APPLICATION OF HORIZONTAL DRILLING IN LOW-PERMEABILITY RESERVOIRS

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ABSTRACT

Horizontal drilling has revived many plays and areas once thought uneconomic to develop. With over 1 million wells in the Permian Basin and the quantity and quality of data available, many of these plays have been tested, logged, delineated, thoroughly evaluated, and abandoned. Meanwhile, horizontal technology has developed to the point where it has become dependable, practical, and reasonably priced. This combination has created a bonanza for horizontal drilling in the Permian Basin with favorable results. This paper outlines a strategy for identifying and developing these tight reservoirs.

The technology can be applied to a variety of situations, including fractured reservoirs such as the Austin Chalk in central Texas, or in low permeability reservoirs, such as the Devonian in the Bryant G, Parks, and Midland Southwest Fields or the Montoya in the Block 16 Field in West Texas. The discussion here will be limited to low-permeability non-fractured reservoirs.

INTRODUCTION

The niche of developing tight, previously non-commercial reserves can be illustrated with Figure 1. Lowering the drilling, completion and operating costs required to extract the same reserves improves the economics of developing these low-permeability reservoirs. On Figure 1, each 40-acre tract in Example A is capable of producing 1 BCF of gas. Four hydraulically fractured vertical wells could recover this gas, but would cost a total of $4 million and yield 4 BCF of gas. In contrast, this same 4 BCF of gas can be produced by drilling and hydraulically fracturing a single horizontal well at one-half the cost, or $2 million, thereby effectively getting four wells for the price of two.

Even this scenario can be improved as shown in Example B. Instead of the four hydraulically induced fractures in Example A, up to twenty fractures with closer spacing are created resulting in higher initial rates, a quicker payout, and improved economics.

IMPROVED ECONOMICS DUE TO HORIZONTAL DRILLING IN LOW-PERMEABILITY RESERVOIRS

ECONOMIES OF SCALE MODEL

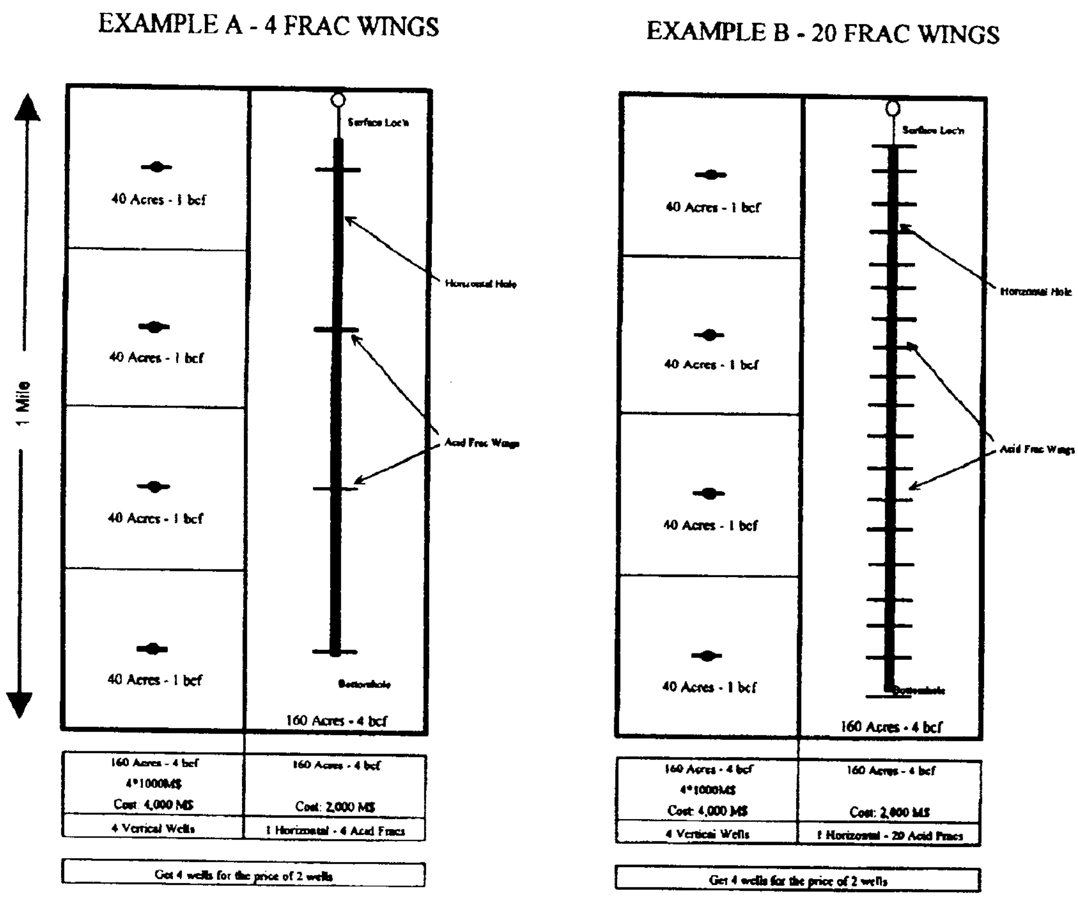

Figure 1 - Economies of Scale Model showing improved economics due to horizontal drilling in low-permeability reservoirs.

CANIDATE SELECTION

The Economies of Scale Model, above, suggests that larger reserves can be expected from horizontal wells drilled in areas where vertical wells have higher reserve potential.

In other words, the expected performance of a horizontal well is simply a multiple of the vertical well performance in the same reservoir. The continuum is driven by economics; on the lower end, vertical well reserves are so low that a 4 to 6 fold multiple in reserves cannot support the cost of drilling a horizontal well. On the upper end of the reserves continuum, where vertical wells are clearly economic, the reservoir has probably already been developed and is now depleted. The ideal candidate falls in between these two extremes favoring the upper end of the reserves scale.

The model assumes small drainage areas in the 40-acres range, which is typical of low-permeability reservoirs. In areas where vertical wells drain large areas, horizontal drilling is not necessary or required to extract reserves. Based on the drainage requirements, the ideal candidate has a thick pay with a limited drainage radius. In contrast, a very thin pay that drains 5 sections is NOT an infill horizontal drilling candidate.

ANALOGS

The Permian Basin has numerous successful tight-gas horizontal analogs and very few low-permeability oil analogs. The predominant tight-gas horizontal analog, the Devonian formation, now has over 150 productive horizontal wells. While it is too early to determine reserve potential with a great degree of accuracy, the Devonian horizontal producers will ultimately produce between 2 to 15 BCF/well with an average near 3 BCF/well. Additionally, these wells produce 100 STBO/MMCF, or about 300,000 STBO/well. The bulk of the successful horizontal Devonian wells are found in the Midland Basin.

Bryant G and Parks Fields

The Bryant G (Devonian) and Parks (Devonian) Fields are clearly the shining stars of tight-gas horizontal drilling. This project began in 1995 as a joint venture between a major oil company and a service company. The initial wells were very successful and prompted a significant development program where Devonian production from the two fields increased from 2,500 mcfpd to over 100,000 mcfpd in a period of 4 years with the drilling of over 60 horizontal wells (See Figure 2). A Devonian type log is shown as Figure 3.

Midland Southwest Field

The Midland Southwest (Devonian) Field, located beneath the city of Midland, was discovered in 1964 and reached its peak production of 500 mcfpd from 2 wells in 1965. A total of four wells were eventually completed in the Devonian and the field was abandoned in 1996 after producing 1 BCF in 33 years. Horizontal drilling was initiated in September 1999 and within 15 months a total of 16 horizontal wells had been drilled with production peaking at 15,000 mcfpd (See Figure 4). Horizontal drilling elevated this field from its abandoned status to a production rate 30 times the maximum rate established 33 years earlier. Further, an additional 40 BCF, or 40 times the ultimate vertical well production will be recovered.

COMPLETION TECHNIQUES

The required completion technique depends on the reservoir characteristics and the development strategy being pursued. If the reservoir has large open fractures, like the Austin Chalk formation for example, a complicated completion is probably not necessary. However, in a non-fracture controlled reservoir, reservoir stimulation becomes paramount to the operation. In fact, drilling and casing the well should be designed to accommodate the fracture treatment.

A common debate, in which many have a strong opinion, is whether a horizontal well should be completed open-hole or cased-hole. If the production is fracture controlled, such as the Austin chalk, an open-hole completion is very effective and inexpensive. If the production is not fracture controlled, which is true in most of the tight-gas horizontal plays, a cased-hole fracture treatment is preferred.

Empirical data suggests that open-hole completions potential higher initially, but decline much faster than cased-hole completions. This makes sense theoretically as well. Greater frac extension will abate the decline and increase reserves, however, to achieve the frac extension, few fractures must be initiated. Since the initial rate is theoretically related to the number of fracture treatments, a lower initial rate would be expected.

Another approach to the cased-hole open-hole debate is the calculation of contact area with the reservoir. In a 6-1/8" open-hole completion 4,300' in length the contact area is 6,895 square feet. Likewise, in a 4,300-foot lateral cased and cemented with 20 fractures growing outward 150 feet, the contact area is 2,827,433 square feet, or over 400 times more contact area.

The typical cased-hole completion involves cementing a 4-1/2" liner in a lateral drilled with a 6-1/8" hole and placing perforations every 300 to 600 feet apart in a limited entry configuration such that frac fluids exit the liner uniformly along the lateral (See Figure 5). Some horizontal laterals are cased but not cemented with variations ranging from non-cemented liners, pre-perforated liners, liquid packers, and ported subs. Regardless of the method employed, the idea is the same; stimulate the entire lateral.

In a non-fracture controlled reservoir, a multiple of initial rate can be accomplished by adding fracture treatments. For example, a wellbore with 20 fracture treatments should, at least theoretically, produce with an initial rate of 20-fold that of a vertical well.

That same process can be carried to extremes: (1) If the lateral has only one set of perforations then only one fracture will be created and the horizontal well will perform identically to a vertical wellbore. However, superb fracture extension can be achieved with a large frac placed in only that one set of perforations. Frac extension, or frac length, generally lessens the decline and increases recoverable reserves. (2)

On the other extreme, where the lateral has a large number of perforated intervals, say over 100 sets of perforations, each perforation may be open but does not enjoy abundant frac extension since it is competing with other perforations for frac fluid during the stimulation treatment. The shorter frac extension in this case, while it may see a higher initial rate, generally equates to more rapid declines and lower recoverable reserves.

A typical compromise of these two extremes is 10 to 20 sets of perforations. This compromise provides good frac extension while at the same time delivering a 10 to 20-fold increase in initial rate.

Drilling direction is another common consideration likely to stir a debate. In both cased-hole and open-hole completions, the preferred drill direction is perpendicular to the frac planes. In the open-hole case, where natural fractures are the target, drilling perpendicular to the frac plane is obvious. In a cased-hole completion, direction can be less obvious. Typically, these horizontals are drilled in areas where the drainage area is around 40 acres. If the induced fracture wings are 300 feet apart, the wings will begin interfering with one another after only a few months. If the well is drilled longitudinal, or parallel to the fracture plane, these tip-to-tip frac wings will see interference much sooner. While this is true theoretically, it is difficult to find statistically significant empirical evidence supporting which direction is best. While there are both good and bad wells drilled both transverse and longitudinal to the frac plane, reservoir quality and not direction dominates well performance. This is also true of stimulation; good rock equals good wells.

RESERVE ESTIMATION

Reserve estimation is difficult since these wells generally exhibit a strong hyperbolic decline characteristic of a tight reservoir. Most early reserve estimations, based on well decline, will almost always be conservative. While the initial rates are impressive, a sharp decline should be expected with wells stabilizing at rates 4 to 5 times the stabilized rate of a vertical well in the area.

Typical performance includes a 10 to 20-fold multiple of initial rate declining rapidly and hyperbolically to a 4 to 5 fold multiple of vertical wells with ultimate reserves being driven by the lateral length and the drainage radius of vertical wells. For example, a 4,300-foot lateral drilled in rock that drains 40-acres should recover gas from four 40-acre drainage areas, or 4 times that of a vertical well. That same logic can be extended to an 8,600-foot lateral, where eight 40-acre drainage areas are reached with reserves 8 times that of a vertical well. Instead of 4 wells for the price of 2, the ratio now becomes 8 wells for the price of 3. The economics improve in proportion to lateral length. However, the technical limits of the completion become the limiting factor. From a practical standpoint, a 6,000-foot lateral may be reaching the limits of a single-stage frac treatment. Multiple fracture treatments, required by longer laterals, could place the wellbore at risk in the event a bridge plug cannot be retrieved.

CURRENT PLAYS

The applications of horizontal drilling in tight reservoirs are numerous. The Devonian formation dominates horizontal drilling activity due to excellent analogs and its widespread existence. The Devonian is gas saturated over a major part of the Permian Basin and the rock is generally too tight for commercial production. It is commonly produced as a bail-out zone to a deeper objective. Other reservoirs currently being drilled horizontally are the Montoya, Pennsylvanian, Mississippian, and Fusselman.

RISKS

Besides hydrocarbon risk and reservoir quality risk, the biggest risks facing a horizontal development program are mechanical risk and depletion risk. Depletion risk unfortunately is a by-product of the tight-gas horizontal niche. While drilling close to an existing well reduces reservoir risk, it can introduce depletion risk. Depletion increases mechanical risk and compromises the stimulation since the frac treatment will preferentially treat the depleted portion of the lateral leaving the high-pressure rock unstimulated.

CONCLUSION

Horizontal drilling can and will revive many plays and areas once thought uneconomic to develop. The niche of developing low-permeability reservoirs horizontally is mechanically viable and economically lucrative. A properly completed horizontal well should deliver a 20-fold increase in initial rate with ultimate reserves increasing 4 to 8 fold. Drilling costs for a typical horizontal well are typically double of a vertical well and economies of scale drive the economics of "getting 4 wells for the price of 2."

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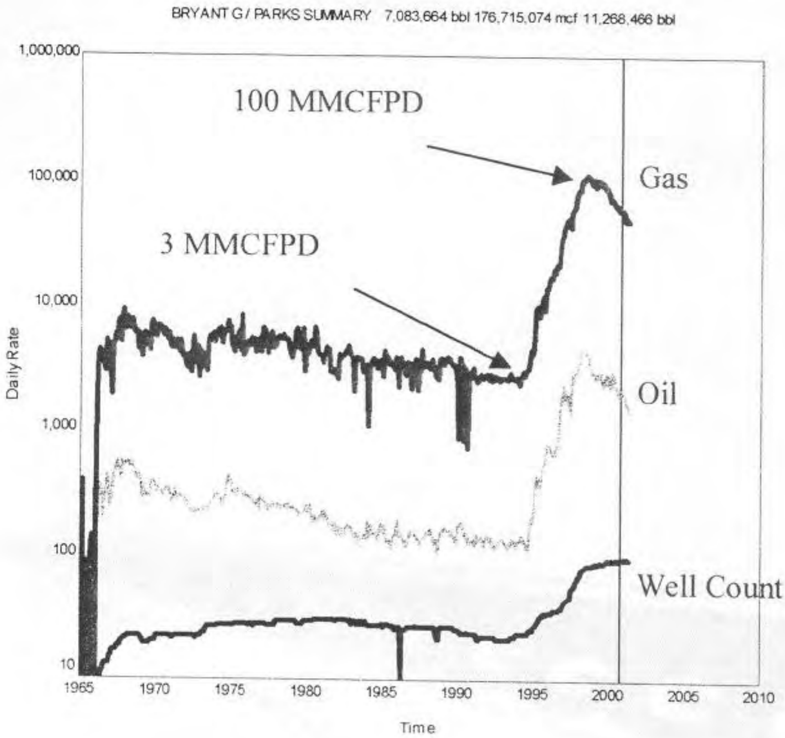

Figure 2 - Bryant G (Devonian) and Parks (Devonian) Summary Production Plot.

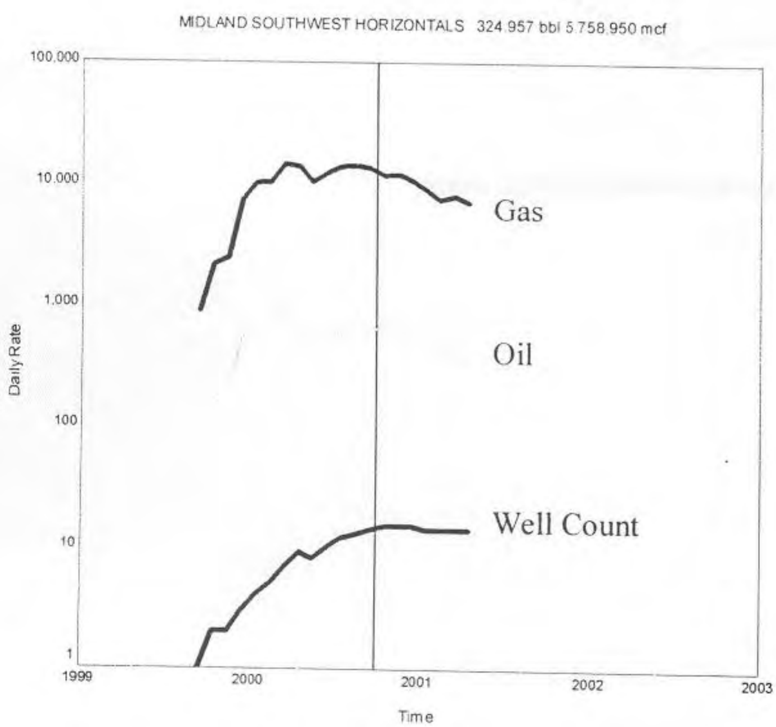

Figure 4 - Midland Southwest (Devonian) Production Plot.

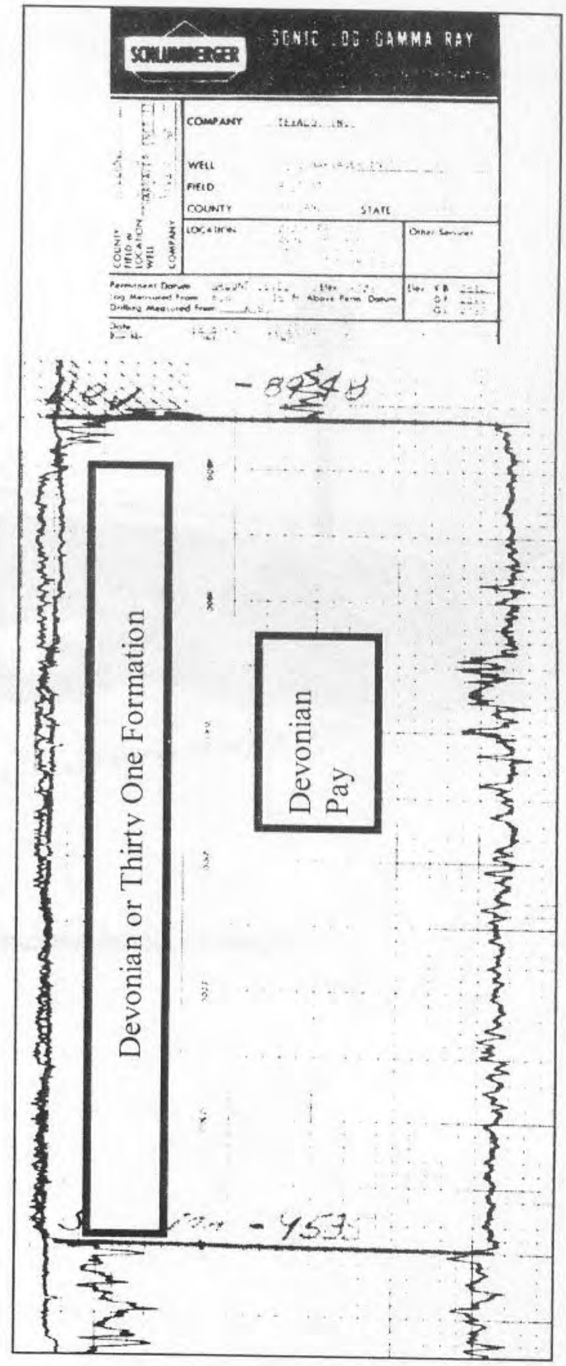

Figure 3 - Bryant G Type Log.

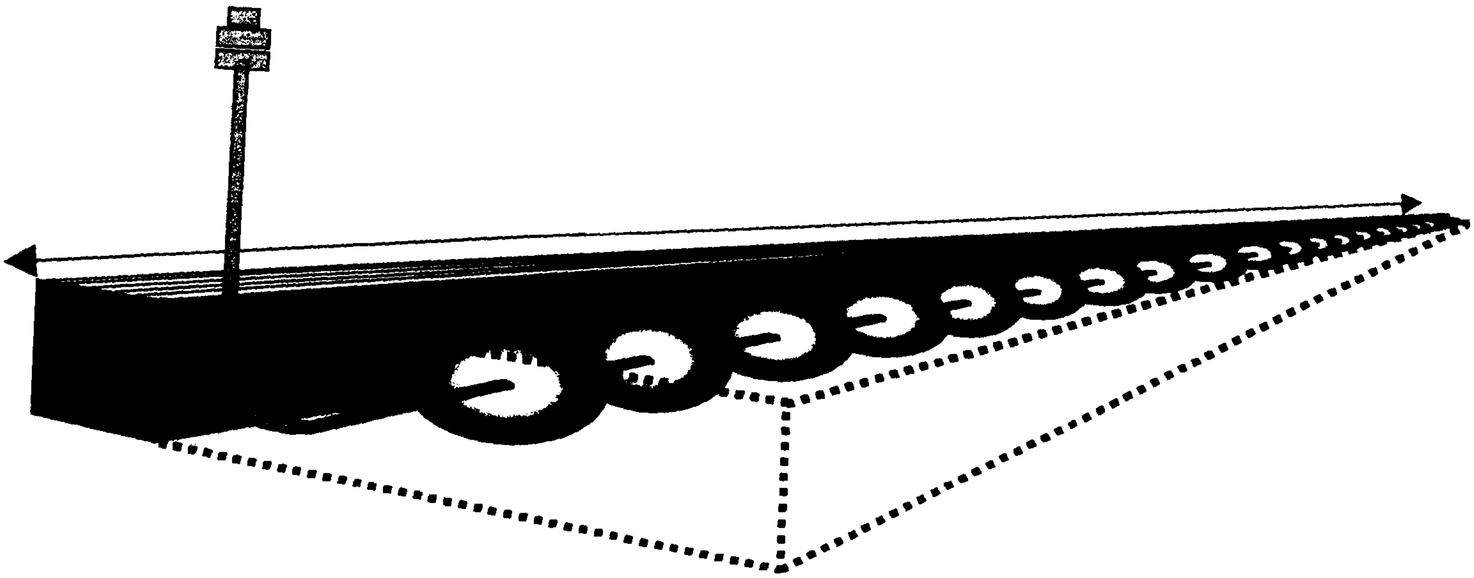

Figure 5 - Horizontal cased-hole completion showing 20 frac wings.