news began to spread about Drake's successful oil well. Scientists, naturalists, explorers, adventure-seekers, capitalists, and suppliers of goods and services needed by the rapidly increasing population made their way to the new boomtowns.

Railroads were built and expanded to accommodate the influx of activity in the petroleum-producing region and to transport the oil out of the area to the refineries. When several important railroad bridges were completed in the mid-1860s, trains connected the oil region to the large cities of the eastern seaboard, to other cities such as Buffalo, Rochester, and Pittsburgh, and to the Great Lakes area.

A replica of Drake's second well house and derrick is located on the grounds of the Drake Well Museum in Titusville, Pa. Visitors can enter the wooden building and see the simulated pumping process, which uses a steam engine and a boiler. Drake's drilling tools are on display inside the main museum building.

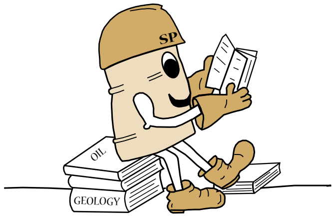
The growing petroleum industry required large quantities of new iron and steel products. Each new well required between one and three tons of steel drive pipe as well as boring tools, valves, fittings, derricks, cables, and a myriad of other specialty parts. Iron and steel manufacturers in the western region of Pennsylvania met the challenge of providing the equipment—not just for the local petroleum industry, but for other oil fields in the United States, Europe, Russia, Peru, India, Japan, and China. The coal industry in western Pennsylvania also benefited from the increased demand for iron and steel products, because coal fueled the iron- and steel-making furnaces of the day.

Manufacturers of pumps, engines, rope, tubing, glass, chemicals, and wooden barrels also realized positive benefits from the activities in the oil fields. By 1866, five glass factories in Pittsburgh were shipping 48,000 oil-lamp chimneys per week. Services such as machine shops, blacksmithing, freight, and hauling were in high demand. Oil-field-related employment kept workers in Pennsylvania and surrounding states busy and had positive, lasting impacts on the reputation of the industrious, hardworking population of the region.

The importance of petroleum to the economy and history of Pennsylvania is represented in Edwin Austin Abbey's painting, *The Spirit of Light,* one of four lunettes in the rotunda of the Pennsylvania State Capitol Building in Harrisburg. The 1911 painting features a background of derrick towers and a foreground suggesting both light and lightness of spirit. Petroleum has long been recognized as a treasure in the Commonwealth of Pennsylvania.

ADDITIONAL READING

If we have oiled your enthusiasm, you may want to check your library for these books:



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PLACES TO VISIT

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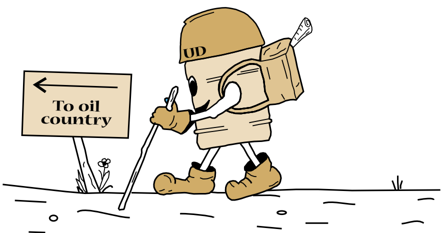
Warren, PA 16365
Telephone: (814) 723–5150 or (814) 726–2710 (TTY)
Fax: (814) 726–1465

Drake Well Museum
205 Museum Lane
Titusville, PA 16354
Telephone: (814) 827–2797
Fax: (814) 827–4888



Oil Creek State Park
R.R. 1, Box 207
Oil City, PA 16301–9733
Telephone: (814) 676–5915

Penn-Brad Oil Museum
Highway 219
Bradford, PA 16701
Telephone: (814) 362–1955

Pithole City Visitor Center
Route 227 between Pleasantville and Plumer, Pa.
Contact the Drake Well Museum for information

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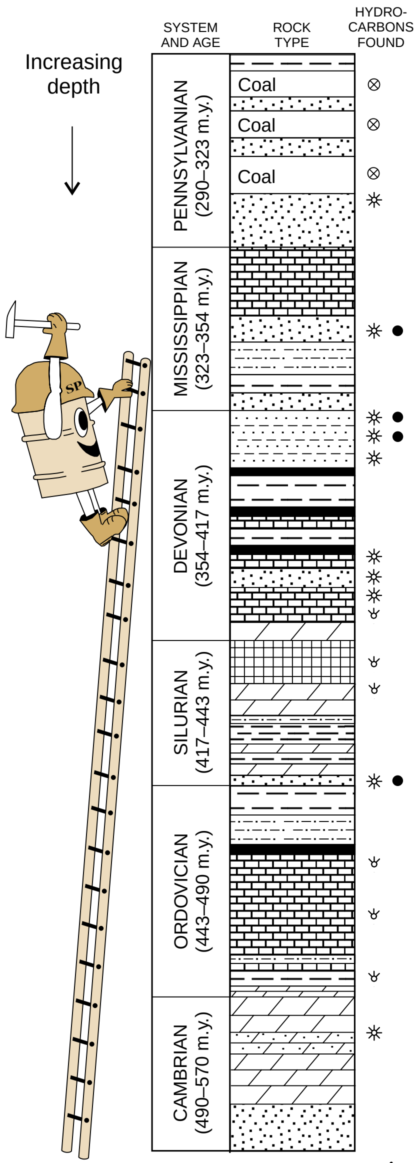

Generalized stratigraphic column for the rocks found beneath the western part of Pennsylvania. The numbers in the left column represent the age of the interval shown (m.y., millions of years ago). The types of rock are shown in the middle column. The symbols in the column on the right indicate if oil, gas, or coal-bed methane has been found. The gas symbol also indicates regional gas reservoirs.