Introduction

The Oriskany Sandstone is the main deep gas reservoir in western Maryland. Appalachian gas drillers have long suspected that the dark gray to black shale, known as the Marcellus Shale, that overlies the Oriskany was the likely source for the gas within this prolifically productive sandstone. The Marcellus was considered "tight" or unproductive as a potential gas reservoir, but recent innovations in gas well drilling and stimulation have changed that long-held paradigm. In 2003 Range Resources was the first company to prove that the tight shales of the Marcellus could produce economical amounts of gas if drilled and stimulated unconventionally.

Origin of the Marcellus Shale

The Marcellus Shale was deposited during the Devonian Period. The Devonian spans the interval of Earth's history stretching from 415 to 360 million years ago (Mya). Maryland's geography was very different at that time. Approximately 410 Mya, western Maryland was submerged beneath a shallow current-swept sea in which sand, now preserved as the Oriskany Sandstone, was being deposited. Eastern Maryland was part of a long peninsula that extended from New York to Georgia. At about 390 Mya, eastern Maryland was uplifted and deformed into a low mountain chain by plate tectonic forces. As eastern Maryland was uplifted, the crust beneath western Maryland buckled downward. The shallow sea in which the Oriskany was deposited was transformed into a deep marine trough. In eastern Allegany County the trough may have been thousands of feet deep. However, thinning of the Marcellus westward suggests that the trough shallowed into Garrett County and northern West Virginia where water depths may have been quite shallow. Although the shallow surface waters within this trough were warm, sunlit, current-swept, and full of marine plankton, waters somewhat deeper were stagnant and devoid of any oxygen or life. This is because there were few currents present in this inland seaway. Without currents to stir up and oxygenate the waters, a dense layer of cold and salty water settled into the deepest parts of the marine basin. Such sharp density gradients are called pycnoclines (pronounced *pick-no-cline*). Plankton that flourished in the shallows or near the surface would die and sink into the stagnant depths below the pycnocline. Over millions of years their remains accumulated on the sea floor as hundreds of feet of black, putrid muds (Figure 1). As the mountain chain in eastern Maryland was uplifted, weathering and erosion of the highlands outpaced the subsidence of the marine trough to the west. Rivers flowing from the mountains carried sand, silt, and clays to the sea to the west. These sediments were deposited along a deltaic shoreline that built itself westward. Finer sediments were swept into the deeper parts of the trough. The organic muds accumulating on the Marcellus sea floor were mixed with, and ultimately buried by, fine sand, silt, and clay that came from the uplifted mountain chain to the east. These overlying layers of sediment were thousands of feet thick. Burial of the Marcellus organic-rich muds beneath this thick stack of sediments compressed and compacted the muds into shale, but it also began to heat and change organic matter.

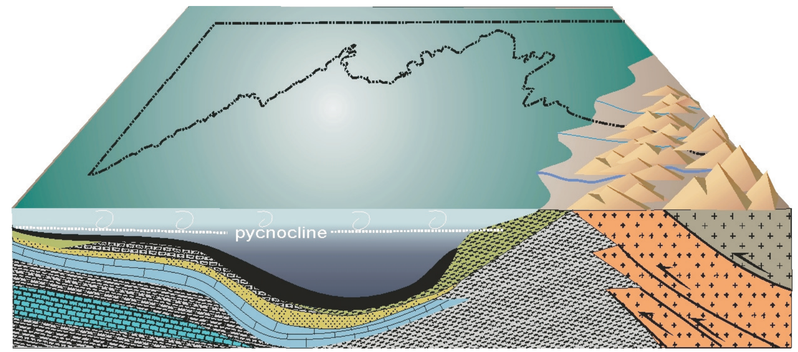

Figure 1. Idealized paleogeography of western Maryland 385 million years ago.

Changing the Original Organic Matter

It took several million years to deposit the Marcellus Shale. During that time, millions of generations of plankton lived and died in the shallow parts of the Marcellus sea. The remains of each generation sank to the sea floor and were buried in the bottom muds. In the black muds their remains began to break down into an amorphous mass or organic molecules termed kerogen. Kerogen is a prerequisite for the formation of hydrocarbons. Following the deposition of the Marcellus, the shale was buried under thousands of feet of sediment that by the end of the Devonian filled the trough. This burial began to heat the kerogen within the Marcellus Shale. As the paleo-temperature of the shale was elevated, the kerogen within the Marcellus began to change. This low temperature metamorphism of organic matter is called catagenesis. As the temperature of the kerogen was raised, the weaker bonds between some of the hydrogen atoms were broken. Such breaking of the hydrogen molecular bonds is known as "cracking." Cracking produces shorter hydrocarbon molecules. Initial cracking of the kerogen molecules leads to the production of liquid hydrocarbon molecules. If the heating of the kerogen were to end at this point, primarily petroleum or "oil" would be produced. However, increased and prolonged heating continues to break the hydrogen bonds into shorter and shorter molecules. Application of enough heat and pressure results in the breaking of nearly all the hydrogen bonds, producing molecules that are gas. Methane, the shortest hydrocarbon molecule, is the principal component of natural gas. The organic residue left behind when all the shorter hydrocarbon molecules are broken and driven off is called asphalt.

As the kerogen is metamorphosed, and the liquid or gaseous hydrocarbons are released, these relatively small molecules move through pores or fractures in the rock to nearby accumulation sites, known as reservoirs. For most of the Appalachian region the nearest suitable reservoir is the Oriskany Sandstone. However, much of the hydrocarbon remains in the source bed, and, in the case of the Marcellus, has remained there sealed within this, tight, rock unit of very limited porosity.

The Marcellus Shale in Maryland

The Marcellus Shale extends continuously in the subsurface from central New York State southward to northeastern Alabama, and from Maryland westward to central Ohio. In western Maryland, the Marcellus Shale underlies all of Garrett County and much of Allegany County (cover illustration). Within Garrett County and westernmost Allegany County the Marcellus is between 5,000 and 9,000 feet deep (Figure 2). In this part of Maryland, the Marcellus Shale is between 150 to 200 feet thick (Figure 3). Eastward from Dans Mountain to Town Creek, the Marcellus has been eroded along the crests of anticlinal folds, but is shallowly buried within synclinal troughs. In this part of the state the shale ranges from 200 to 230 feet thick (Figure 3). From Town Creek to Tonoloway Ridge the Marcellus is deeply buried beneath the Town Hill and Sideling Hill synclines. In this area the Marcellus Shale may be buried by as much as 10,000 feet of overlying rocks (Figure 2, cover illustration). The Marcellus in this part of the State is between 230 and 250 feet in thickness (Figure 3). East of Tonoloway Ridge, folding of the rock layers has preserved small areas underlain by the Marcellus Shale between Hancock and Clear Spring (cover illustration). In this area the Marcellus exceeds 250 feet in thickness (Figure 3).

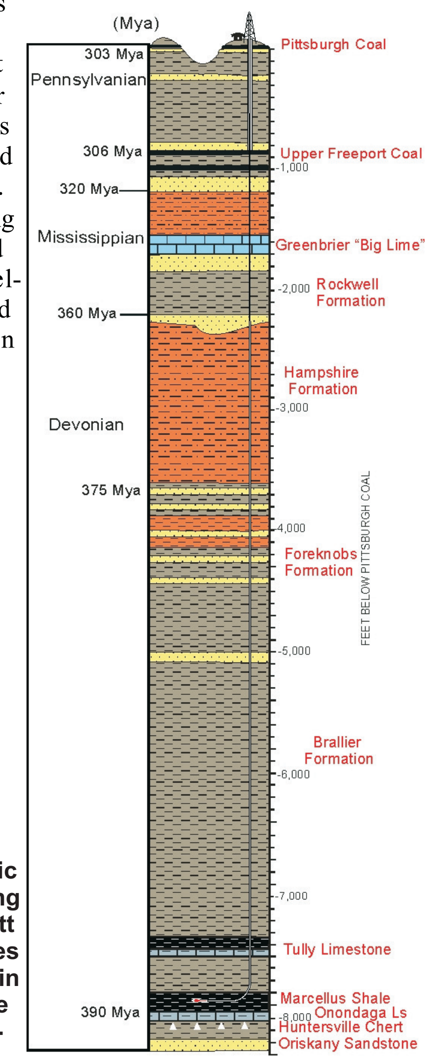

Figure 2. Generalized stratigraphic column for rock units overlying the Marcellus Shale in Garrett County, Maryland. Thicknesses and depths vary slightly within Garret County, but change more signifcantly to the east in Alleghany and Washington counties.

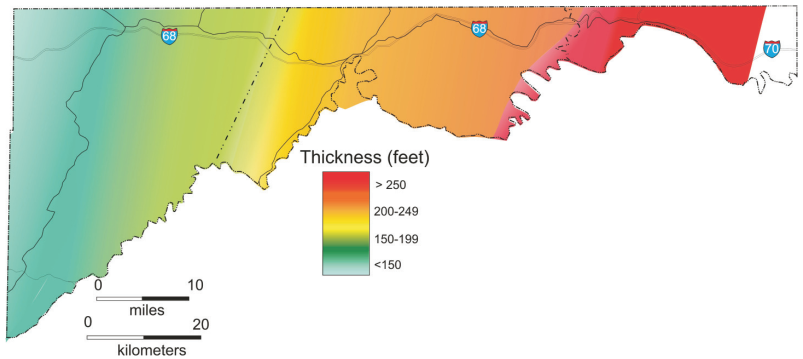

Figure 3. Generalized thickness trends within the Marcellus Shale in Maryland.

Drilling the Marcellus Shale

It has long been recognized, by Appalachian geologists, that the impermeable Marcellus Shale serves as an excellent seal, or cap, for the porous Oriskany Sandstone gas reservoirs (Figure 4). Furthermore, it had been suspected that the gas contained within the Oriskany originated within the black Marcellus. Recent innovations in well drilling and stimulation now allow drillers to produce economical levels of gas from what was previously believed to be a "tight" (i.e., impervious) rock unit.

Hundreds of conventional gas wells have been drilled in Maryland. In conventional drilling, the well bore is drilled vertically from the drilling rig, or platform, to a target reservoir rock layer below ground level by connecting a continuous string of drilling pipe. At the end of the drill string, at the bottom of the hole, a drill bit grinds away at the rock. The motor at the drilling rig turns the entire string of drill pipe as the bit penetrates deeper and deeper. Drilling mud forced down the center of the drill string cools and lubricates the bit and carries ground-up rock to the surface. As the well is deepened, segments of pipe are added at the drilling platform. Once the target layer is reached, the drill string is removed from the well bore and a string of steel casing is inserted into the bore and cemented into place. The pipe adjacent to the target layer is perforated using directed explosives. Afterwards, a high-pressure slurry of water and sand is forced through the perforations in the casing and into the cracks in the reservoir layer. The sand props open the cracks, allowing gas to flow freely from the rock. This final procedure is known as hydraulic fracturing, or "hydrofracing."

In unconventional well drilling, conventional procedures are followed until the driller achieves the rock layers just above (about 500 feet) the target unit (e.g., the Marcellus Shale). Then the conventional drill bit is removed and a "downhole mud motor" is attached to the end of the drill string. Drilling mud, pumped at high pressure through the drill string, acts as a hydraulic fluid. The mud motor is the only object that rotates in the well bore. This allows the driller to gently, and over long distances, change the orientation of the drill string from vertical to horizontal (Figure 4). As a result, the driller can bore laterally for thousands of feet within the target layer. This part of the well is called "the lateral."

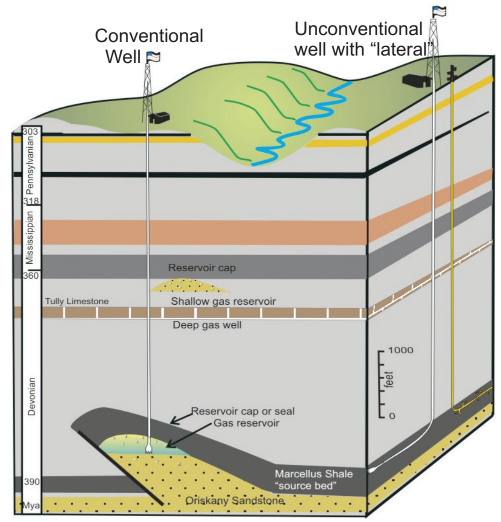

Figure 4. Conventional versus unconventional gas well drilling. In unconventional drilling the source bed becomes the gas reservoir.

Once completed, the horizontal segment of the unconventional well is cased with steel pipe, cemented into place, perforated, and hydrofraced just as in a conventional well. In conventional wells the amount of cased well bore perforated and fraced usually is several tens of feet long. Fracing this amount of area requires thousands of gallons of frac water. Because unconventional well lateral segments can extend for thousands of feet, hydrofracing requires hundreds of thousands to millions of gallons of water to complete the process. Most of the water used in the fracing process remains within the rock unit. However, about 25% of this water is recovered after fracing. Most commonly, this water is then used to frac additional wells. Recovered water that is not reused must be treated to remove harmful chemicals.

Useful Resources and References

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GEOLOGY OF THE MARCELLUS SHALE IN MARYLAND

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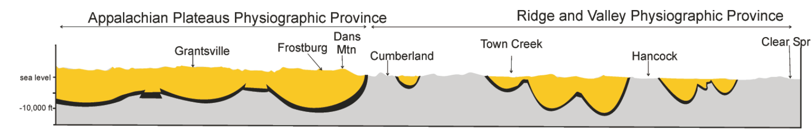

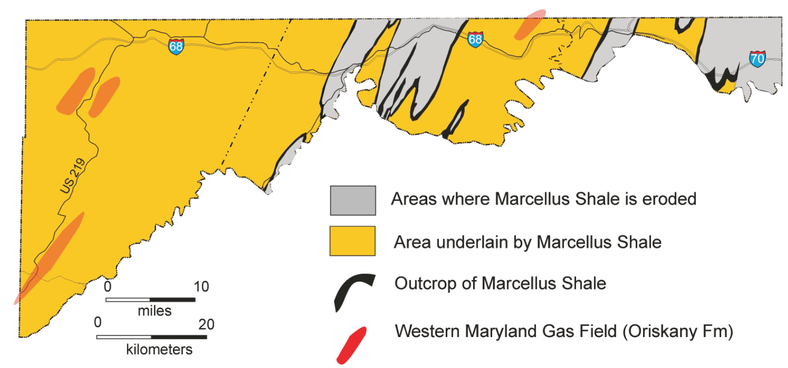

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