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Reservoir Characterization and Development Strategies of the Permian Wolfcamp and Bone Spring Formations of the Delaware Basin, West Texas and Southeast New Mexico, USA

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Introduction

The Delaware Basin, a western sub-basin of the Permian Basin, is located in west Texas and southeast New Mexico. Production in the Permian Basin had been on heavy decline since the early 1970s when deep gas-dominated structural traps were exploited through vertical drilling. Horizontal well development initiated in 2009, reversing the decline within the basin, resulting in a current daily production of over 2.5 MMBOEPD. Operators are focusing on liquid-rich tight sand and organic shale reservoirs of the Bone Spring and Wolfcamp formations of the Delaware Basin. The new growth intervals include at least 14 productive Permian-aged horizontal targets; the Wolfcamp, Avalon, and Bone Spring shales, and the Bone Spring and Delaware Mountain Group low-resistivity sands. Subsequently, optimal completion design and drilling strategies may be assumed in early development but adjusted as development progresses.

The Wolfcamp Formation

The Wolfcamp formation consists of a multiple billion barrel oil equivalent resource opportunity in the Delaware Basin. Subsequently, the bulk of recent drilling activity has been targeting the Wolfcamp shale. This review will examine the Wolfcamp shale pay distribution, corresponding optimal landing zones, and elucidate the thermal maturity corridor that exists across the Delaware Basin.

The Delaware Basin can be divided into two GOR thermal regimes; low GOR to the east and high GOR to the west. Multiple hypotheses may explain this segregation; chromatographic migration, basin inversion, heat flow fluctuation, etc. This review will explore these alternatives to thermal maturity and demonstrate the potential for fluid flow in low permeability systems not only at a local scale, but more regionally.

The remaining Total Organic Carbon (TOC) content of shale source rocks plays a key role in the characterization and development of self-sourced unconventional plays. Resource in-place calculation and landing target selection for horizontal wells commonly reflect the magnitude of TOC in the reservoir and varies across the basin. The underlying assumption is that the permeability of shales is insufficient to allow for the migration of hydrocarbon generated during the thermal maturation process. Subsequently, remaining TOC is a good proxy for original hydrocarbon in place (OHIP). The Wolfcamp can be differentiated into 5 stratigraphic pay zones distributed across the basin. A review of the basin stratigraphy and architecture will demonstrate

this, followed by a discussion leveraging core data showing 1) the middle and lower Wolfcamp reservoirs (Wolfcamp C & D) where TOC and OHIP are co-located and 2) log-based techniques used to characterize these reservoirs. We also discuss the upper Wolfcamp reservoir (Wolfcamp A & B) where the hydrocarbon generated during the thermal maturation process has migrated, at least at a local scale. Production logs verify TOC-based pay calculations can lead to suboptimal landing zone placement in the upper Wolfcamp. Thus, an alternative OHIP-based characterization is the preferred pay and subsequent landing zone identification. This petrophysics workflow can provide insight in qualifying pay in hybrid lithologic systems.

Bone Spring Formation

The Bone Spring Formation lies conformably above the Wolfcamp. The Bone Spring formation is subdivided into the 3rd, 2nd, and 1st Bone Spring sands overlain by the Avalon Shale. Operators are targeting the low-resistive tight sands within the channel and unconfined basinal lobe facies. However, sands grade to more shale prone facies deeper in the basin resulting in a hybrid-play of both organic shales and tight sands. Landing strategies are thus adjusted to land lower in the organic-rich shales.

General depositional trends of the Bone Spring indicate that better potential for oil production exists in the northern half of the basin where it is comprised of deepwater channels and subsequently, better reservoir quality. These channels naturally transition southward (down-dip) into more unconfined channels, lobes, and basinal deposits. Seismic data located in the central Delaware Basin has revealed ~400 feet of disrupted strata characterized by a series of imbricate thrust faults within the down-dip section of Bone Spring. These features are interpreted as the slumps and slides of a mass transport deposit (MTD). Several recent wells within the MTD are performing better than expected given their location in the depositional system and assumed poorer reservoir quality. Notably, these types of deposits in The Gulf of Mexico are avoided as drilling targets due to proven poor reservoir quality. Therefore, we are investigating how this MTD played a role in enhancing production in the 2nd Bone Spring sand of the Delaware Basin. A detailed study was conducted and showed better producing Bone Spring wells stayed within individual thrust imbricates.

Fracture Network

A comprehensive fracture characterization study was completed within the Delaware Basin. This study confirms the presence and character of natural fractures throughout the basin and the varying relationships that exist between the natural fractures and present-day SHmax orientations. Most natural fractures are healed with calcite, have heights averaging ~2 feet, and apertures ranging from hairline to 2 mm. A terminus of the fractures against a bedding surface is almost always seen in image log and core, suggesting that contrasts in mechanical strength between stratigraphic layers strongly controlled natural fracture propagation. Open fractures are present but sparse, and they do not have the same orientation or density trends as the abundant healed fractures. Healed fracture densities generally increase with depth throughout the basin, with the presence of a secondary set in the deeper formations that is likely contributing to these higher densities. Image logs from horizontal wells are valuable to characterize the spatial

clustering of fractures, displaying systematic clustering of fractures that cannot be determined from vertical well logs. Healed fracture orientations have a systematic change in the Delaware Basin, from NE-SW in the north, E-W in the central portion, and NW-SE in the southern portion of the basin. Present-day SHmax orientations for the Delaware parallel those of the dominant healed natural fracture trend. Conversely, in the Midland Basin, the dominant healed fracture trend strikes NE-SW, regardless of location, and SHmax is orientated E-W, oblique to the fractures. The observed relationships between natural fractures and SHmax has implications to well path planning, completion strategy and efficiency, stimulated rock volume, and field development plan decisions. Despite similar fracture characteristics (height, apertures, fill) between the Midland and the Delaware Basins, each should be treated distinctly to maximize the natural fracture system during field development.

Avalon Shale Case Study

The self-sourcing Avalon shale (top of the Bone Spring Formation) in the northern half of the Delaware Basin can be subdivided into three zones based on sequence stratigraphy; upper, middle and lower hemi-pelagic shale packages bifurcated by carbonate debris flows. The three distinct Avalon zones have well defined core development areas that migrate spatially cross the basin and at places overlap, enhancing the resource density.

The initial Porter Brown exploration well in Salado Draw, Lea County, NM, was drilled in 2012. A robust formation evaluation program was conducted which included a vertical and lateral logging suites, conventional core, side-wall core, well-site drill cutting analysis, and post-drill geochemical analysis of headspace gas, mud gas, and produced liquids. Ultimately, petrophysical logs plus well-site cutting and gas (C1/C5 ratio) analysis were used to identify the optimal landing zone.

Multiple follow-up offsetting wells were drilled to begin full-field development at 80 acre spacing. A micro-seismic survey was implemented to monitor a multi-well zipper frack to define the hydraulic fracture geometry and after initial flow-back a retrievable fiber optic cable was ran to record the potential communication between wells and production allocation along the lateral. A follow-up geochemical cutting analysis was completed on the development wells to further optimize completion design and 3D seismic was integrated to assess the effectiveness of the lateral placement. The 3D seismic was subsequently calibrated to predict rock properties and fracture complexities as we develop further from the initial development pads. The results will be reviewed. Regional mineral anomalies were identified to provide a geochemical framework to better define the stratigraphy. This integrated study ultimately defined our optimal spacing and completions designs to maximize hydrocarbon recovery.

Conclusions

The Delaware Basin is the most active basin in the United States. The Wolfcamp and Bone Spring Formations have a large resource density with multiple benches for exploitation. Plays are at different evolutions and optimal development strategies differ depending on rock type, well spacing, and completion design.