

**EVALUATION OF FRACTURES
FOR FUTURE OIL PRODUCTION IN THE STEELE SHALE:
NAVAL PETROLEUM RESERVE NO. 3, TEAPOT DOME,
WYOMING**

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ABSTRACT

Knowledge of the fracture trends within the Upper Cretaceous Steele Shale Formation is important for siting future directional wells on NPR-3. Historically, the majority of oil in the Teapot Dome area has been produced from the Shannon and Second Wall Creek sandstones. Currently, over twenty-four percent of petroleum production on the reserve comes from fractures in the Steele Shale, which encases the Shannon Sandstone Member. Though the lack of primary porosity and permeability prevents the shale from trapping hydrocarbons in its matrix, fractures within the Steele serve as excellent reservoirs for oil and gas.

At Teapot Dome, tectonic stresses applied to the Steele Shale created nearly vertical fractures in the rock. In order to optimize production by maximizing the exposure of the well to fractures, a directional well should penetrate as many fractures as possible and intersect them perpendicular to the fracture planes.

In Phase One of this study, conducted in the summer of 1999, field observations were made in the vicinity of Salt Creek, five miles north of the current study area. Fracture orientation data gathered at Steele Shale outcrops across the Teapot Dome anticline comprise the dataset for Phase Two. Analysis of these data and correlation with the findings of Phase One will determine the predominant fracture orientations across the structure. These findings will aid in the selection of future drilling sites in the Steele Shale formation at Teapot Dome.

INTRODUCTION

The tectonic stresses that formed the Teapot Dome anticline on Naval Petroleum Reserve No. 3 (NPR-3) also created fractures in the Steele Shale, from which the reserve produces nearly 25% of its oil. As shale has low primary porosity and permeability, fractures provide secondary reservoirs and conduits for oil migration. To efficiently produce oil from the Steele Shale Formation, directional wells should intersect as many fractures as possible by drilling perpendicular to fracture planes. For this reason, it is necessary to understand the orientations of major fractures – those that are likely to serve as reservoirs and conduits for oil – across the structure at Teapot Dome.

SITE DESCRIPTION

Created in 1915, Naval Petroleum Reserve No. 3 is located in central Wyoming, 35 miles north of Casper on the southern edge of the Powder River Basin (Figure 1), and encompasses most of the Teapot Dome anticline. Today, NPR-3 is home to the Rocky Mountain Oilfield Testing Center (RMOTC), administered by the Department of Energy to test new methods of oil

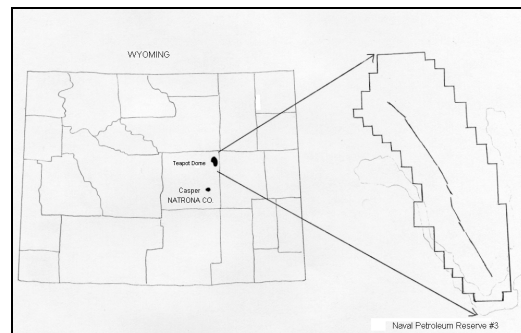


Figure 1 - Wyoming and Teapot Dome

exploration, second- and third-generation extraction, and processing of by-products including produced water. Teapot Dome produces oil at a rate of approximately 650 BOPD from an average of 500 wells.

GEOLOGICAL DESCRIPTION

Teapot Dome formed as a result of geologic stresses created by the Laramide orogeny, a period of uplift in the Rocky Mountain region of the United States beginning in the Paleocene and ending in the Lower Eocene (Fanshawe, 1971). The dome is asymmetrical, trending NW-SE, with a steeper slope on the western side and a gentler dip on the eastern side. The sedimentary sequence overlying the basement rocks is about 5,000 feet thick. The Steele Shale Formation is about 2,000 feet thick and is generally exposed at the surface throughout the field.

Teapot Dome contains several reservoirs (Appendix A): (1) The Tensleep Sandstone Formation contributes about 9% of the total production at NPR-3. (2) The Frontier Formation produces gas and accounts for an additional 14% of oil from its Second and Third Wall Creek Members. (3) The Steele Shale Formation and its Shannon Sandstone Member produce approximately 75% of all oil at Teapot Dome. Other minor producing zones include the Lakota, Thermopolis, Mowry (Muddy), and Niobrara Formations (Figure 2).

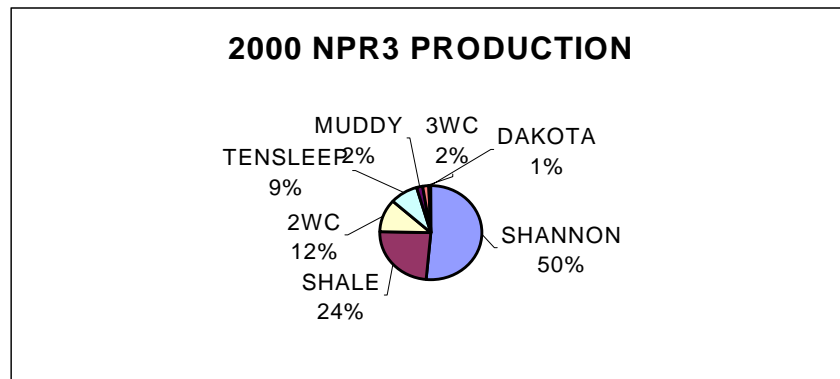


Figure 2 – Zone Production

This study focuses on the Steele Shale which includes two members, the Shannon Sandstone and the Sussex Sandstone. The shale is separated into two parts, above and below the Shannon. The uppermost portion of the Steele Formation includes the Sussex Member, which consists of light greenish-gray, fine-grained glauconitic sandstones (Watson, 1980).

The lithology of the lower Steele is slightly different from that of the upper Steele. The lower Steele, which underlies the Shannon, is composed of gray shale with thin iron-bearing beds, bentonite, and conglomerate beds. The upper Steele Shale, directly above the Shannon, contains concretions, bentonite beds, and a thin sandstone bed. Both the upper and lower Steele were deposited in a marine environment (Watson, 1980). Current

production logs show that fractures within the Steele Shale currently produce 24% of the oil at Teapot Dome.

The Shannon Sandstone Member of the Steele Shale Formation contains gray, green, and buff-colored sandstones. Up to five distinct sands are present (Watson, 1980). The sandstones formed from sand bars on the margins of the Cretaceous Western Interior Seaway. The thickness of the Shannon ranges from fifty feet to five feet (Parker, 1958). A major oil producer for NPR-3, the Shannon accounts for half of all the oil derived at the field.

FRACTURE DESCRIPTION

In order to obtain oil from a unit, it must be porous and have good permeability. Porosity is the measure of the empty space surrounding the grains of a rock. This is important as it defines the capacity of a rock to hold hydrocarbons. Permeability is the measure of a rock's capacity to transmit a fluid. If hydrocarbons cannot flow through the rock and into the well, then they cannot be extracted from the formation. Units composed of shale, such as the Steele, have low porosity and will not retain fluids. Fractures, breaks within rock bodies, provide a secondary porosity enabling oil production in otherwise nonproductive formations. The fractures which form within a shale unit provide a conduit for hydrocarbon migration. Fractures must be of sufficient spacing and length to have an important effect on enhancing porosity and permeability (Harstad, 1997). Tectonic forces formed large fractures which are found throughout the Steele Shale Formation. These major fractures intersect smaller ones, providing a connected network for fluid flow.

Drilling a well perpendicular to the predominant fracture orientation maximizes the chance of encountering the most fractures and, therefore, the chance of obtaining a high-productivity well (Figure 3). When drilling vertically into a formation, the chance of hitting a fracture is slight. If the wellbore misses the fracture (well #1), the well will be dry. If a well is drilled directly into a fracture (well #2), there will be some production from the site, but only for a short time before it is depleted. A well drilled perpendicular to the predominant fracture plane (well #3) will likely encounter several fractures. Production will draw from each of these and from any networked smaller fractures. Also, this will provide production from the Shannon Member as gravity draws fluids out of the Shannon into the fractures and down to the wellbore in the lower Steele.

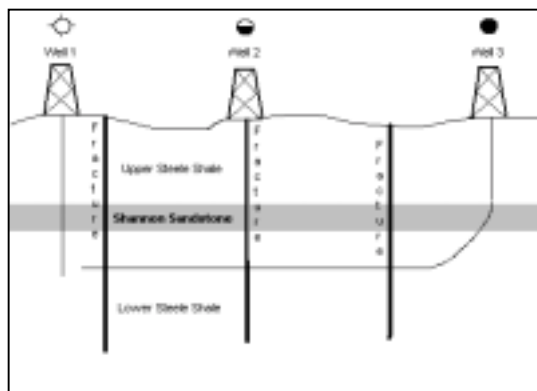


Figure 3 – Drilling Fractures

METHODS AND PROCEDURES

Site Selection

In selecting sites for this study, there were two main considerations. First, it was necessary to sample as much of the structure as possible. To this end, sites were selected on either side of a line closely approximating the axis of the fold. This way, any variation in fracture orientation resulting from the change in attitude of the units would be sampled in the dataset. The second criterion proved far more limiting: in order to measure the fracture orientations at a site, the shale must be exposed. There is a large amount of recent alluvium, sediments deposited due to erosion, in the field area. Outcrops were often covered by more than one foot of float, which made it impossible to discern the orientation of the fractures at those sites. Many seemingly suitable sites had to be abandoned due to the lack of good exposure. As a result, the data reflect fractures at outcrops that were often nearly vertical. Cliffs, newly washed-out gullies, road and well cuts, and an open pit provided outcrops because their verticality kept them free of float washed down from the surrounding areas.

Data acquisition

Once sites were chosen, their positions were marked using a handheld Global Positioning System (GPS) receiver. Accuracy of GPS readings depended on the number of satellites acquired. Areas deep within gullies had a lower accuracy than did the areas with good line-of-sight to most of the sky. Typically, enough satellites were within view to achieve between 14 and 20 feet accuracy. One GPS waypoint, an arbitrary number assigned to a specific latitude/longitude position, was taken for each group of readings. Smaller outcrops and roadcuts often needed only one waypoint, while larger areas required several GPS readings. For instance, if the outcrop was larger than the accuracy, it would require at least two waypoints.

Fracture orientation data were acquired using a Brunton pocket transit to measure the strike direction of the fractures. Dips taken at each outcrop show that the fractures were all nearly vertical. No fracture group had a dip variance greater than 5° , so dip information is not included here.

DATA DESCRIPTION

Data were collected over four weeks in June and July of 2001. Eleven areas across the Teapot Dome structure within the reserve were sampled. The dataset is comprised of orientation observations for 199 major fractures, defined as those which obviously extend over three feet in length (Figure 4).

Each line of data consists of three parts: a location, an orientation, and the total number of fractures found with that attitude at the waypoint location. Due to the limited

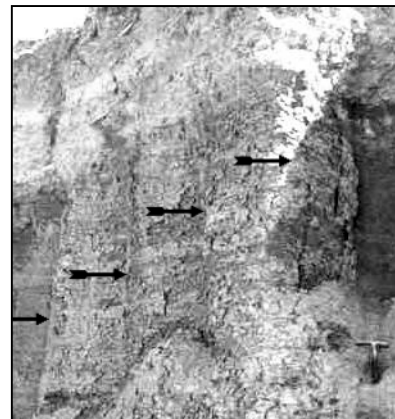


Figure 4 – Major Fractures

accuracy of the handheld GPS unit, each waypoint corresponds to multiple fracture measurements. The data presented in a table at the end of this paper (Appendix B) consist of a waypoint, a pair of position coordinates, and a set of measurements for each location. Rose diagrams express the frequency of each fracture orientation as a petal on a polar-coordinate graph. To account for variations in cover or other factors, the rose diagrams divide the data in 10° classes.

The data are represented on a map with rose diagrams at each waypoint location (Appendix C). Displaying rose diagrams according to their geographic locations facilitates relating fracture orientations to the overall structure of the field, and allows for a more detailed interpretation. Each rose diagram is annotated with a waypoint number (WP) that corresponds with the waypoints in the data table. The N-value represents the total number of fractures measured at each waypoint location, and is included on the diagrams to give a sense of scale.

ANALYSIS

All data points were illustrated in two ways. First, rose diagrams were plotted for fractures at each waypoint. These individual rose diagrams were then superimposed on a map of the study area (Appendix C). Next, all fracture observations were plotted on a master rose diagram (Appendix D).

As appendix D shows, when all data are plotted on a single rose diagram, there is a very large petal at N 70 W. This petal represents 38 values, or 19% of the total fracture measurements for the entire study area. Though the majority of fractures with this orientation were measured at WP 3, the petal is present at waypoints 6, 8, 10, and 11, throughout the length of the field. WP 9 also shows a large petal at N 80 W. When the fractures represented by petals at N 80 W and N 70 W are grouped together, the 49 fractures in that group account for more than 25% of the total observations

Extensional fractures resulting from uplift exhibit fracture patterns in which the predominant orientation is roughly parallel to the hinge of the fold. Previous studies, such as that done by Cooper, Lorenz, and Goodwin have found a majority of fracture orientations parallel or subparallel to Teapot Dome's fold hinge, which trends N 65 W (Cooper, 2001). This relation of the fractures to the fold axis supports the conclusion that the N 70 W trend seen in this study is significant.

Despite the large number of fractures with the predominant orientation, there are several sites across the study area that do not exhibit the same strike. It may well be that the aspect of the outcrops prevented observation of fractures striking N 70 W. In addition, the preferential cut of the stream through the shale, the spatial relationship to the axis of the fold, or some complex combination of extraneous factors may have affected the visibility of this fracture orientation. Regarding the fractures trending NE, previous studies found that these were less significant and probably formed prior to the Laramide orogeny (Cooper, 2001).

Correlation With Phase One

The data for Phase One were collected on two days in July of 1999 at eight sites in the Salt Creek field, approximately five miles north of Teapot Dome. A total of 120 fracture orientations were recorded. The authors of Phase One saw a concentration of the fractures in their study area around N 60 E (Doyle and Hoskins, 1999).

Phase One's predominant fracture plane of N 60 E differs from the findings of Phase Two. Though the major orientation does not agree with the new results, the third largest petal on the Phase One rose diagram is at N 70 W. It is possible that over the five miles between the Teapot and Salt Creek study areas, there could be sufficient changes due to structural or other variations that might cause other fracture orientations to be more clearly observable in Salt Creek outcrops.

RECOMMENDATIONS

It is apparent from the Phase Two data that the predominant fracture orientation in the study area is N 70 W. For this reason, it would seem that the most promising option would be a horizontal well drilled on a line trending N 20 E through the lower Steele Shale. If the two largest petals containing 25% of all orientations are considered, the range of fracture orientations would be between N 60 W and N 80 W. Therefore, this recommendation includes horizontal wells drilled with an orientation of N 10 E to N 30 E.

SUMMARY

With 19% of fractures striking N 70 W, the recommended horizontal drilling direction of N 20 E should encounter several major fractures. In addition, if NPR-3 fractures within ten degrees of N 70 W are included, the percentage of fracture orientations increases to a quarter of all Phase Two data. Although Phase One reached a different conclusion, their site was several miles from Teapot Dome. It must also be noted that the N 70 W petal was the third largest of the Phase One data. Therefore, the trend of N 70 W is not only seen throughout Teapot Dome, but also into the Salt Creek field.

These major fractures should provide good secondary porosity and permeability within the Steele Shale formation. Economically viable production of hydrocarbons should be possible since a well would not only intersect several major fractures, but also their network of smaller fractures. Today, 24% of petroleum production at Teapot Dome comes from fractures within the Steele Shale. Therefore, by understanding the predominant fracture orientation across the reserve, there is high potential for increased production from future horizontal wells on NPR-3.

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