Marcellus Shale – Geologic Controls on Production*

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Introduction

The modern era of Marcellus Shale production in the Appalachian Basin began in 2004 when Range Resources completed the Renz Unit #1 well in Washington County, Pennsylvania using a large Barnett style slick water frac. This well tested at commercial rates and led to the current drilling boom targeting the Marcellus Shale. Subsequent to this discovery well, many companies have acquired large lease positions and drilled numerous horizontal and vertical discovery wells across a play area encompassing over 30 million acres in Pennsylvania, West Virginia, New York, and Ohio.

The boundaries of the Marcellus can be defined to the north, south, and east by the outcrop belt of the unit and to the west by the removal of the Marcellus by the Middle Devonian Unconformity Surface. Historically, there have been more than 20,000 penetrations of the Marcellus throughout the Basin targeting deeper reservoirs, mainly the Devonian Oriskany and Silurian Medina. These penetrations provide a large database of well information from open-hole well logs and well records.

Stratigraphy

The Middle Devonian Marcellus Shale Formation is located stratigraphically in the lower portion of the Hamilton Group. It is divided into two members, the Upper Marcellus/Oatka Creek Shale and the Lower Marcellus/Union Spring Shale (Figure 1). The Marcellus lies conformably on the Onesquethaw Group. The Onesquethaw Group is composed of three facies-equivalent formations, grading generally from west to east from a cherty limestone (Onondaga Limestone) in the central and western portions of the basin thence into a formation that is predominantly chert (Huntersville Chert) and finally into a calcitic shale facies (Needmore Shale) in the easternmost areas. The Marcellus is bounded above by the gray non-organic shales of the Mahantango/Skaneateles Formation. The Tully Limestone is the upper bounding formation of the Hamilton Group and can reach a thickness of more than 100 feet. There are also several other significant limestone formations in the Hamilton Group including; Purcell, Cherry Valley, Stafford, Centerfield, and Tichenor Limestones.

The Middle Devonian Unconformity eroded into the Tully Limestone in west-central Pennsylvania and West Virginia, removing subsequently older units to the west. Moving west, the unconformity removed the entire Tully and Marcellus intervals and provides the western limit of potential Marcellus production in eastern Ohio and western West Virginia.

The Marcellus Shale play extends through five states, and the stratigraphic terminology for the formations varies depending on the location. These differences are mainly divided into the New York terminology versus the West Virginia- Pennsylvania terminology. This discussion provides both names as the West Virginia - Pennsylvania terminology/New York terminology.

Geologic Controls

Creties Jenkins of DeGolyer and MacNaughton lists seven (7) geologic factors that control shale project success:

1. Thickness
2. Maturity
3. Gas Content/Rock Properties
4. Areal Extent
5. Depth
6. Structural Complexity
7. Lateral Continuity

It is proposed herein that two additional categories need to be analyzed to adequately evaluate the production potential of the Marcellus Shale:

8. Pressure Gradient
9. Natural Fracturing

Basin Architecture

Frank Ettensohn (2004) assigned the period of Marcellus deposition to the second of four tectophases of the Devonian Acadian Orogeny. He linked the basin deformation and subsidence to the fold-belt orogeny, wherein a migrating foreland basin was created cratonward of the orogen. Thus, it was proposed that a major orogenic highland was located to the east and southeast of the current Appalachian Basin from which sediments were derived. This orogenic highland also contributed to deformational loading (e.g., Walcott, 1970; Price 1973), which provided the accommodation space required for the sediments to accumulate.

Thickness

The gross thickness of the Marcellus Shale increases generally eastward from the zero isopach in eastern Ohio and western West Virginia to a maximum thickness of more than 250 feet in northeast Pennsylvania (Figure 2). The trend of thickening generally parallels the Appalachian

Structural Front, as shown by the Onondaga outcrop in Figure 1. Schmoker (1982) documented a direct correlation between the organic content of Appalachian shales and the wire-line log gamma ray intensity. Using this relationship, a net radioactive Marcellus Shale map was constructed in order to map the net thickness of the organic-rich Marcellus Shale. This radioactive shale was defined as Marcellus Shale having gamma ray greater than 60 API units "hotter" than a shale baseline established in the overlying gray shales of the Mahantango and Harrell shales. The axis of maximum thickening of this radioactive organic-rich shale roughly parallels the present day Appalachian structural front and 20 to 40 miles cratonward of the front. The lessening of the net thickness of the organic-rich Marcellus approaching the front can be explained using Ettensohn's model of clastic influx into the basin from the orogenic highland to the east.

Pressure Gradient

Production from the Marcellus is impacted both positively and negatively by variations in the pressure gradient. The most significant negative impact on production is documented in portions of central and southern West Virginia, where a significantly below normal pressure gradient is found in the herein named Big Sandy Low Pressure Sink and the adjoining Transitional Pressure Area (Figure 3). Normal and above-normal pressure gradients are postulated for much of the remaining portions of the play, although detailed data is scarce at the time of publication. Completion practices in the low pressure gradient areas are dominated by straight gas fracs and foam fracs due to the low pressure and associated well clean-up issues, while large slick water fracs have been utilized in nearly all completions in the normal and overpressured areas. It is proposed that consistent high production volumes and high ultimate reserves in the Marcellus Shale will only be found in the areas that are normally or overpressured.

Thermal Maturity

The thermal maturity of the Devonian rocks, based on CAI and %Ro, generally increases from thermally immature rocks in the northwestern portions of the basin into areas of high thermal maturation approaching the structural front (Figure 4). The highest levels of thermal maturation are found in northeastern Pennsylvania and southeastern New York.

Natural Fracturing

Devonian Shales from several organic-rich units younger than the Marcellus have been produced in the Big Sandy Field of Eastern Kentucky and southern West Virginia since the late 1800's. Within the field, tens of thousands of wells are currently producing from the Rhinestreet, Upper and Lower Huron, and the Cleveland shales. It is well documented that the primary controlling factor in this field is the presence of open natural fractures leading to superior production performance. Indirect evidence also points to the possibility that open natural fractures may play a significant role in influencing Marcellus production; as many of the more than 20,000 penetrations of the Marcellus had reported natural flows of gas from the Marcellus, and many others had indications of natural flow from the open-hole logs (temperature and audio). These natural flows of gas are indicative of micro-fracturing of the rock, as the low permeability (nanodarcies) would not allow for natural production without enhancement by natural fracturing.

Depth

Figure 5 is a map of the drilling depth to the base of the Marcellus. This illustrates that the maximum drilling depths (>7000 feet) are encountered in synclines just basinward of the structural front, and drilling depth gradually decreases to the west and northwest. Minimum drilling depth for economic production has not been determined at this time; however, the vast majority of the permitted and drilled Marcellus wells are located in areas where the drilling depth exceeds 5000 feet.

Geologic Hazards

Geologic hazards encountered during drilling and completion of the Marcellus include:

1. No Upper Frac Boundary – leading to fracing up and out of zone.
2. No Lower Frac Boundary – leading to fracing downward into possibly water-bearing units.
3. Fracture Migration Along Faults – leading to either upward or downward fracture migration and failure to adequately stimulate the target zone.
4. Horizontal Hole Failures.

One of the seemingly attractive areas for Marcellus in the southern portion of the basin, based on thickness, depth, and thermal maturity, is located basinward of the structural front. Portions of this area lie within the "High Amplitude Fold Area" (Kulander and Dean, 1986). This area, however, has additional risk from increased structural complexity due to the presence of large, heavily faulted detached anticlines and associated synclines. This area is located within the Allegheny Mountain section of the Appalachian Plateau Physiographic Province but is quite different structurally from the remaining portion of the Plateau to the west and northwest, which is characterized by low-amplitude folding and reduced structural complexity.

Areal Extent

Utilization of the various parameters discussed above allows a "core area" of Marcellus Shale production to be established and encompasses approximately 18 million acres. This
Core Area was defined by:

1. Net Organic-rich Marcellus Thickness > 30 feet
2. Pressure Gradient > .40 psi/ft
3. Thermal Maturation > 1.25 % Ro (mean)
4. Depth >5000 feet

Production

The Marcellus Shale play at this time (2009) is still in its infancy and official production data is nearly non-existent due to state regulations. Publicly traded companies have provided production data via news releases and quarterly reports which provide indications that the production to date may be comparable to the other recent high-volume shale-resource plays, including the Barnett and Haynesville. The maximum reported daily rate of production to date is 24.5 Mmcf per day from a horizontal completion in Washington County, Pennsylvania, and daily rates from vertical in Pennsylvania and northern West Virginia are commonly in excess of 2.0 Mmcf into line.

Summary

The quality of the production reported to date combined with the huge areal extent of the play indicates that the reserve base of the Marcellus Shale may one day achieve the status as the largest of all the shale gas plays in North America.

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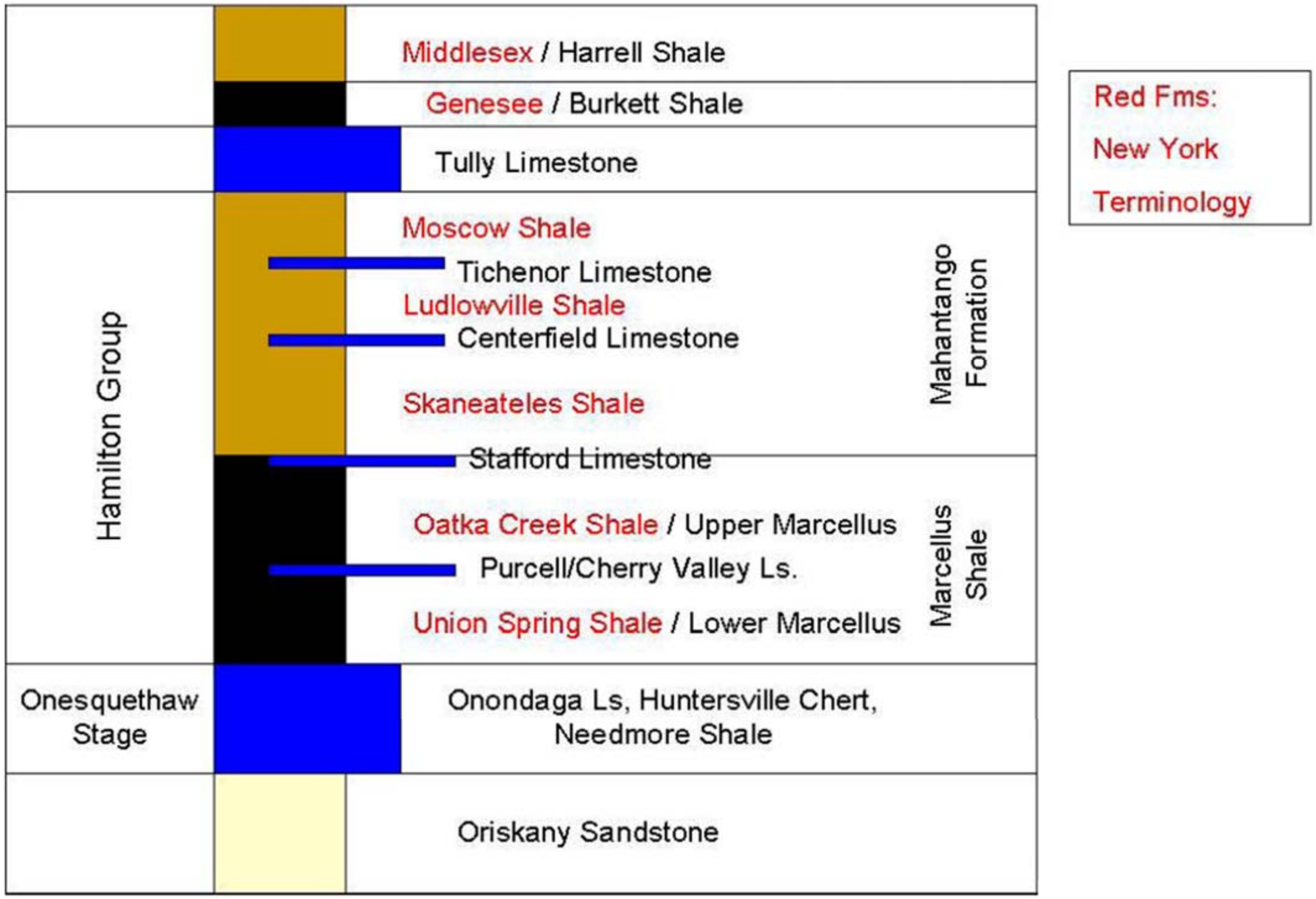

Figure 1. Stratigraphy of Lower and Middle Devonian in Appalachian Basin.

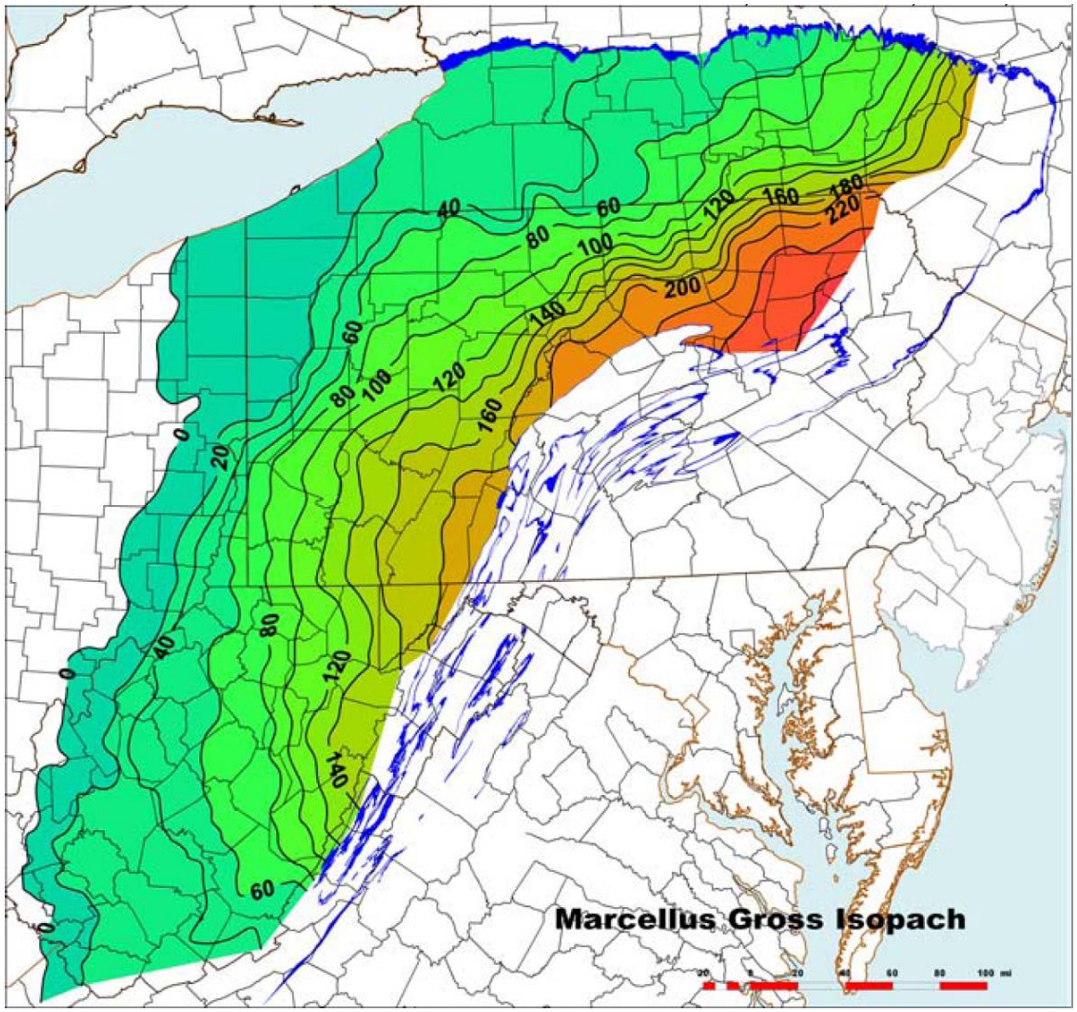

Figure 2. Marcellus Shale gross isopach.

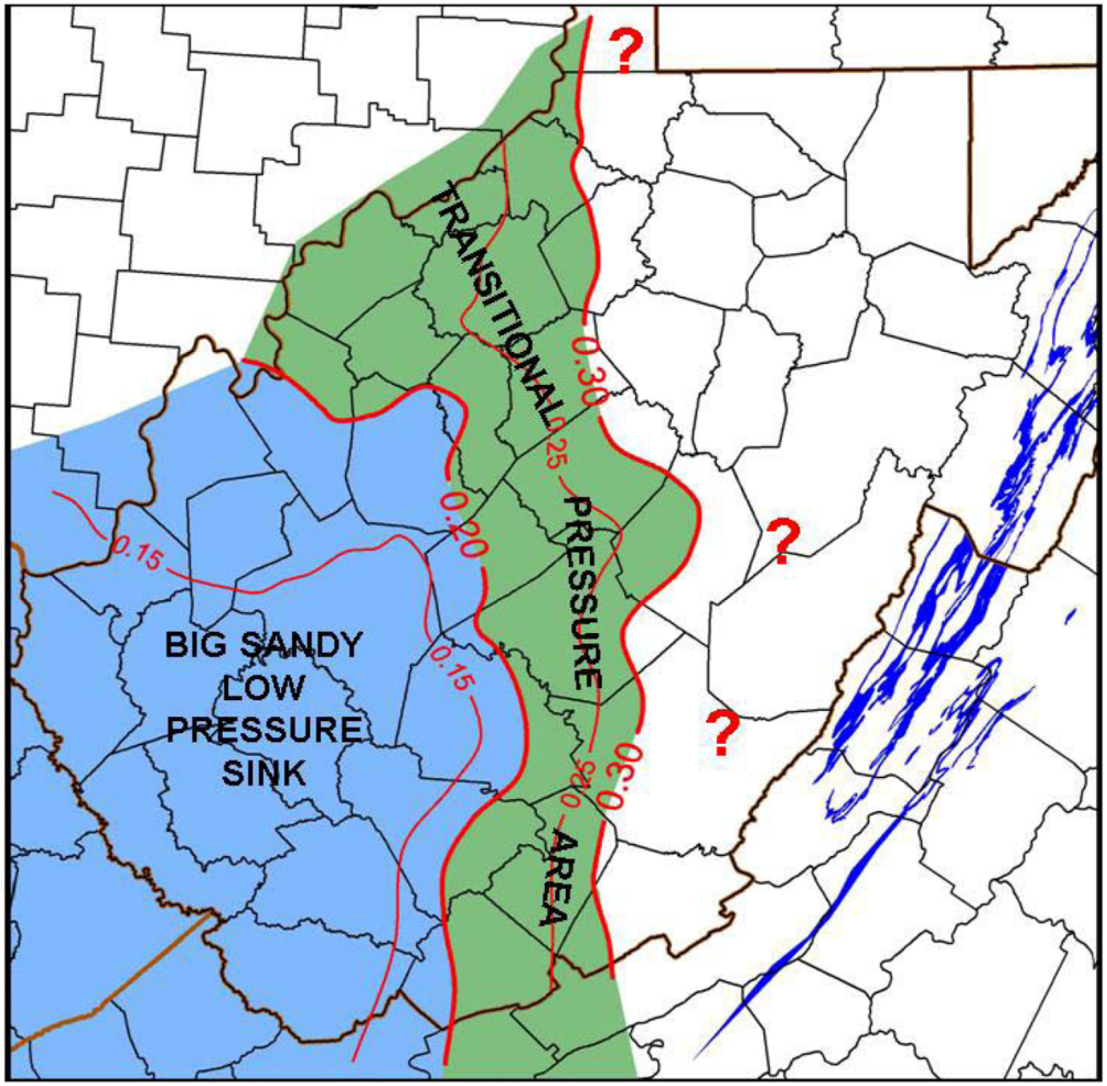

Figure 3. Pressure gradient in West Virginia.

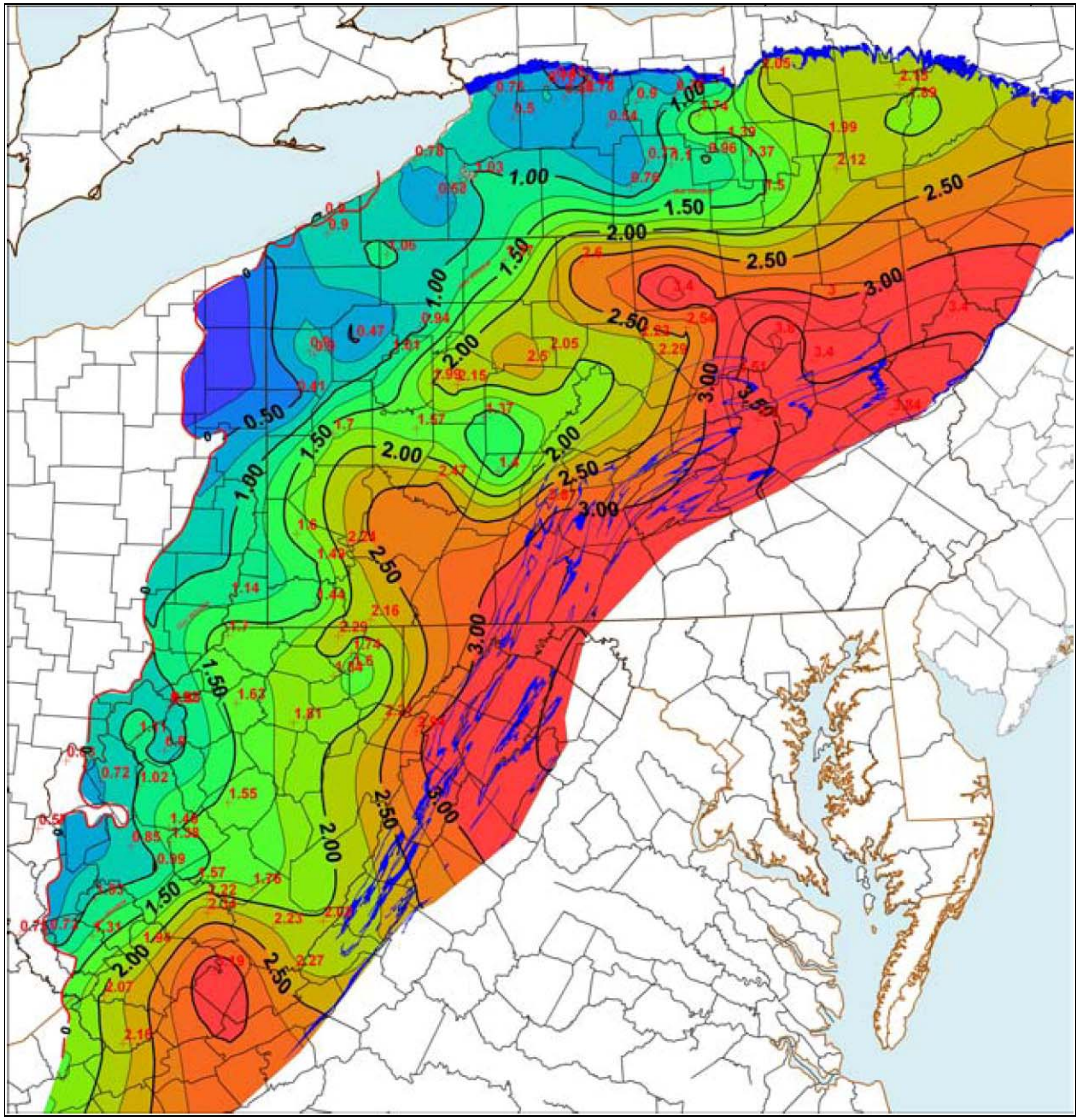

Figure 4. Devonian thermal maturity (%Ro)

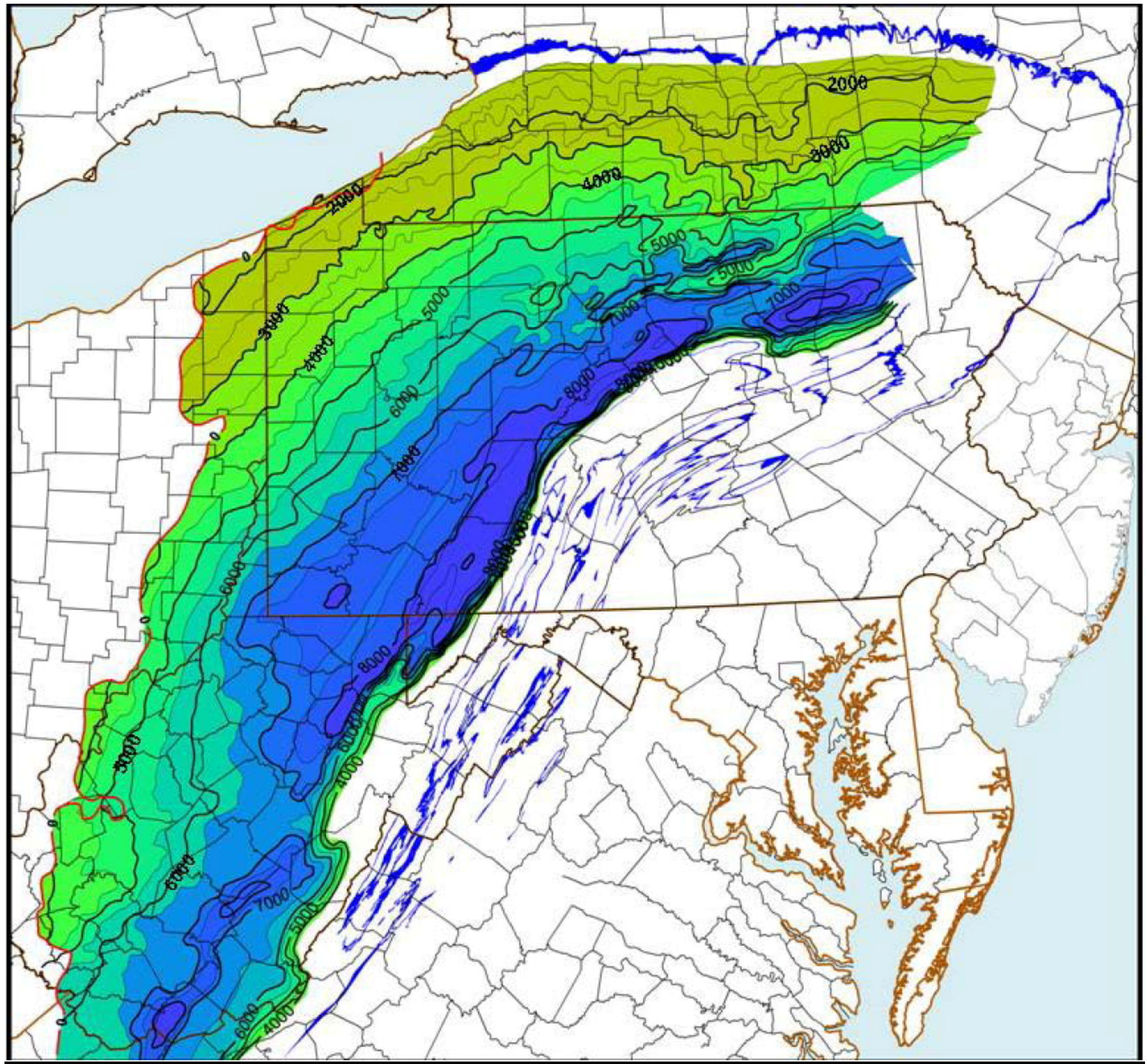

Figure 5. Drilling depth to base of Marcellus.