PS Potential Shale-Oil Reservoirs in the Eastern Bighorn Basin, Wyoming*

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Abstract

The identification of new oil-producing shale reservoirs can be facilitated through the application of full 3-D petroleum system modeling. This study presents the results of a full, 3-D petroleum system model of the Bighorn Basin, north-central Wyoming, and the identification of potential shale oil reservoirs that are currently not being produced. Multiple data types were obtained and integrated into a single, large-scale 3-D model which was used in the petroleum systems simulation. Calibration was then performed to improve modeling results. This study was performed in five phases – 1) 3-D structural framework construction, 2) geochemical data integration, 3) preliminary 1-D simulations, 4) 3-D predictive model simulation and 5) calibration. Previously studies utilized 1-D petroleum models which are limited geographically. This study utilized advanced 3-D modeling techniques to simulate the basin's geologic history from the Precambrian to present day. Results indicate that the Permian petroleum system has a high degree of thermal maturity, however, the drill depth to these formations make them currently uneconomic for development. The model indicates that the Lower Cretaceous formations also have a high degree of thermal maturity and the thermal maturity decreases upwards into the Upper Cretaceous formations. Based on the structural framework developed as input for the modeling process and the calibrated thermal-maturity results, the base of the marine Cody Shale and the upper portion of the marine Frontier formation, which includes shales, have been determined to be within the oil generation window and economic drill depths in the eastern Bighorn Basin.

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1. Abstract

Main factors associated with exploration for shale oil reservoirs include various economic as well as geochemical factors. This study present the results from an early (or "Pathfinding") exploration study to identify potentially economic shale oil reservoirs in the Bighorn Basin of north central Wyoming (see **Figure #1**). In addition to Petroleum Systems Modeling, consideration has been given for the main economic factor of Drill Depth. Successful shale reservoirs within the US have included shales with vertical drill depths of 10,000' to 11,000' (Haynesville) before going horizontal.

This study presents the results of a full 3-D petroleum system model of the oil- and gas-bearing Bighorn Basin for shale oil reservoir play identification. While previously published studies contain 1-D petroleum system models, this study utilizes advanced 3-D modeling techniques to simulate the basin's history and thermal maturity. The study integrates multiple types of data into one large-scale model which is simulated and calibrated to yield the most accurate results. The project consisted of five phases; 1) structural framework construction, 2) geochemical data integration, 3) preliminary 1-D simulations, 4) 3-D predictive model simulation and 5) calibration. See **Figure #3** for this study's workflow. Because of the extensive workflow used, it was possible to achieve high degree of calibration.

Additional considerations for shale oil reservoirs include the intersection with of the horizontal bore hole with open, natural fracture trends. The intense structuring that has occurred within the Bighorn Basin suggests of the high probability of open fracture trends existing within the basin that could be exploited for shale oil exploration. The results indicate a high degree of thermal maturity within the Permian petroleum system with high transformation ration values. However, these were judged to be non-economic at the present time due to their drill depth.

For the Cretaceous petroleum system, the results also indicate a high degree of thermal maturity and transformation ratios in the Lower Cretaceous with decreasing thermal maturity for the Upper Cretaceous formations. Gas-bearing shales are predicted to be encountered in the lower Cretaceous, however, as with the Permian petroleum systems, these potential reservoirs are currently non-economic due to their depth. The Upper Cretaceous Shale reservoirs have been determined to be within the oil generation window and are within economic drill depth.

2. Objective

The purpose of this study was to extend the understanding of the Bighorn Basin's thermal and hydrocarbon maturation history by replicating the generation, expulsion, migration, and accumulation of hydrocarbons within the basin using 3-D petroleum systems modeling. This study determined the transformation ratios and thermal maturities of the various sources rocks within the basin, which have a direct impact on understanding the potential for unconventional reservoirs and their location and characteristics, such as amount of absorbed gas and secondary porosity. It is hoped that results of this study can be used to help guide future exploration efforts in the basin for shale oil reservoirs.

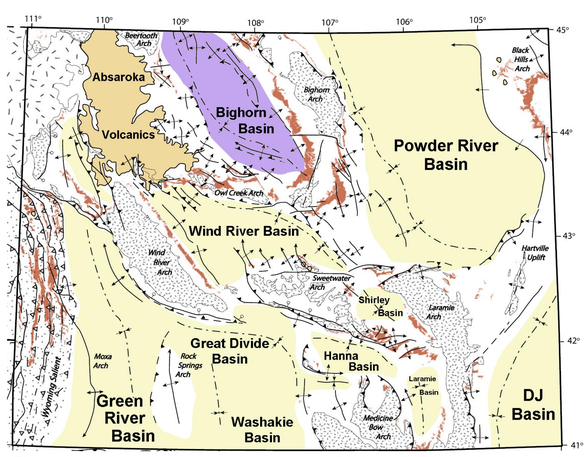

Figure #1: Map showing the location the Bighorn Basin and other major basins and uplifts in Wyoming.

2-D surfaces for the 27 formations within the basin were constructed in Petrel using public data. An example is shown here in Figure #2. These were transferred to PetroMod and used to construct the 3-D structural model of the basin.

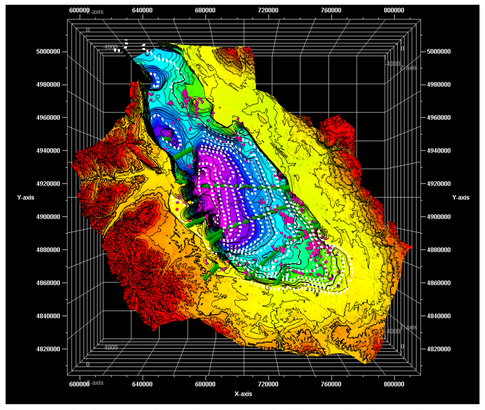

Figure #2: One surface (Mesaverde Formation) used to develop the basin's structural framework. Due to software requirements this surface was combined with the topography on the basin flanks.

3. Methodology

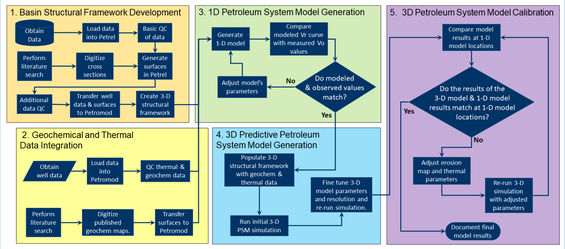

Figure #3: Workflow used in this study.

This study was performed in five phases, which are shown in the study's Workflow Chart at left in **Figure #3**. Additionally, the individual tasks that were performed are also shown within their respective phases. Data quality control tasks were performed at the start of the study in order to filter out erroneous data points within the public data set. Iterative loops were performed during the "1D Petroleum System Model Generation" and the "3D Petroleum System Model Calibration" phases in order to ensure the greatest accuracy possible.

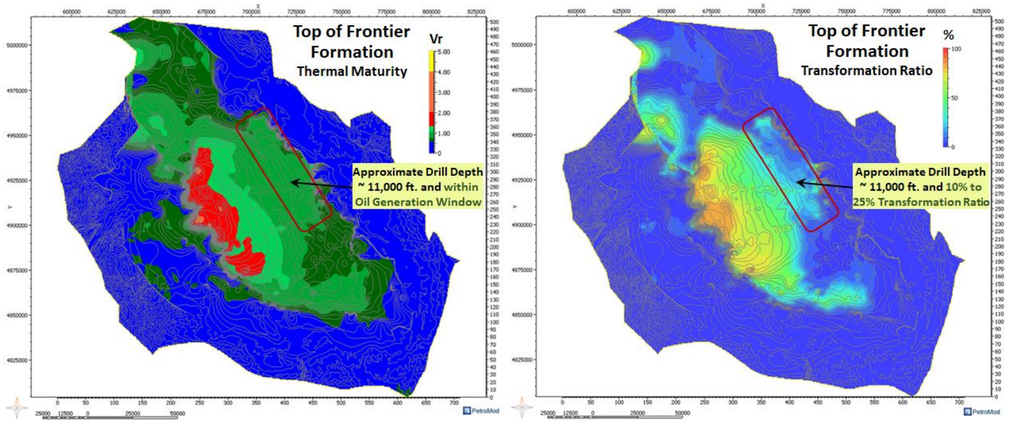

Figure #4: Calculated thermal maturity (Rv) map and Transformation Ratio Map for the Top of the Frontier Formation.

4. Results

Before final migration modeling was performed, the 3-D Petroleum Systems Model was calibrated. Initial 1-D models and the advanced heat flow relationships provided fairly good calibration. The erosion map was fine-tuned to provide a very good relationship between simulated VR values and measured Ro values. During the process of fine-tuning the model, a new erosion map was constructed. This map corresponded to the post-Eocene erosion. However, in this project the post-Eocene erosion was treated as a sum of all the erosional events that had occurred over the basin's history. Other erosional events were not calibrated due to lack of Ro data. The results indicate increasing amount of erosion from the center of the basin to the outskirts. However, these results should be taken with caution since the outskirts of the basin lack proper calibration due to a lack of wells and data.

Within the Bighorn Basin, there are two major petroleum systems. The Cretaceous petroleum system composed of source rocks within the Lance Formation, Meeteetse Formation, Mesaverde Formation, Cody Shale, Frontier Formation, Mowry Shale, Muddy Sandstone and Thermopolis Shale. The Permian-Pennsylvanian petroleum system is composed of the Phosphoria Formation and Tensleep Sandstone. Based on the results of the simulation, all of these formations are thermally mature to varying degrees.

Figure #4 shows the VR thermal maturity map and the Transformation Ratio map for the top of the Frontier Formation. The shades of green on the VR map indicate values between 0.6% and 1.35%, which are areas that are currently within the oil-generation window for Type I and Type II kerogens. Those colored red indicate areas that are in the gas-generation window and can be seen in the basin's center. The results of the migration modeling indicate that the hydrocarbon pool locations as modeled align well with the actual conventional fields locations within the basin. However, the alignment is not perfect because a basin scale resolution of the structural framework was needed for the study. A higher resolution would result in significantly longer and unacceptable modeling times for the simulations.

Study's results are shown in Figure #5 in the column at far right. Shales, which are thermal within the oil generation window AND within economic drill depth are indicated.

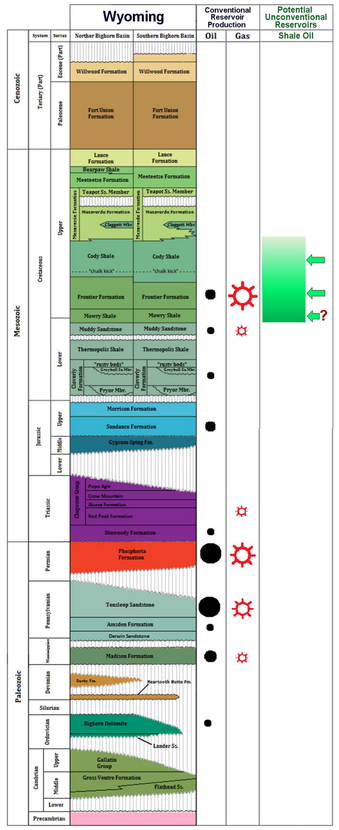

Figure #5: Generalized stratigraphic column for the Bighorn Basin showing those Shale Oil reservoirs identified as potentially economic by this study.

5. Conclusions

The results of the migration modeling and the location of the modeled conventional reservoir accumulations are in general agreement with the oil and gas fields that have been located by drilling in the Bighorn Basin. Along with the various model calibrations performed during this study this finding provides an additional indication that the model's results are highly accurate.

Results suggest that a large area on the eastern side of the basin is highly prospective with regard to potential for economic development of shale oil reservoirs. This area is outlined in red in **Figure #4.** In this area the top of the Frontier Formation has a drill depth of approximately 11,000 feet. Outcrop studies (Hutsky et al, 2012) performed nearby indicate the presence of marine shales and nearshore environments of deposition within the Frontier. These would make excellent source and reservoir rocks that should contain Type II kerogens. This study indicates that they should be in the oil generation window and within economic drill depths. Additionally, the organic-rich Cody Shale, time-equivalent to the Niobrara Formation, directly overlies the Frontier Formation. Finn (2014) indicates the Cody Shale was deposited in a marine environment. The base of this formation would also be in the oil generation window.

The area identified and outlined in red covers approximately 60 square miles and may contain shale oil resources of significant value. The Niobrara Formation in the northern DJ Basin has proven to be a prolific oil producer. It has been shown that in the Niobrara play open natural fractures have significant influence on the economics of the production. The Bighorn Basin has undergone extensive structural deformation and the presence of open natural fracture systems is highly probable. The combination of the potential for open natural fractures contained within multiple marine shales that are within the oil generation window make this portion of the Bighorn Basin highly prospective for exploration for unconventional reservoirs. Other areas within the basin and other formations are also considered prospective.

Figure #5 shows the stratigraphic column for the Bighorn Basin. Conventional reservoirs that are already productive are indicated. Additionally, the potential economic shale oil reservoirs are indicated in the column at far right in this figure. This study indicates that the potential for economic production from unconventional reservoirs, particularly shale reservoirs, within the Bighorn Basin is high and exploration boreholes are recommended. It should be noted that, at the time of this study, very few horizontal wells have been drilled within the basin to test these potential reservoirs.