

Producing the Marcellus Shale: Field Experience in Pad Drilling Techniques

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Abstract

The Marcellus Shale region in the northeastern United States is the scene of intensive shale gas development. In this paper, the authors discuss the advantages and challenges of multiwell pad-design drilling in a region where conventional vertical well approaches are often no longer ideal because of changing environmental, economic, and regulatory factors. In particular, they will examine the importance of effective anticollision methodologies and the increasingly critical role of collaboration among service providers and operators.

Introduction

First identified from surface outcroppings in the mid-19th century, the Marcellus Shale region extends through several states in the northeastern section of the United States (Figure 1).

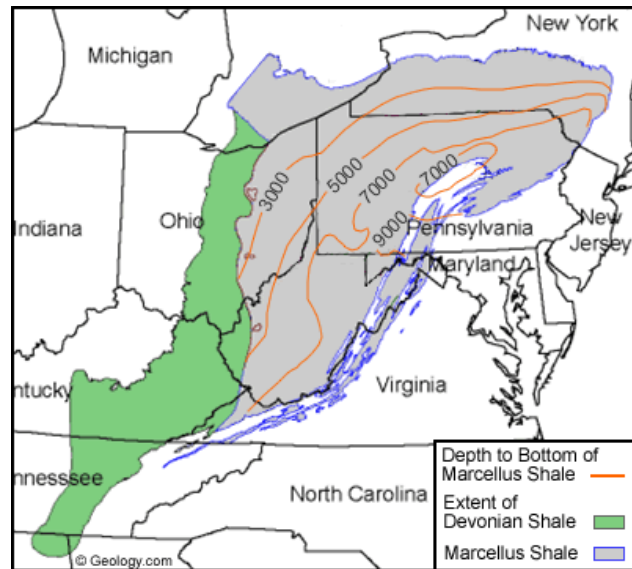


Figure 1: Location and approximate depths to the base of the Marcellus Shale. Credit for map to Milici and Swezey¹; depth contours derived from data published by deWitt².

Figure 2 details the stratigraphy in the Appalachian Basin, which encompasses the Marcellus Shale region.

System	Ohio	N. Virginia and West Virginia	Western Maryland	Western Pennsylvania	Northwestern New York	International Stage
Middle Devonian	Orientangy Shale	Harnett Shale	Harnett Shale	Harnett Shale	Genesee Fm.	Frasnian
	Proud Limestone	Tully Limestone	Mahantango Formation	Mahantango Formation	Moscow Shale	Givetian
	Plum Brook Shale	Mahantango Formation	Mahantango Formation	Mahantango Formation	Ludlowville Shale	
	Delaware Limestone	Marcellus Shale	Marcellus Shale	Marcellus Shale	Skaneateles Shale	Eiffelian
Columbus Limestone	Huntersville Shale	Needmore Shale	Needmore Shale	Onondaga Limestone		
Lower Dev.	Bois Blanc Limestone	Huntersville Shale	Needmore Shale	Needmore Shale	Onondaga Limestone	Emsian

Figure 2: Lower and Middle Devonian stratigraphy of the Appalachian Basin, including the Marcellus Shale (from Milici and Swezey¹).

Developing the Marcellus Shale poses some significant challenges to operators, including limited surface hole locations because of the mountainous terrain, water disposal and related environmental issues, limited pipeline capacity, and difficulties in establishing supply lines for drilling operations. Formerly relying primarily on single, vertical well designs, operators have begun to take a multiwell pad-drilling approach, placing as many as 14 or more wells on 7-ft centers from a single pad location.

Historical Drilling Practice

A reliance on older technology and drilling practices in the Appalachian Basin has created legacy issues for current development. Surveying was not a priority when development consisted of single, vertical wells, and the data that were collected were compromised by the use of older gyroscopic and steering technologies and limited quality control. Air drilling has been commonly used in the region, making hole control and surveying while drilling more difficult.

A typical pad-drilling example illustrates some of the obstacles commonly faced by operators in the region.

The 17.5-in. surface hole section is typically air-drilled blind and surveyed. Next, the 12.25-in. water protection string is drilled with air hammers or air motors, using gyro

measurement while drilling (MWD) to achieve the initial separation of well paths from the pad. Trips are optimized based on the periodic drop in rate of penetration (ROP), which is strongly affected by bit dulling in this section.

Next, the 8.75-in. section is typically drilled on air to the greatest depth feasible, using a rotary steering system (RSS) and MWD to control well path placement. The pad is optimized to complete the directional work in the 12.25-in. section and to minimize the tangent sail angle during separation of the wellbores.

Extreme drilling mechanics in this laminated section, including shock and stick-slip, often adversely affect RSS and motor performance and must be closely monitored to reduce the number of bit, MWD, motor, and RSS failures. Roller reamers are typically used instead of stabilizers to reduce the effects of stick-slip during rotation to the kickoff point.

During the tangent section in the 8.75-in. section, directional assemblies have commonly seen a dropping tendency of 3°–5° per 100 ft in rotation.

Collaborative Pad Drilling Design

In a recent project in the region, the operator and contractor worked closely together to create a 14-well pad drilling design to fully maximize the potential of a wellsite, with special attention to the avoidance of well collisions. This close collaboration at the planning and design stage helped to ensure that the project achieved both its production and financial targets, and did so safely.

The contractor was able to draw on extensive experience in small-footprint, multiwell drilling programs offshore, where close and systematic attention to collision avoidance is a routine element in project execution. Both parties agreed to use the anticollision standard as specified in Poedjono et al.³ In accordance with this standard, the pad design included a detailed surveying program to acquire the precise data required to effectively prevent well collisions.

The operator and contractor discussed and agreed upon the definition of the slot grids, naming conventions, and bottomhole locations designed to meet the project's Phase 1 and Phase 2 production objectives. Phase 1 consisted of the five wellbores in the Marcellus shale, two in an adjacent target reservoir designated as "Other," and the seven corresponding paired wellbores.

Acceptable degrees of positional uncertainty were defined for anticollision purposes after completion of a survey program at three different true vertical depths (TVDs): 1,000 ft, 2,500 ft, and 5,000 ft. North-seeking gyro while drilling would be used to a maximum inclination of 20°. Once a given well had been drilled to a sufficient distance to be free of external magnetic interference from nearby wellbores, MWD

surveys would be used to drill to total depth (TD).

The 17.5-in. section, which would run to a TVD of approximately of 1,000 ft, would be drilled with air without directional control. The 12.25-in. section to a TVD of approximately 2,500 ft would be drilled with air, with the minimum directional control required to prevent wellbore collision at this shallow depth. A maximum dogleg severity (DLS) of 1.25° per 100 ft was used and the sail angle ranged from 13° to 20°.

The 8.75-in. section would be drilled to a TVD in the target reservoir and would have a maximum DLS of 10° per 100 ft with a minimum negative section.

Figure 3 illustrates the typical wellbore profile for this project.

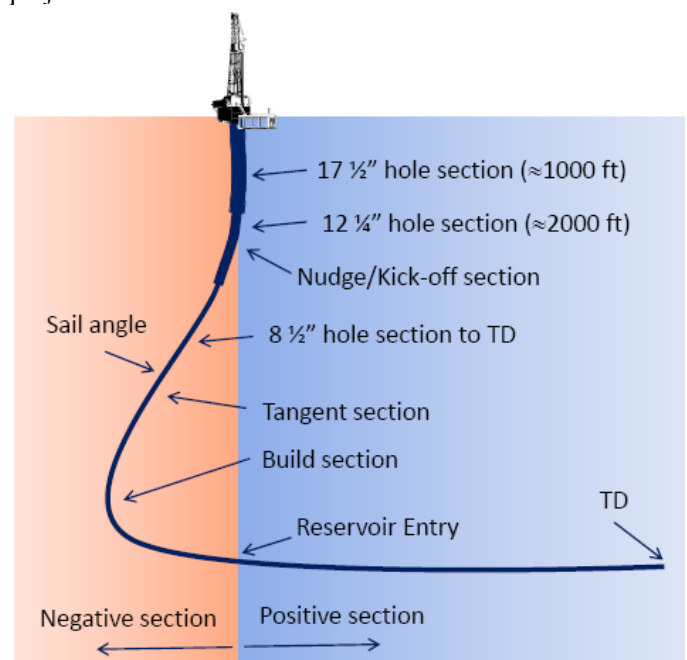


Figure 3: Typical wellbore profile for multiwell Marcellus Shale project pad design.

Per the design, each of the seven initial reservoir entry points must have a 200-ft separation distance from its paired well going in the opposite direction. Both parties agreed to perform anticollision analysis of the trajectories to ensure that the wellbores were sufficiently separated to minimize the risk of collision and then optimize the trajectory to its target reservoir.

Refining the Pad Design

Once the general program goals and design were agreed upon, the contractor received an initial set of surface and target coordinates, which included restrictions of surface hole location (SHL) and targets to be assigned to each slot. These

were plotted to create a preliminary pad visualization. Slots and targets were paired so that none of the planned trajectories would cross each other at any depth, while maintaining an optimum total footage drilled. Figures 4 through 7 illustrate this initial program design.

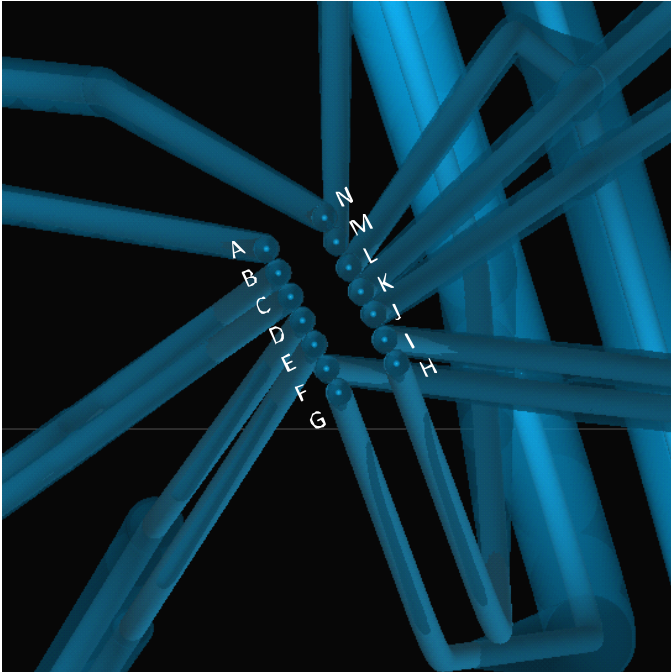


Figure 4: Original slot map showing well-naming conventions. The graphic depicts the ellipsoid of uncertainty (EOU) defined for each wellbore in the survey program.

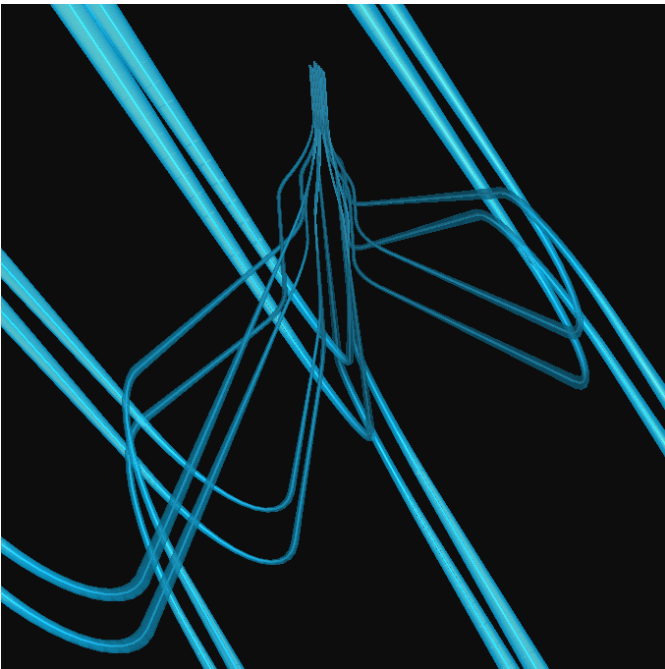


Figure 5: Original design showing wellbore separation from surface to landing points.

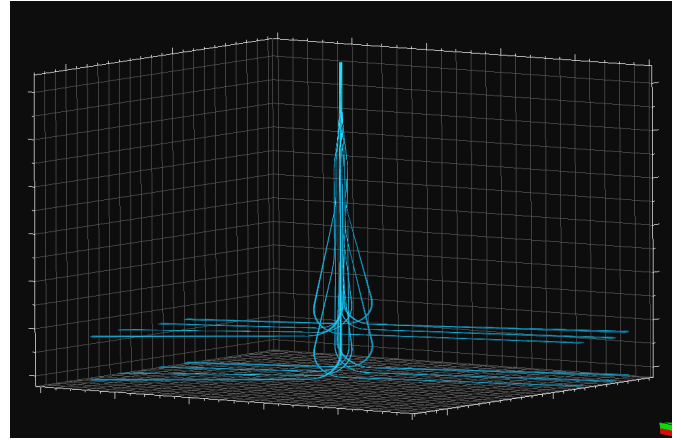


Figure 6: Vertical section of initial pad design shows optimal SHL and target assignments within the two horizontal reservoirs.

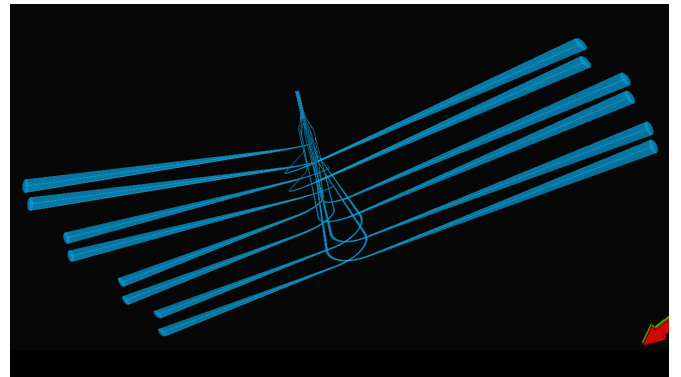


Figure 7: Initial pad design seen from below, showing safe separation of wellbore trajectories at all depths from surface to TD.

To help ensure accurate execution of the plan, uncertainty areas were added to the well paths at 2,500 ft and 5,000 ft TVD (Figure 8). These transitional uncertainty areas provide accountability of the actual trajectory's deviation from plan without creating anticollision issues.

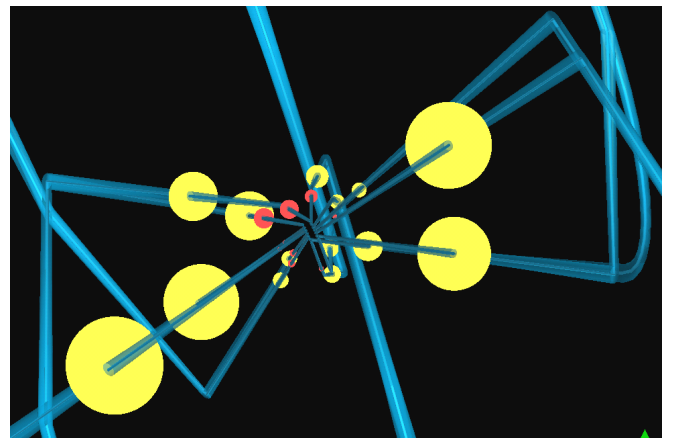


Figure 8: Initial pad design with added uncertainty areas at 2,500

ft TVD (red circles) and at 5,000 ft TVD (yellow circles).

Once actual surveyed surface-hole coordinates were available, and another revision of geological targets was received, several additional design iterations were performed. In keeping with permitting requirements, the operator specified slot options for drilling each target. These options are summarized in Table 1.

Table 1: Slot Assignment Options Based on Operator’s Reservoir Requirements

Well Name	Reservoir	Slot Options
AA55-T	Marcellus	A,B,C,D
AA56-T	Marcellus	A,B,C,D,E,F
AA57-B	Marcellus	A,B,C,D,E,F,G
AB77-B	Other	A,B,C,D,E,F,G
AB78-T	Marcellus	B,C,D,E,F,G
AB79-B	Other	C,D,E, and either F or G
AB70-T	Marcellus	E,F,G

The pad design was finalized after Phase 1 surface holes had been drilled and surveyed (Figures 9 through 12). Based on the actual surface hole trajectories, all wells were replanned, collision risks were reassessed, and uncertainty areas were recalculated to meet the permitting requirements.

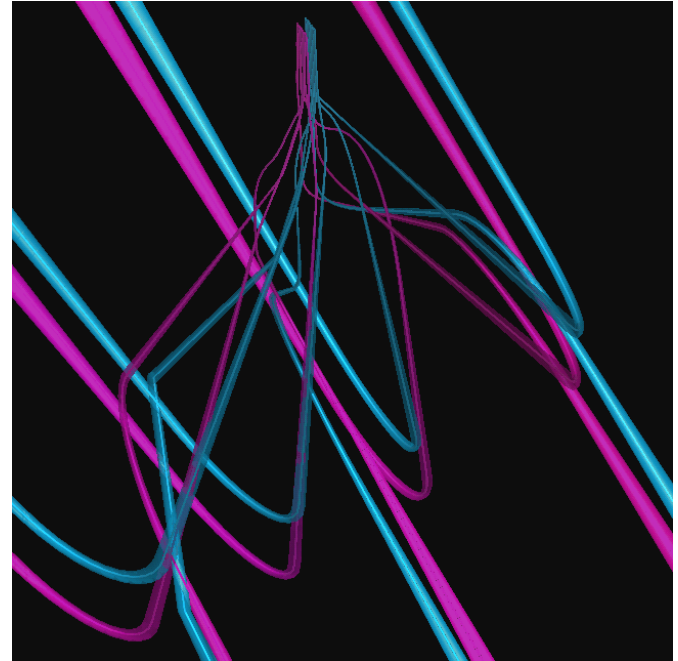


Figure 10: Final pad design adjusted to meet the approved permit as specified by the operator.

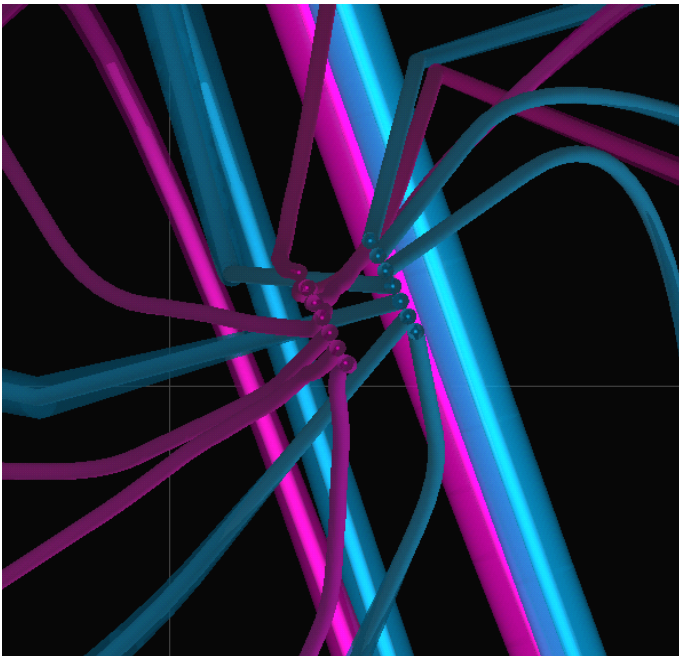


Figure 9: Final slot assignment. Phase 1 drilling campaign noted in red; Phase 2 plan in blue. The graphical size of each wellbore corresponds to the EOUs defined in the survey program.

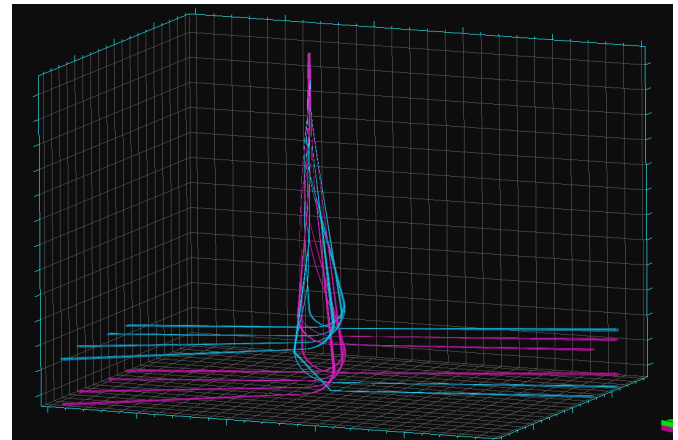


Figure 11: Vertical section of final pad design; Phase 1 drilling campaign in red, Phase 2 in blue.

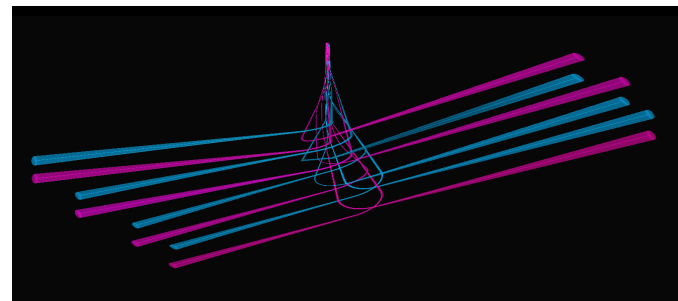


Figure 12: Final pad design seen from below showing safe separation of wells from surface to TD.

Conclusion

The concept and implementation of pad design described above represents a step-change in the approach to reservoir development in this region. This is still an active drilling project, and contractor and operator continue to collaborate to improve the drilling program by introducing new techniques and fit-for-purpose technologies.

Pad design for this particular project was not optimal, due in part to permitting and surveying restrictions which required the surface locations to be modified. The contractor's experience in the offshore environment has been applied to this land-drilling project to reduce the risk of collision and its associated costs. For the operator, the ability to safely drill multiple wells on the same footprint as a single vertical well has helped to ensure the economic viability of operations in this challenging region.

Acknowledgments

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3. Poedjono, B., Lombardo, G.J., and Phillips, W. 2009. Anti-Collision Risk Management Standard for Well Placement. Paper SPE 121040 presented at the SPE Americas E&P Environmental and Safety Conference, San Antonio, Texas, USA, 23-25 March.