WOLFBERRY TRANSISTION IN STIMULATION

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ABSTRACT

The "Wolfberry" play is named after the two main productive formations, the low-permeability Wolfcamp and Spraberry, and is a very large part of the everyday business in the Permian Basin. Activity in the Wolfberry has recently increased, spurred by the current relatively strong oil prices. However, the economic foundation of these producing wells is their stimulation and the management of completion costs.

All of these wells require multistage fracture treatments to achieve economic production and therefore significant effort has been given to continuous improvement in efficiently completing and fracturing Wolfberry wells. To illustrate the evolution of the optimization process, a retrospective of the changes implemented in fracturing Wolfberry wells over the past 10 years in several counties in the Permian Basin is presented.

This paper addresses in particular, choices involved in optimizing stimulation stages (including perforation schemes), treatment fluids and proppants, to maximize net present value contribution of the hydraulic fracturing treatments.

INTRODUCTION

The Permian Basin has seen many changes over the last few years, one of which is the expansion of oil plays. Besides oil prices being at a high the number of horizontal wellbores going from 2000 to 2008 have doubled in these plays (**Figure 1**). 2009 activity on **Figure 1** reflects the downturn in the industry and 2010 activity represents the first half of the year. However, the largest oil plays in the basin, the Wolfberry (**Figure 2**), named after the two major producing intervals being commingled, Wolfcamp and Spraberry, employs vertical wellbores. The first true "Wolfberry" wells were drilled in Upton County at the turn of the century by Henry Petroleum.[1,2] The success of these wells brought upon a spread of "Wolfberry" wells all across West Texas. Currently the number of rigs drilling in the play is over 200 and with each rig drilling two wells per month there are over 400 wells being drilled per month in the Wolfberry. To illustrate the change in activity, **Figure 3** displays the number of wells completed in the Wolfberry from 2001 through the first half of 2010 in Upton County. It also shows the change in the average number of fracture treatment stages per well over the same time period.

Even with a good price for oil the play is tight on economics and the only way success can be achieved is to minimize costs, especially on the completions since these are typically one third of the total well cost. In 2002 the average Wolfberry well cost $800,000 with this increasing to $1.5 million by 2008. Today a well costs in the neighborhood of $2 million with the completions costs still making up about one third. The way to minimize costs is to perform the multistage fracture treatments in as few days as possible. Typically this is done using wireline placed plugs between stages followed by the perforation of the next interval to be fraced. A fracture crew on location for two days may pump as many as six to seven stages per day.

BJ Services has over 45,000 treatments in its database performed in the Permian from 2000 through 2010 to draw on for information. The average perforated depth for the Spraberry Formation ranges from 6569 ft in Reagan County to 8155 ft in Midland County. The Wolfcamp Formation ranges from an average of 7749 ft in Howard County to 9701 ft in Midland County. The weighted average depth for all six counties is 7509 ft for the Spraberry and 9236 ft for the Wolfcamp Formation (**Figure 4**). The Spraberry has historically been easy to fracture stimulate with very low fracture gradients and very few incidents of screen-out or prematurely reaching max pressure before completion of job leaving proppant in the wellbore. A comparison of fracture gradients in the Spraberry between counties revealed an average ranging from 0.517 psi/ft in Howard County to 0.556 psi/ft in Upton County (**Figure 5**). The Wolfcamp on the other hand can be difficult to "break down" or initiate a fracture without the aid of acid. It has become common practice during cementing operations to displace the production casing string with acetic acid followed by water, typically 1000 gallons of 10% acetic acid. When the first stage of a Wolfberry completion is perforated the acetic acid will be "on spot" or covering the perforations. The acetic acid helps clean up the perforation debris and initiate the fracture. The same "spotting" of acid over the perforations is typically performed on subsequent

Wolfberry stages by using hydrochloric acid during the flush portion of each fracture stimulation stage (not including the final stage). Typically 500 to 2000 gallons of 7.5% - 15% hydrochloric acid is used per stage. Once a fracture is initiated the Wolfcamp fractures fairly easily with frac gradients averaging 0.642 psi/ft in Howard County to as high as 0.746 psi/ft average in Upton County **(Figure 5).** For the purpose of this paper we will concentrate on the six most active counties, Martin, Howard, Midland, Glasscock, Upton and Reagan. These six counties total over 6,000 square miles of land. Being such a vast combined area, a county comparison was performed in order to determine the differences in Wolfberry wells by area.

WOLFBERRY STIMULATION HISTORY

Figure 6, illustrates the number of "Wolfberry" wells in the counties studied over the time period of interest. Of the nearly 7000 wells in these six counties approximately 50% are located in Upton and Reagan counties. The early Wolfcamp wells having been drilled into the top of the Upper Wolfcamp were fracture treated using a single stage. These consisted of a borate crosslinked 30 pound guar gelled water based fluid pumped at approximately 30 bpm. These treatments placed typically 600,000 pounds of 20/40 mesh white sand at a maximum concentration of 7 to 8 ppg. In the mid-1990's the same basic single stage fracture treatments were being performed with the same gaur gelled borate crosslinked fluid, however now the proppant quantity had been reduced and the type of proppant varied somewhat. The treatments now consisted of 100,000 to 150,000 pounds of 20/40 mesh brown sand followed or tailed-in with an equivalent amount of 20/40 mesh white sand. The maximum concentration had been reduced to 2 to 4 ppg. In the early 2000's with the deeper drilling through the Wolfcamp and the emphasis on cost controls stage fracturing began.[3]

Staging

The Spraberry has seen some changes in the number of fracture treatment stages from the typical three. This is also the case for the single stage fracture treatment of the Dean. However, as **Figure 7** indicates for the years 2000 through 2005 the number of stages in the Wolfcamp has risen. Depending on the area the number of stages in a Wolfberry well in the last five years has varied from four to ten, as represented by **Figure 3** for Upton County, the average for 2010 being eight and three quarter stages per well. The number of stages varies as the operator decides how much vertical coverage he is getting per stage.

Perforation Schemes

Perforation schemes are in most counties operator dependent. Howard County (**Table 1**) illustrates the change in schemes over the 2006 to 2010 time period on average. **Tables 2 and 3** illustrate the difference in operator preferences in Martin and Upton Counties. Operator C in Upton County has made little change in the scheme by which they perforate in the 2006 to 2010 time period. They are firm believers in a 20 feet cluster of perforations with 4 shots per foot (spft) as their normal scheme; however, they do on occasions vary the spft. In most cases the perforation phasing is 120 degrees. The placement and number of perforations, as with the number of stages per well has been evaluated and varied over the years as the operators developed a better understanding of the effectiveness of the stimulation treatments to cover intervals. Some of this was trial and error and some was based on microseismic evaluations.

Fluids

As with the perforation schemes the fluids of choice have varied. The Spraberry intervals are still being fracture treated with borate crosslinked guar gelled water systems today as they were in the early 2000's. These fluids range in polymer loadings from 15 to 20 pounds per thousand gallons of water (pptg). However, the Wolfcamp intervals have seen a greater variety in fluids used over the last ten years. Many wells have been fracture treated in these intervals using slickwater, others have used borate crosslink assist systems with 10 to 15 pptg of polymer and some have used linear gelled water systems using 10 to 20 pptg polymer loadings. Some operators are using a combination of these fluids to treat their wells. Specifically over the last five years the fluid variances are shown in **Tables 4 through 6** for Howard, Martin and Upton counties.

Proppants

From 2000 to 2005 white and brown sands were almost always the proppant of choice. In the Wolfcamp 45% of the time 20/40 mesh white sand was used and the other 55% of the time 20/40 mesh brown sand was used. The maximum concentration of proppant in the Wolfcamp stages was 2 ppg while the average per stage was 0.92 ppg. Total proppant per Wolfcamp stage averaged approximately 52,000 pounds. The Spraberry was fracture treated carrying typically 95% of the time 20/40 mesh brown sand at an average of 2.9 ppg per stage with a maximum of 5

ppg and average total sand per stage of 125,000 pounds. **Tables 7 through 9** show the changes in proppant quantities in Howard, Martin and Upton counties over the time period of 2006 through 2010.

Over the ten year period proppant types and volumes between the Spraberry and Wolfcamp formations vary substantially. The Spraberry proppant type is predominantly brown sand with volumes ranging from an average volume of 113K in Reagan County to 133K in Martin County **(Figure 8).** Brown or Brady Sand is the proppant of choice in the Spraberry due to its low cost and sufficient strength to provide a conductive path in this formation. However White or Ottawa Sand which is stronger but also more expensive has been used when Brown is unavailable. Typical sand concentrations range from 1 pound per gallon (ppg) to 4 ppg, although higher concentrations are not uncommon. Wolfcamp treatments range in proppant volume from 56,000 pounds in Midland County to 121,000 pounds in Howard County, with a weighted average of 76,000 pounds over the six counties studied. There is a much wider range of proppant type in the Wolfcamp. This is due to the higher closure stresses some of the deeper Wolfcamp intervals exhibit on the proppant pack. Proppant type varies from the most common White Sand, to Brown, resin coated proppants and intermediate strength ceramics. Typical sand concentrations range from .5 ppg to 3 ppg with the bulk of most Wolfcamp treatments being pumped at the 1 to 2 ppg concentrations.

Pump Rates

2000 through 2005 pump rates were typically in the 43 to 47 BPM range were the norm on fracture treatment of the Spraberry. The Dean however, over the same time period saw an increase from 40 to just less than 60 BPM. The Wolfcamp is where the greatest variance in pump rates occurred with the steady increase over this time period from approximately 35 to 60 BPM. These rates have changed only slightly over the last five years; Spraberry stages typically are still pumped at approximately 40 BPM and the Dean and Wolfcamp stages at 60 BPM. The Spraberry has historically been known to have a great deal of height growth during fracture treatments, so slower rates have been used to help control the fracture coverage interval and minimize stimulation of un-productive rock. Occasionally these rates are increased when a zone is encountered that is showing signs of being difficult to propagate a fracture. Some specific cases in Upton and Martin counties over the 2007 through 2010 time frame have Wolfcamp stages averaging around 55 BPM, while Howard County the average has increased from 55 to 65 BPM.

PRODUCTION RESPONSES AND ECONOMIC IMPACT OF STIMULATION

The production response of the "Wolfberry" wells in the study area is varied because of reservoir quality, which will not be addressed here do to the complicated nature of the producing wellbores with multiple producing intervals. It has been said that "a good well will make 100 barrels per day, but initial rates vary from several hundred to 20 barrels a day"[2]. A map of Upton County with the location of all the "Wolfberry" wells BJ Services has treated (**Figure 8**) illustrates the variance in production based on the first two years cumulative production of oil. It can be seen that there are three localized areas of highest cumulative production with wells having accumulated over 45 MBO in the first two years after stimulation. In contrast **Figure 9** reflects the production of Reagan County where there are two areas exhibiting higher two year cumulative oil production. However, Reagan County Wolfberry wells have not proven to be as prolific in production and these areas are wells with over 25 MBO accumulated production.

Based on data collected from IHS Energy on December 16, 2010 there are approximately 6935 wells that have spud since January 2000 and have produced for at least one month in the Wolfberry. **Figure 6** illustrates the breakdown by county of these wells with Reagan and Upton being the most active with over 1700 wells each. A comparison of the initial six and twelve month oil production averages between counties reveals Upton County to be by far the best county with a six month average of 61.5 barrels of oil per day (bopd) and twelve month average of 48.8 bopd. Reagan County had the lowest averages with six month of 25 bopd and twelve month of 19.6 bopd. The weighted averages over all six counties are 41.2 bopd for the first six months and 33.3 bopd for the first twelve months (**Figure 11**).

Profitable Wolfberry wells rely on economical completion of multiple stages. Comparing all the BJ Services treated Wolfberry wells with multiple stage completions by number of stages versus production shows a general trend of higher production as the number of stages increases (**Figure 12**). However based solely on **Figure 12** the optimal number of stages is nine. This could be due to many different factors unrelated to number of stages. For example more stage jobs may have been performed in the "sweet" spots or better producing areas. Or the operators who

typically fracture stimulate their Wolfberry wells with nine stages are using "best practices" or methods that are creating better performing wells. The wells with ten or more stages may also have "cross-flow" or higher pressured Wolfcamp zones flowing into the lower pressured Spraberry, reducing the total production of the well.

The economics of the staging can be evaluated looking at some comparisons of production improvement versus additional costs. The first comparison is to look at the average daily oil production over the first year of an eight stage fracture treated well versus a four stage, **Table 10.** The first year revenue increase using an $80 per barrel oil price is approximately $782,560. Assuming a cost per stage of $80,000 (2010 pricing), the additional cost of an eight stage treatment reduces this improved revenue to $462,560. A similar comparison of a nine stage versus a five stage, **Table 11,** results in improved first year revenue of $301,960.

A look at the top ten Wolfberry operators by total number of producing Wolfberry wells in the six county study area reveals a total of 5148 wells between them. With the most active operator (Operator A) having over 1700 wells (**Figure 13**). A comparison of their production over all six counties shows Operators G, C, and F having the highest average production with six month rates of 71.1, 64.8 and 59.2 bopd and twelve month rates of 57.9, 52.5 and 49.9 bopd (**Figure 14**). Further investigation revealed that operators G, C and F are 3 of the top 5 operators in Upton County. Since the operators with the best production averages have a large presence in Upton County, a comparison of operators within Upton County was performed. Operator C is the most active in Upton County with over 600 wells (**Figure 15**). Comparing production averages of the top five operators in Upton again reveals Operators G, C and F having the highest average production rates with even higher average rates for their Upton only averages. Their six month averages being 75, 66.9 and 59.2 bopd and twelve month averages of 61.9, 54.2 and 50.2 bopd (**Figure 16**).

Another issue that has been of interest gets back to proppant choice. A comparison of proppant type in Upton County Wolfcamp zones shows White Sand being used in over 96% of the wells with only a few jobs with Brown Sand and high strength proppant. The production average of the wells fracture stimulated with White Sand is over 50% higher for the initial month's production versus the fracture stimulated wells with Brown Sand. When comparing longer term production values, the percentage difference increases. At the end of three years this difference has risen to 98% (**Figure 17**). The difference in early production between the two proppants could be due to increased initial crushing of the Brown Sand versus White Sand. The continuing increase in production difference could indicate further proppant crushing of the Brown Sand as reservoir pressure continues to decline. Using Brown sand saves approximately 41% on Wolfcamp proppant costs but these savings are not greater than the revenue lost. When comparing high strength proppant versus White Sand in the Wolfcamp it is important to point out that in Upton County only 1.3% of wells used high strength proppant, such as resin coated or ceramic proppant. The small number of wells could be the reason the results are mixed with the production of the high strength proppant being higher for the first month versus White Sand but lower for the longer term production. Resin coated proppant used in place of White sand in the Wolfcamp stages increases the overall well stimulation cost approximately 17%. The first year increase in average daily oil production (assuming $80 per barrel) has to be approximately 4 BOPD to break even on the usage of the higher strength proppant.

CONCLUSIONS

1. Upton County proves to be the best producing area for the "Wolfberry".
2. Reducing the study area from the entire play as done in 2005 improved the understanding of treatment performances; however a further reduction in the areal extent of a study may prove to be even more beneficial.
3. Nine appears to be the optimal number of stages in fracture treating a "Wolfberry" well.
4. Choosing appropriate proppant for the closure promotes improved productivity.

ACKNOWLEDGEMENTS

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NOMENCLATURE

BOPD	Barrels of Oil per Day
BPM	Barrels Per Minute

ppg	Pounds per gallon
pptg	Pounds per thousand gallons
MBO	Thousand barrels oil

REFERENCES

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2. Williams, P: "The Wolfberry," www.oilandgasinvestor.com, Downloaded 18 January 2008.
3. Edgeman, R., 2005, Permian Basin Fracturing: A Best Practices Approach, Southwestern Petroleum Short Course, Lubbock, Texas, USA (April 19, 2005).

Table 1 – Howard County Perforation Schemes 2006 to 2010

Year	Perforation Scheme per Stage
2006	**3 to 5 Sets of 3' to 10' 2 to 3 spft of 0.4" holes**
2007	**1 to 5 Sets of 3' to 10' 2 to 3 spft of 0.27" to 0.42" holes**
2008	**1 to 4 sets of 4' to 20' 3 to 4 spft of 0.39" to 0.41" holes 1 to 10 Sets of 2' to 20' 4 spft of 0.38" to 0.41" holes**
2009 - 2010	**1 to 2 Sets of 10' to 20' 4 spft of 0.41" holes**

Table 2 – Martin County Perforation Schemes 2006 to 2010

Year	Perforation Scheme per Stage	
	Operator D	**Operator L**
2007	**Scattered perfs over large intervals of 100' to 594' 1 spft of 0.34" to 0.38" holes**	**4 to 12 Sets of perfs of 2' to 8' 3 spft of 0.41" holes**
2008	**Scattered perfs over large intervals of 263' to 474' 1 spft of 0.38" to 0.4" holes**	**1 to 8 Sets of perfs of 3' to 7' 3 to 6 spft of 0.41" holes**
2009 - 2010	**N/A**	**4 to 5 Sets of perfs of 2' to 3' 3 spft of 0.41" holes**

Table 3 – Upton County Perforation Schemes 2006 to 2010 followed by Operator C

Year	Perforation Scheme per Stage
2006 -2010	**Lower Wolfcamp 20 feet of perforations 6 spft Middle and Upper Wolfcamp 20 feet of perforations with 4 spft Spraberry 10 feet of perforations 4 spft**

Table 4 – Howard County typical fluids used from 2006 to 2010

Year	Fracture Fluids
2006	**Borate Crosslinked 12 pptg guar gelled water based fluid**

2007	**Borate Crosslinked 10 to 15 pptg guar gelled water based fluid**
2008	**Borate Crosslinked 10 to 16 pptg guar gelled water based fluid Linear 10 to 16 pptg guar gelled water based fluid Slickwater**
2009 - 2010	**Borate Crosslinked 12 to 18 pptg guar gelled water based fluid**

Table 5 – Martin County typical fluids used from 2006 to 2010 by two of the operators in the area.

Year	**Fracture Fluids**	
	Operator D	**Operator L**
2006	**Slickwater**	**Borate Crosslinked 10 pptg guar gelled water based fluid Slickwater**
2007	**Slickwater and Borate Crosslinked 9 to 10 pptg guar gelled water based fluid**	**Borate Crosslinked 10 to 20 pptg guar gelled water based fluid and Linear 10 to 20 pptg guar gelled water based fluid**
2008	**Slickwater**	**Borate Crosslinked 12 to 18 pptg guar gelled water based fluid and Linear 5 to 15 pptg guar gelled water based fluid**
2009 - 2010	**N/A**	**Borate Crosslinked 10 pptg guar gelled water based fluid Linear 10 pptg guar gelled water based fluid Slickwater**

Table 6 – Upton County typical fluids used from 2006 to 2010 by Operator C in the area

Year	**Fracture Fluids**
2006	**Borate Crosslinked 10 to 15 pptg guar gelled water based fluid**
2007	**Borate Crosslinked 10 to 30 pptg guar gelled water based fluid and Linear 10 to 15 pptg guar gelled water based fluid**
2008	**Borate Crosslinked 10 to 15 pptg guar gelled water based fluid Linear 10 to 15 pptg guar gelled water based fluid**
2009 -2010	**Borate Crosslinked 10 to 15 pptg guar gelled water based fluid**

Table 7 – Howard County proppant usage from 2006 to 2010

Year	**Proppants, averages per stage**
2006	**74,000 to 117,000 pounds of 20/40 mesh White**
2007	**31,000 to 216,500 pounds of 20/40 mesh White 15,000 to 42,000 20/40 mesh curable resin coated sand**
2008	**84,500 to 211,000 pounds of 20/40 mesh White 15,000 to 42,500 20/40 mesh curable resin coated sand Some 20/40 mesh pre-cured resin coated sand and ultra**

	lightweight proppant
2009 - 2010	**26,300 to 80,000 pounds of 20/40 mesh White**

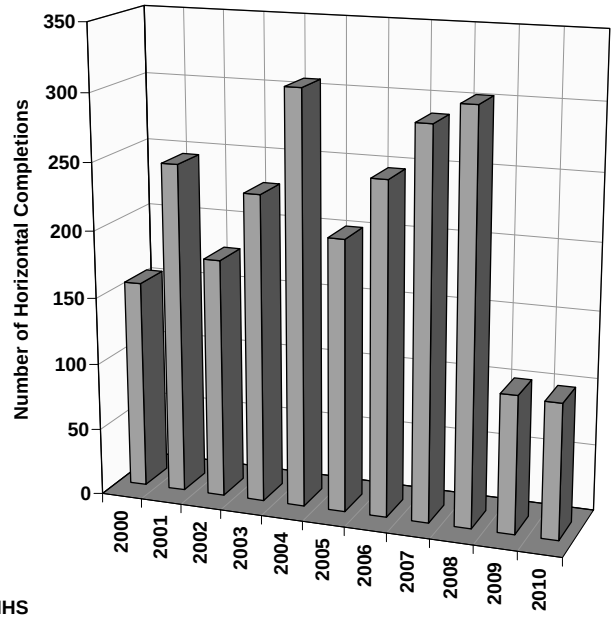
Table 8 – Martin County proppant usage from 2006 to 2010	
Year	**Proppants, averages per stage**
2006	**75,000 to 125,000 pounds of 20/40 mesh White 75,000 to 125,000 pounds of 20/40 mesh Brown**
2007	**25,000 to 179,000 pounds of 20/40 mesh White 25,000 to 156,000 pounds of 20/40 mesh Brown**
2008	**30,000 to 186,000 pounds 20/40 mesh White Average 110,000 first nine months Average 70,000 last three months**
2009 - 2010	**32,200 to 43,900 pounds 20/40 mesh White Average 35,890 pounds**

Table 9 – Upton County proppant usage from 2006 to 2010	
Year	**Proppants, averages per stage**
2006	**Basal Wolfcamp Average96,750 pounds 20/40 mesh White Wolfcamp Average 82,575 pounds 20/40 mesh White Dean and Spraberry Average 96,750 and 117,500 pounds 20/40 mesh Brown**
2007	**Average 73,000 pounds 20/40 mesh White Average 43,300 pounds 20/40 mesh Brown 76,600 pounds 40/70 mesh White in one or two wells**
2008	**Average 89,000 pounds 20/40 mesh White Average 61,000 pounds 40/70 mesh White**
2009 -2010	**Basal Wolfcamp Average 89,250 pounds 40/70 mesh White Wolfcamp Average 71,759 pounds 20/40 mesh White[1] Dean and Spraberry Average 92,000 pounds 20/40 mesh Brown**
[1] Averages of the 40/70 usage based on one operator	

Table 10 – Economic comparison based on an 8-stage versus a 4-stage treated well			
8 Stage Treated Wells	**4 Stage Treated Wells**	**Difference**	**Effect on 1st Year Revenue**
Average 1st year Daily Oil Production			
53.4	**26.6**	**26.8 BOPD**	**$782,560**

Treatment Cost Based on 2010 Pricing			
$640,000	**$320,000**	**$320,000**	**$462,560**

Table 11 – Economic comparison based on a 9-stage versus a 5-stage treated well.			
9 Stage Treated Wells	**5 Stage Treated Wells**	**Difference**	**Effect on 1st Year Revenue**
Average 1st year Daily Oil Production			
53.8	**32.5**	**21.3 BOPD**	**$621,960**
Treatment Cost Based on 2010 Pricing			
$720,000	**$400,000**	**$320,000**	**$301,960**



Courtesy IHS

Figure 1 – Chronological change in number of horizontal wellbores in the Permian Basin (2010 data is for only six months).

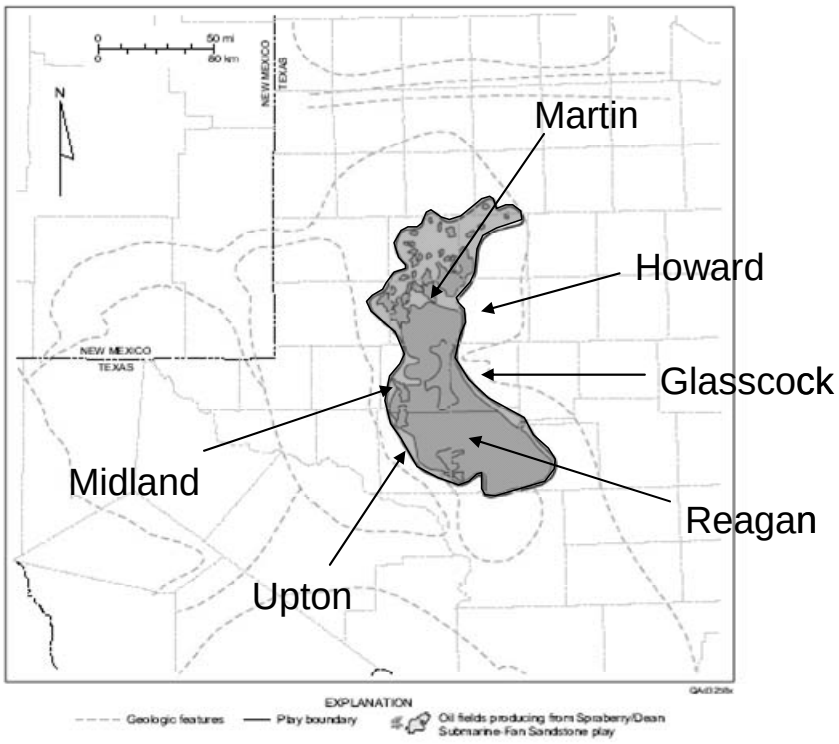


Figure 2 – Areal extent of the “Wolfberry” Play in the Permian Basin.

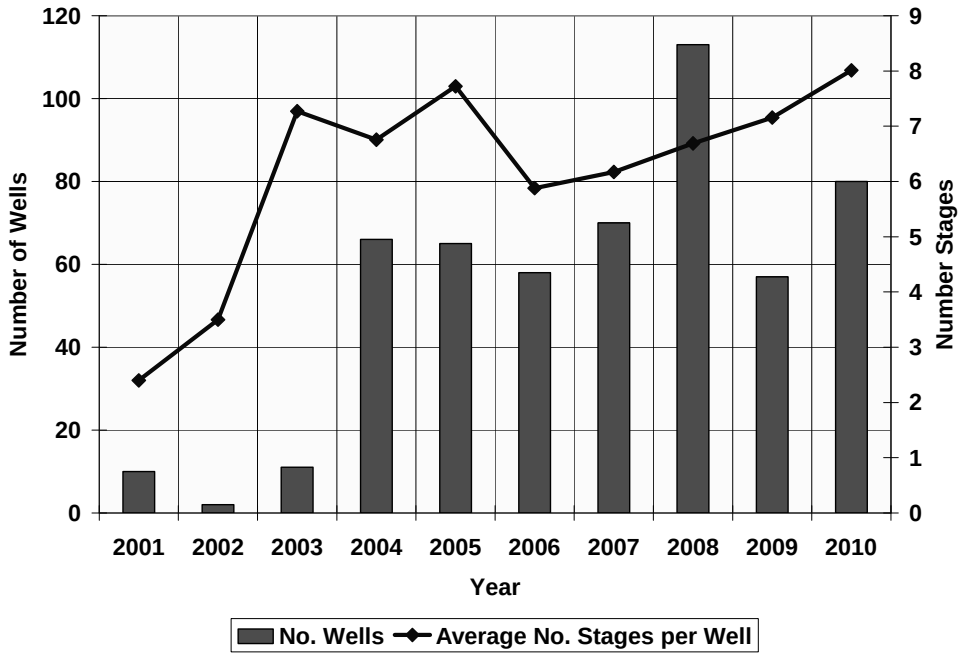


Figure 3 – “WolfBerry” completions in Upton County, Texas and average number of stages of stimulation per well.

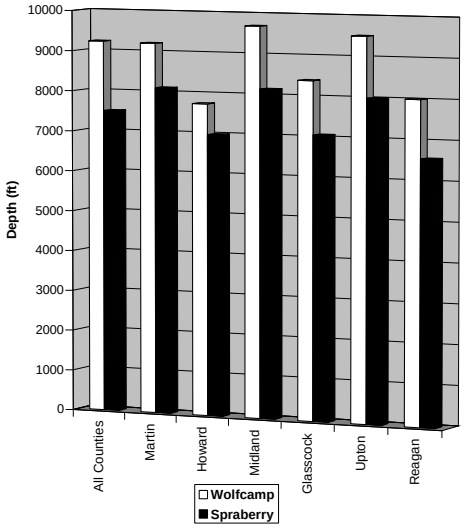


Figure 4 – Average depth of Spraberry and Wolfcamp in six of the counties in the “Wolfberry” play.

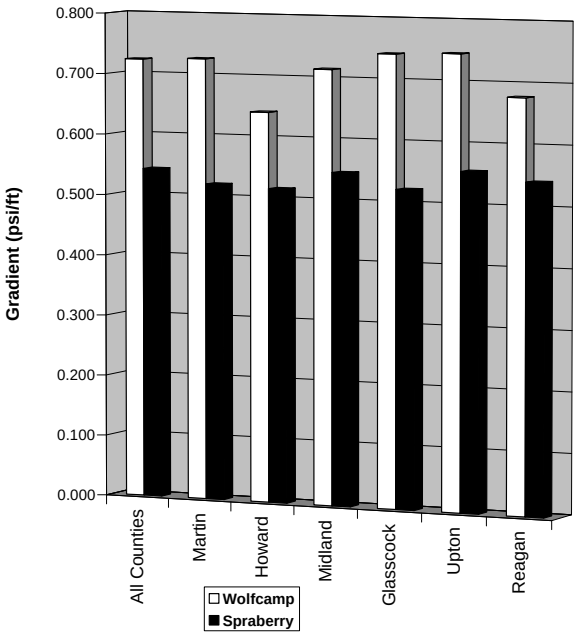


Figure 5 – Average Fracture Gradients per formation per county.

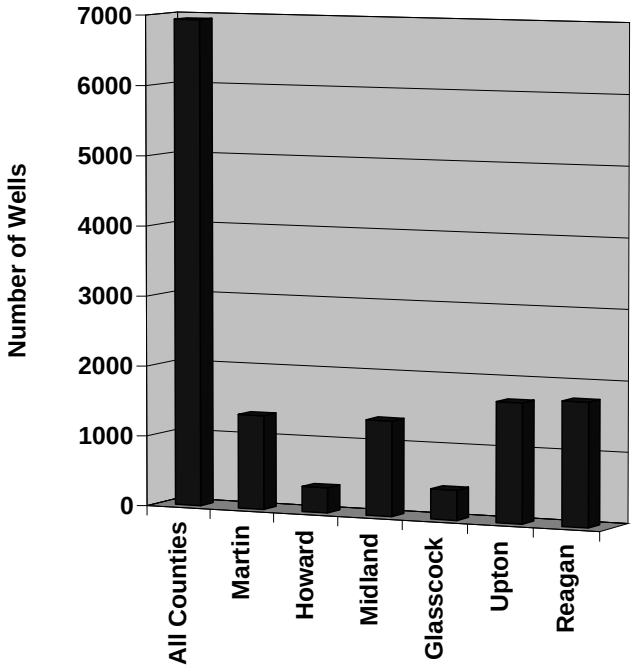


Figure 6 - “Wolfberry” wells in the area of interest.

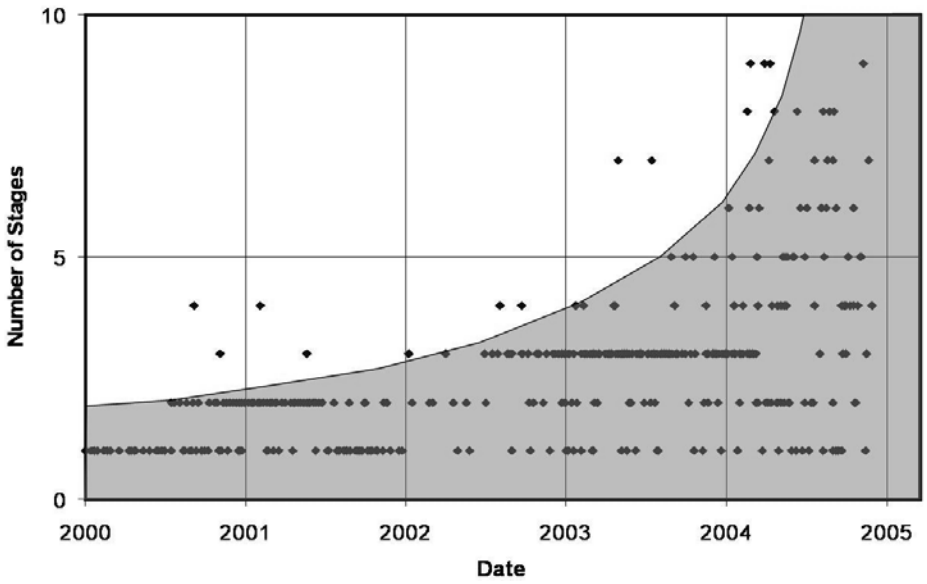


Figure 7 – Changes in the number of fracture treatment stages in the Wolfcamp.

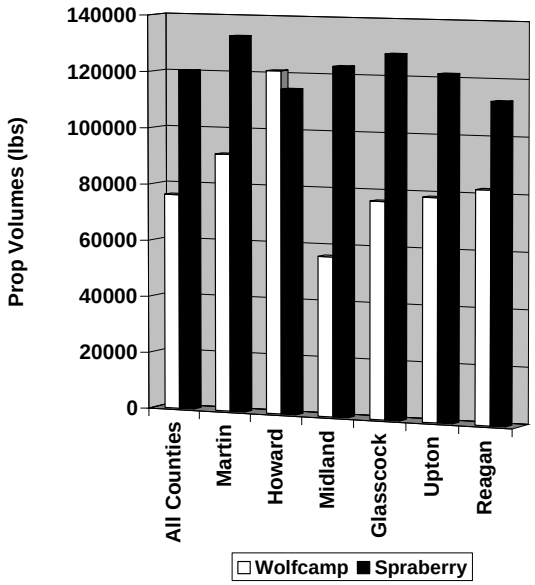


Figure 8 – Proppant usage by county

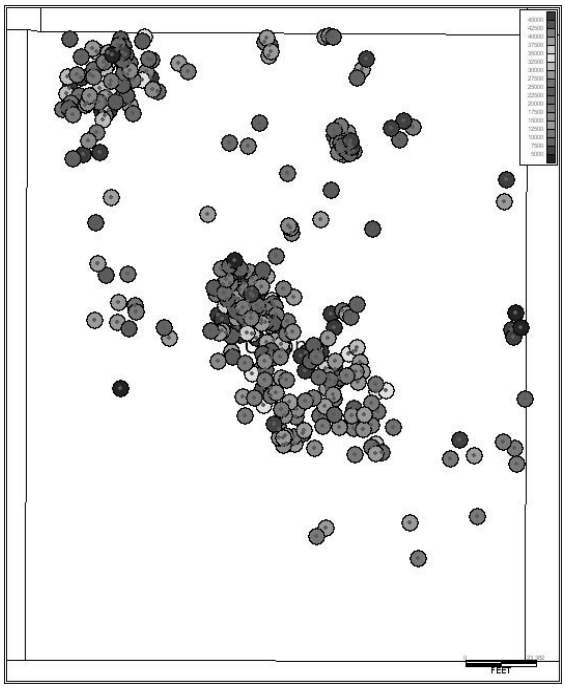


Figure 9 – Upton County BJ Services treated "Wolfberry" wells two year cumulative oil production.

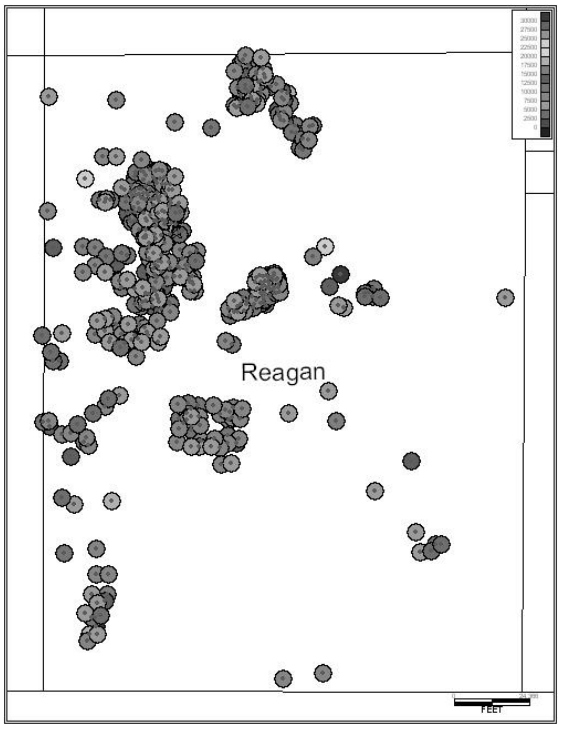


Figure 10 - Reagan County BJ Services treated "Wolfberry" wells two year cumulative oil production.

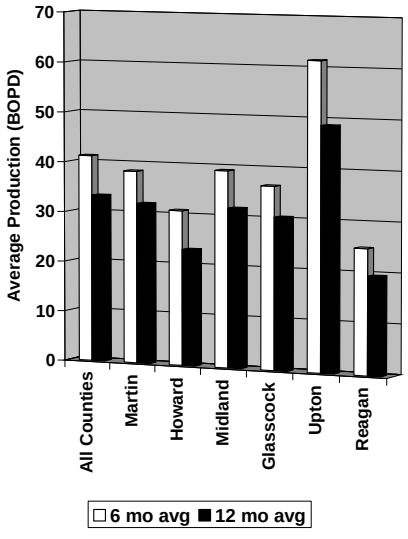


Figure 11 – Average daily oil production per county in the study area.

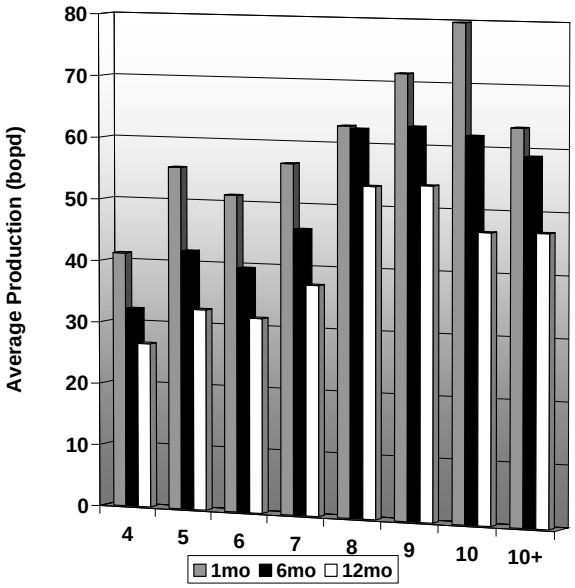


Figure 12 – Average daily oil production as a function of the number of stages pumped in the six-county study area.

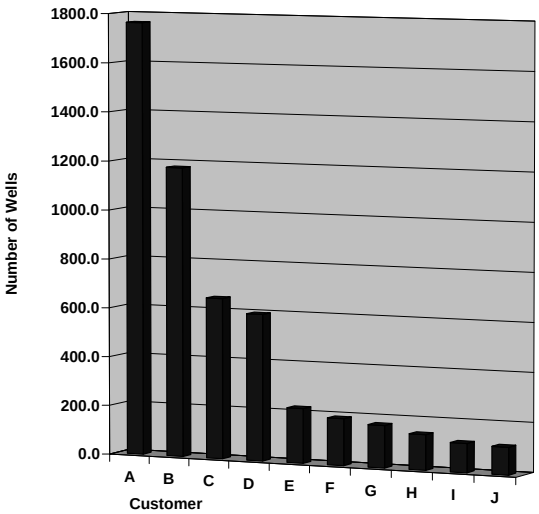


Figure 13 – Number of wells by customer in the six-county study area.

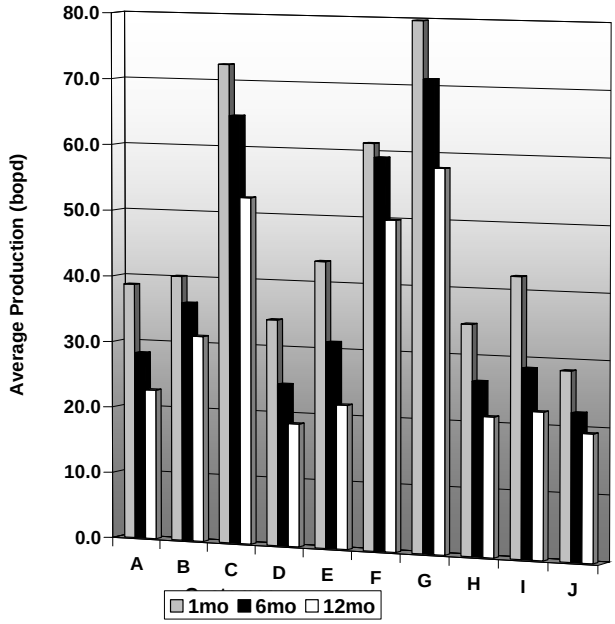


Figure 14 – Average daily oil production by customer in the study area.

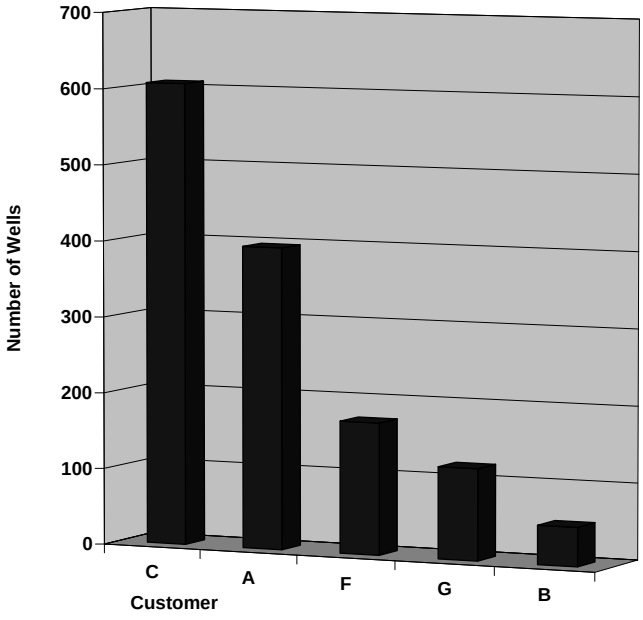


Figure 15 – Number of wells per customer in Upton County.

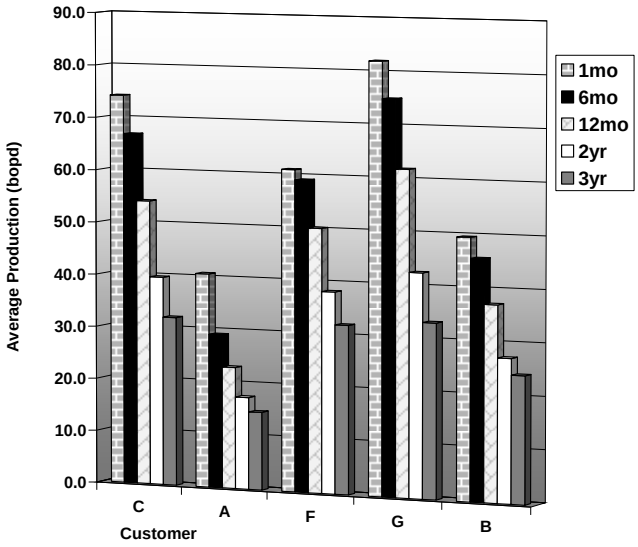


Figure 16 – Average daily oil production per customer in Upton County.

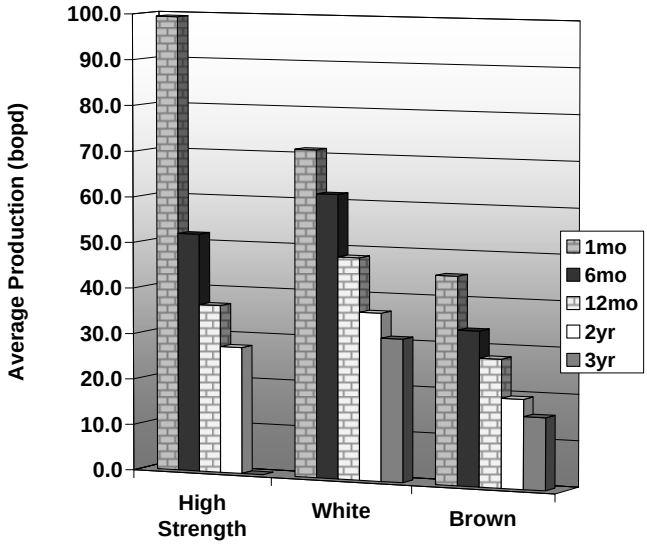


Figure 17 – Comparison of average daily oil production as a function of proppant pumped.