USING ENGINEERED DIVERSION STRATEGIES TO EFFECTIVELY STIMULATE NEW ROCK

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Drill2Frac

ABSTRACT

When hydraulically fracturing a horizontal wellbore with multiple perforation clusters, the fluid being pumped into the reservoir will preferentially take the path of least resistance. Perforations that are located in the lowest stressed rocks will take a larger amount of fluid, and those perforations located in highest stressed rocks will receive less, or in some cases none. One of the ways that engineers are trying to overcome these differences is the use of diverters. A fluid diverter is typically inserted at some point within a hydraulic fracturing pump schedule to seal off dominant fractures, allowing fluid to flow into under-stimulated fractures.

The problem with this methodology is that without reservoir knowledge, operators rely on rules of thumb developed through trial and error to determine when and how much diverter to use. Data has shown how this methodology can be ineffective, leaving some clusters over stimulated and others under-stimulated. Anecdotal evidence also supports these concerns because equally sized diverter slugs do not always have equal pressure response. This paper will present a methodology currently in use that examines well heterogeneity, and designs the diversion strategy based on actual reservoir properties. Estimations of minimum insitu stress at each cluster are combined with estimates of stress shadow effect both from previous stages and between treatment clusters to determine at which pressure each cluster will accept fluid. This data is then used to bin clusters into primary clusters which will be treated first, followed by a diverter slug, then secondary and possibly tertiary clusters. The volume of diverter slug used will be proportional to the number of clusters within the previous bin.

In addition to this, an engineered diversion strategy will look at the perforation design, fracture treatment design and pump rate. The result of this workflow is a tool that will maximize the effectiveness of diverters that will ultimately result in better producing wells at lower completions cost.

INTRODUCTION

The use of diverting materials in hydraulic fracturing stimulation is not a new concept. Diverters are defined as a substance that is added to the fracturing fluid whose primary purpose is to divert fluid from one portion of reservoir to another portion to better distribute where the treatment fluid is being injected. Historically many types of diverters have been used in the stimulation of vertical oil and gas wells. Those that were most common included rock salt, benzoic acid flakes, foams, and ball sealers. In most cases, these diverter materials were designed to either dissolve, flow back to surface, or remain deposited in the rathole of the well.

There has been a resurgence in the use of diverters in horizontal well completions, and there has been significant innovation in the types of diverters being used. The predominant type of diverter being pumped today is particulate diverters, which are engineered to specific sizes, shapes, and compositions to maximize diverter effectiveness and to ensure both stability through the pumping process followed by predictable dissolution so as to not hinder production. There has also been innovation on the ball sealer style diverter to improve isolation of the perforation tunnel.

However, with these innovations in the diverter material, the industry has seen very little change in the engineering around how to apply these diverters, with most using a trial-and error strategy in the search of an optimal application procedure. The difficulty with this approach is that the geological variability of each and every stimulation stage, which can be significant, is not considered. As a result, a procedure that works on one stage may not be as effective on the next stage. In practice, operators need to constantly monitor pressure responses and actively attempt to modify their diverter application strategies during pumping based on their observations of treatment pressure. The result is that many diverter drops are not effective, resulting in either too much pressure increase, or little to no pressure increase.

DIVERTER DESIGN CONSIDERATIONS

When diverter is included in a fracturing design, the objective is to ensure that each perforation cluster is adequately stimulated by equally distributing the hydraulic energy and proppant along the lateral. Thus, when designing a diverter strategy, engineers have many design criteria which they must consider. The most obvious considerations are when, and how much diverter to drop. In early applications of diverters in horizontals, many operators were pumping 50% of the treatment slurry volumes, pumping diverter, and then pumping the remaining 50% of slurry volume. Another variation sometimes used is to pump two thirds of the job followed by diverter and the remaining one third.

Diverter schedules are a very important consideration because they will affect how effectively the fluid will be distributed. This is demonstrated in SPE 173348 (Ugueto et al), Figure 1. An example in this paper showed a fracture stage that contained six perforation clusters. The operator pumped 50% of the job followed by application of the diverter followed by the remaining 50% of the job. The fracturing treatment was monitored with fiber optics, which gave insight as to where the fluid was being placed.

Very early in the treatment all 6 perforation clusters took treatment fluid, however, once proppant reached the formation, cluster 4.6 stopped taking fluid. After pumping diverter, there was a strong pressure response when the diverter contacted the perforations, and flow was greatly restricted to clusters 4.1 through 4.4 with the majority of fluid going to 4.6 and some to 4.5. Evaluating the effectiveness of this treatment, Ugueto et al stated the following:

> The combined diagnostic information from these displays suggest that the particulate diverter clearly plugged two-thirds of the perforations. In this case diversion was considered a successful application by many. However, a case can be made that the diverter actually took a stage with effective slurry distribution and created one or two “super fractures”. There is a strong argument that the application of diverter in this stage created conditions that resulted in under-treatment of two-thirds of the clusters and placed excessive fluid and proppant volumes in one-third of the clusters. Not only does this pose risk to flowing rate, EUR, and economic value for this stage, but it could also increase the chance of production drainage interference with offset wellbores

The above statement clearly indicates why it is important to properly understand when diversion should be attempted within a pumping stage. In the above case, had the diverter been used after two-thirds or even three-quarters of the fluid had been initially pumped, a more even distribution of fluid and proppant among all perforations might have been achieved. The problem that arises is that, without a real time diagnostic tool such as fiber optics to know where the fluid is travelling, operators are left guessing how many clusters are taking fluid at any one time. It should be noted that fiber optic results are open to interpretation, and typically need significant calibration and operational experience to determine fluid distribution.

However, if engineers understand the geomechanical properties along the lateral, attempts can be made to predict which clusters are most likely to take fluid, and at what pressure. This information can then be used to predict which clusters will take fluid before diversion and the conditions required so that the remaining clusters will take fluid after diversion, as reported by Bartko et al (SPE 184824). Such data can also be used to shift clusters to areas of stress that will improve diverter use and will be discussed later in this paper.

The other primary consideration is how much diverter to drop. Many manufacturers of diverter will give recommendations of how much diverter to drop that is usually in the form of XX lbs. of diverter per perforation or per perforation cluster. Again, without real time monitoring of the fracture treatment, it is very difficult to discern how many perforations are taking fluid prior to the diversion drop. Thus, this one-size-fits-all recommendation cannot work when you have varying rock characteristics along a lateral

For example, a US shale operator provided a chart of pressure response based on the amount of particulate diverter that was applied (Figure 2). This was done by calculating the difference in pumping pressures at surface directly before and after the diverter material had been pumped. Although it appears that using more diverter generally results in higher diversion pressures, it is also clear that the difference in pressure for a given quantity of diversion material is highly variable.

In this example, engineers felt that an ideal pressure response was between 700 psi and 3000 psi after the diverter hit. Some treatment stages failed to achieve sufficient pressure increase to meet the minimum guideline, while others experience greater than the maximum of 3000 psi of pressure increase, with corresponding difficulties placing proppant.

Obtaining Lateral Geological Profiles

The above examples demonstrate very clearly that the effectiveness of diversion treatments might be improved if the stress profile along the lateral was better understood. However, most operators are not measuring lateral stress profiles. The high costs and additional operational complexities of running electrical logs such as sonic or pulsed neutron logs to acquire the necessary measurements combined with inherent risk of poor data quality makes this avenue of data acquisition unpopular in the industry. Gamma ray measurements are a possible alternative but it has been shown that gamma ray signatures in most reservoirs tend to have only a loose correlation to rock strength (Xu SPE 177297)

Lateral Measurements using Drilling Data

More recently, many operators are turning to using data obtained during the drilling process to characterize laterals through the calculation of Mechanical Specific Energy (MSE) (Logan).

Mechanical Specific Energy or MSE has been used in the drilling domain for over fifty years *(Teale)*. Simply put, MSE is a measure of energy input per unit rock drilled. There already exist multiple variants of published formulae to calculate MSE with drilling parameters (WOB, ROP, RPM etc.) acting as the primary inputs.

The original MSE equation consists of a thrust component derived from the weight on bit, and a rotary component that takes into account the torque and rate of penetration.

$$MSE\ (psi) = \frac{WOB}{AOB} + \frac{120 * N * T}{AOB * ROP}$$

Where:
WOB = Weight on Bit (Klb)
N = Rotational Speed (rev/min)
T = Torque (Kft-lb)
A = Area of bit
ROP = Rate of Penetration (Ft/hr)

Under ideal conditions, MSE has a 1:1 relation with UCS (Uniaxial Compressive Strength*) (Teale)*.

The assumption that MSE perfectly correlates with UCS cannot be used in practical application because factors such as bit wear, tortuosity, and drilling practices also need to considered.

By applying proprietary modeling workflows, petrophysicists can calculate an MSE that is reflective of the formation by removing many of the drilling induced artefacts. Several providers are now providing this analysis service. This makes the use of drilling data very attractive because the costs are significantly lower than alternative approaches, and requires no additional wellbore operations.

The sample plot below (Figure 7), represents a wellbore trajectory with the MSE mapped on to it. The colors indicate similar rock hardness. This is the starting basis for creating a lateral profile to be used in improving diverter application

Incorporating Stress Shadow

Obtaining an accurate lateral profile is just the first step to create an effective diversion strategy. During the fracturing operations there are other factors in play that can affect the stresses in the lateral. The biggest of these effects is what is known as a stress shadow. In horizontal well shale completions with multiple treatment stages and with multiple perforation clusters per stage, each created hydraulic fracture alters the stress field around it. When hydraulic fractures are placed close enough together, these stress shadow effects can greatly inhibit or prevent the growth of new fractures.

Many papers have been written where the effects of stress shadowing have been reported. Ugueto et al that recognized a heel bias (Figure 8), where more fluid flows to the heel-ward cluster than the toe-ward cluster within a stage. The stress shadow can significantly affect the rock stresses, and must be accounted for when trying to fully engineer diverter strategies.

In addition to stress shadows causing a heel-toe flow bias, stress shadows also have a significant effect on fracture growth within a stage. Figure 9 is taken from a paper written by Wu et al and shows a numerical simulation that was performed to analyze the effect of stress shadowing on interior perforations. In this example, a model was built in which four clusters attempted to propagate simultaneously. The fractures are initiated fifty feet apart from one another in similar rock. The result of this is that the interior fractures are inhibited due to the close spacing.

ENGINEERED DIVERTER STRATEGY

Based on the premise that one can predict how many clusters take fluid before diversion and after diversion based on lateral profile, a novel engineering workflow has been created. This workflow is based on first predicting which perforation clusters within a stage will initially take fluid, and then to develop a methodology that effectively diverts fluid from those clusters to the remaining clusters to achieve equal distribution of slurry to along the wellbore. This methodology, known as Engineered Diverter Strategy, was created with the goal of making diverter use more effective as well as more predictable.

The engineered diverter strategy contains four key parts which will be discussed in detail. 1) Placement of Perforations, 2) Calculation and Adjustment of Breakdown Pressures, 3) Perforation Friction 4) Engineered Diversion Pressure Analysis.

Placement of Perforations

The first step is to map the mechanical properties of the fracturing stage in question, using either wireline logs, MSE, or any other method to get a reliable profile. On top of this profile, the stress shadow from the previous stage (assuming it has already been hydraulically fractured) is added to approximate the stress regime of the entire stage.

Once the states of stress are calculated, perforations are then placed so that several clusters of perforations within a treatment stage are located where they are most likely to take fluid early in the treatment, such as areas of low stress. These clusters will be known as the “Primary Clusters” and will be the first clusters to take fluid before diverters are pumped. The remaining clusters of perforations will be placed in areas of the lateral with the stage that are less likely to take fluid early in the treatment (areas of higher stress). These clusters are known as the “Secondary Clusters”, and they will be designed in such a way so that they will only initiate after diverter has been applied. Should an operator want to do two or more drops of diverter, then the perforation clusters will be placed in such a way so as the Primary Clusters are in the lowest stressed rock, the Secondary Clusters will be placed in rock with higher stresses and the Tertiary Clusters will be placed in rock that have higher stresses than the Secondary Clusters.

An example of cluster placement is shown in Figure 10. An MSE based compressive strength profile was created and perforations are placed in relation to that profile. Here there are seven clusters total placed within the stage with the blue clusters being the primary clusters, placed in areas of low rock strength, and the red secondary clusters are placed in areas of higher strength.

The objective in the placement of the perforation clusters is to maximize the differences of stress while also paying attention to the spacing of the clusters. If clusters in the same pumping segment, such as 2 primary clusters, are too close together, then intra-stage stress shadows may inhibit effective growth of those clusters. The ideal means to avoid intra-stage stress shadows is to alternate the clusters between relatively lower and higher stresses. The additional advantage of alternating clusters in this way is that this should promote additional fracture complexity. As stress shadows build between the primary clusters, the minimum horizontal stresses are increased and will eventually reach a level where the two principal horizontal stresses become equal, which will promote more complex fracturing between the primary clusters.

Calculation and adjustment of breakdown pressures

After the perforation cluster locations have been chosen, the next step is to calculate the breakdown pressure of each perforation cluster. There have been several methods proposed in various papers to calculate this breakdown pressure. Hubbert and Willis developed the first realistic model relating the recorded hydraulic fracturing test variables to the in-situ state of stress in rock.

At the borehole wall the tangential stress at the two points aligned perpendicular to the minimum horizontal stress, S_h, will be the first to meet this criterion as the test-interval pressure is raised. A hydraulic fracture will thus initiate and extend in the direction of the maximum horizontal stress, S_H. With these assumptions, Hubbert and Willis (1957) were able to obtain an elastic solution relating the hydraulic fracturing initiation pressure P_c (also called critical or breakdown pressure) and the two principal horizontal stresses, S_h and S_H.

$$(P_c - P_o) = T + 3(S_h - P_o) - (S_H - P_o)$$

where T is the tensile strength of the rock, and P_o is the pore pressure. This basic equation has been modified further to fully account for the three-dimensional stress effects, poroelastic effects, and the effects of anisotropic rock properties.

It should be noted that using these more advanced three-dimensional equations of breakdown pressure, proprietary methodologies have been developed that allow perforations to be shot in such a way as to modify the effective breakdown pressure of individual perforation clusters. These methodologies can be adapted to Engineered Diverter Strategies, by perforating the Primary Clusters in such a way as to minimize breakdown pressures of those clusters, and by perforating secondary and tertiary clusters in such a way that significantly increases the breakdown pressures of those clusters.

Perforation Friction

In horizontal wellbores, perforations act as bottom-hole chokes. Flow resistance can be increased by increasing perforation friction, which is a function of the number of perforations, the diameter of the perforations and the flow rate through the perforations. Perforation friction can be estimated by the equation

$$F_{pf} = \frac{0.2369\rho_s}{n_p^2 d_p^4 C_d^2}$$

Where ρ_s is slurry density, n_p is the number of perforations, d_p is the perforation diameter and C_d is the discharge coefficient which typically ranges from 0.55 to 0.85.

By increasing the amount of perforation friction, many operators perform what is known as the limited entry technique. This technique limits the number and size of perforations within a completion interval to so that the flow resistance across each perforation cluster help distribute the stimulation treatment among all perforation clusters.

In diverter applications, many operators still retain the limited entry technique in order to maximize fluid distribution. In an Engineered Diverter solution this is counter-productive because this technique would force fluid flow from primary clusters into secondary clusters before the diverter is applied. Thus, when designing a diverter approach, the perforations must be designed so that there is sufficient perforation friction to equally distribute fluids within pumping segments but not enough perforation friction to breakdown the secondary clusters. This is one of the keys to an effective Engineered Diverter strategy and is why the Pressure Analysis is necessary.

Engineered Diversion Pressure Analysis

The key to an effective engineered diverter strategy is the pressure analysis that incorporates all of the techniques mentioned previously; that is, calculating stresses at each perforation cluster, determining breakdown pressures, and adjusting perforation friction.

Starting with the placement of perforations in sections of reservoir with contrasting mechanical properties as shown in Figure 10, the stress at each perforation cluster can then be calculated as shown in the Table 1.

Table 1 Minimum Stress at perforation clusters

Cluster	Pump Segment	Min Stress (psi)
1	1st	6744
2	2nd	7885
3	1st	6951
4	1st	6951
5	2nd	7740
6	1st	6225
7	2nd	7470

These locations can then be represented by the graph below (Figure 11), with the primary perforation clusters that have been designed to take fluid before diversion in red, and the secondary perforation clusters in yellow. In addition, the breakdown pressures are represented as an orange line above the respective pressures.

The next step of the process is to determine the bottom-hole pumping pressure that is expected during the first pumping segment before the diverter is dropped. In this example, it is assumed that the job will be pumped at 80bpm through the four primary clusters, each with six perforations of 0.42" average diameter. This is represented in Figure 12

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In this example the pumping pressure during treatment of the primary clusters is just slightly lower than the breakdown pressure of one of the secondary clusters (cluster seven). Once net pressure starts to build, or if there are any unexpected changes during the treatment, there is a risk that cluster number seven will prematurely breakdown before the diverter is pumped.

There are several ways that can be used to solve this problem. First, perforation friction can be reduced by adding more perforations per cluster, using perforations with a larger entrance hole diameter, or reducing rate. Making such modifications carries that risk that the fluid will have less consistent distribution between the primary clusters. Another remedy would be to use advanced perforation techniques to increase the breakdown pressures of the secondary perforation clusters. Finally, additional stress shadow can be induced by pumping at lower rates during the beginning of the stimulation job. If the early part of the treatment is pumped at a low rate, then the reduced rate will prevent pressures from exceeding the secondary clusters breakdown pressures. Fractures will initiate and propagate in the primary clusters, creating a stress shadow between those clusters and the secondary clusters. The net effect will be an increase in the effective breakdown pressure of the secondary clusters. This is seen in Figure 13.

To complete the engineered diverter design for this example with, four primary clusters and three secondary clusters, the pump schedule could be divided to pump four sevenths of the job, followed by a diversion step and then the remaining three seventh of the job.

This methodology also provides operators guidelines on how much diverter to drop. In this example, there are 4 primary clusters with 6 perforations each, or 24 primary perforations. If bioballs or perforation pods are being used at a recommended count of 1 ball/pod per perforation, 24 units of diverter would be used. If, however, particulate diverter is being used, then it will be necessary to calibrate how much diverter is required per cluster to determine the optimal amount of diverter to use for each stage.

CASE STUDY

Design

The engineered diverter workflow was applied to an Eagle Ford horizontal completion. The lateral length was approximately 4500' and the well was completed with eighteen stages and an average stage length of 250'. Each stage contained twelve clusters.

The standard fracturing design in this area consisted of three diverter drops of PLA based particulate diverter, dropped at equally spaced intervals. The amount of diverter dropped at each interval was constantly adjusted based on response from previous stage. For this trial, the engineered diverter application incorporated only two diverter drops. The initial plan was to use biodegradable perforation ball sealers as the diverting material, however due to operational constraints, ball sealers were used exclusively for the first diverter drop, and for the most part, particulate diverter was used for the second drop. Over the course of the treatment there were several operational issues which prevented stages from being pumped to completion. Of the 18 stages pumped, two stages had no diverter pumped, and a further two stages had only one of the two diverter drops completed.

The first step to developing the engineered diverter strategy for this well was the creation of a lateral mechanical properties profile. This was done using the method of analyzing drilling data and can be seen in Figure 10. This well shows a moderate to low level of heterogeneity. Since heterogeneity is the primary driver for designing an engineered diverter strategy, this well required detailed analysis of perforation and pump design to ensure effective diverter application.

For this well, it was decided that perforations would be shot with a charge that created holes with an average diameter of 0.42". Based on a 5 perf per cluster design, it was estimated that a design rate of 15 bpm per cluster would create 1600 psi of pressure differential. Based on this clusters were designed around the following parameters

1) Breakdown pressures of primary clusters are lower than breakdown pressure of secondary clusters
2) Pumping pressure (minimum pressure + perf friction + tortuosity) of primary pumping segment is less than breakdown pressure of secondary clusters
3) Breakdown pressures of secondary clusters are lower than breakdown pressure of tertiary clusters
4) Pumping pressure (minimum pressure + perf friction + tortuosity) of secondary pumping segment is less than breakdown pressure of tertiary clusters

As an example, in Figure 11 an estimated minimum in-situ stress is presented (blue line), and the stress shadow from the previous stage is estimated and shown in orange. Perforation clusters were placed in such a way that the perforations were well spaced and that primary, secondary and tertiary clusters were well distributed along the lateral. Additional perforation strategies were used to increase the apparent breakdown pressures of the secondary and tertiary clusters, and is the reason that the most toe-ward perforation cluster could be placed in an area of higher stress.

For this well, for ease of application, it was decided to design all stages around five primary clusters before diverter was used, followed by four secondary clusters after the first diverter drop and finally three tertiary clusters after the second diverter drop for a total number of clusters being treated at once as nine. The pump schedule was designed around equal slurry to each cluster, so 5/12 of the job was pumped, diverter was dropped, then 1/3 of the job was pumped before the next drop which was chased by the final ¼ of slurry.

Results

The well in this case study did not have any direct method to evaluate the effectiveness of the diverter treatment such as fiber optics, microseismic, production logs, or tracers, thus, to evaluate the effectiveness of the strategy, we needed to look at the pressure responses to indicate effective diversion. While this may be very dependent on the formation, fracture design and additives used, typically we expect to see two discrete signatures. 1) When the diverter hits the perforations/ formation, one would expect a sudden pressure increase. This occurs as the primary clusters are blocked of fluid flow, and pressure is increased until the point that the breakdown pressures of the secondary clusters are exceeded. 2) After breakdown, we expect that, if new clusters have been contacted, that there should be increased perforation friction and tortuosity followed by a gradual decrease in pressure (or increase in rate if pressure is held constant). Quite often, the treating pressures during stimulation of the secondary clusters will look similar to the treating pressures of the primary clusters.

For example, Figure 12 shows a typical stage from this well which used ball sealers for the first diverter drops and particulate diverter for the secondary drop. In this example, it is clearly evident that before the first diverter was dropped, pressure was relatively stable and flat. After diverter hit formation, pressure increased, followed by a steady decline in pressures. It is important to note that this pressure decline is significantly greater than hydrostatic changes alone and begins before proppant hits formation. Based on this, there is clear evidence from the pressure response that after each diverter drop, new rock was stimulated.

For this well, there was indication in 21 of the 24 diverter drops that new rock was being stimulated. This equates to an 88% success rate.

In contrast, the operator treated the direct offsets of this well with their conventional design which included 3 drops of particulate diverter. A sample stage is shown in Figure 13. In this stage it is clear that after some diverter drops there is a pressure increase, however, pressures to not seem to indicate that new rock is being contacted, and would imply that diversion may not have resulted in new clusters being treated, but rather that fluid was just re-distributed among existing clusters.

The offset well in question had a total of 45 diverter drops, and of those 45 drops, only 23 of them had clear indications that new clusters were being treated after diversion which is a 51% success rate.

CONCLUSIONS

Based on the work done here, and as shown in previous papers, the current method of designing diverter strategies using rules of thumb and trial and error can never achieve ideal diversion consistently due to variations in lateral rock stresses and mechanical properties. Provided with some understanding of lateral geomechanics and fluid flow mechanics, it is possible to analyze the wellbore heterogeneity, and then use that heterogeneity to design a diverter strategy. In this way, operators can segregate clusters into Primary, Secondary, and, if needed, Tertiary clusters by locating them in rock which will be most likely to breakdown at the lowest stress, and subsequently higher stresses, respectively.

In addition, a diversion pressure balance analysis needs to be performed so that the combined perforation friction and fracture initiation pressures when pumping in to the primary fracture clusters does not exceed the minimum pressure required to initiate fractures in the secondary perforation clusters. Bottom-hole pumping pressures can be manipulated by adjusting perforation friction either through adjusting pump rates, perforation diameter or number of perforations.

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FIGURES

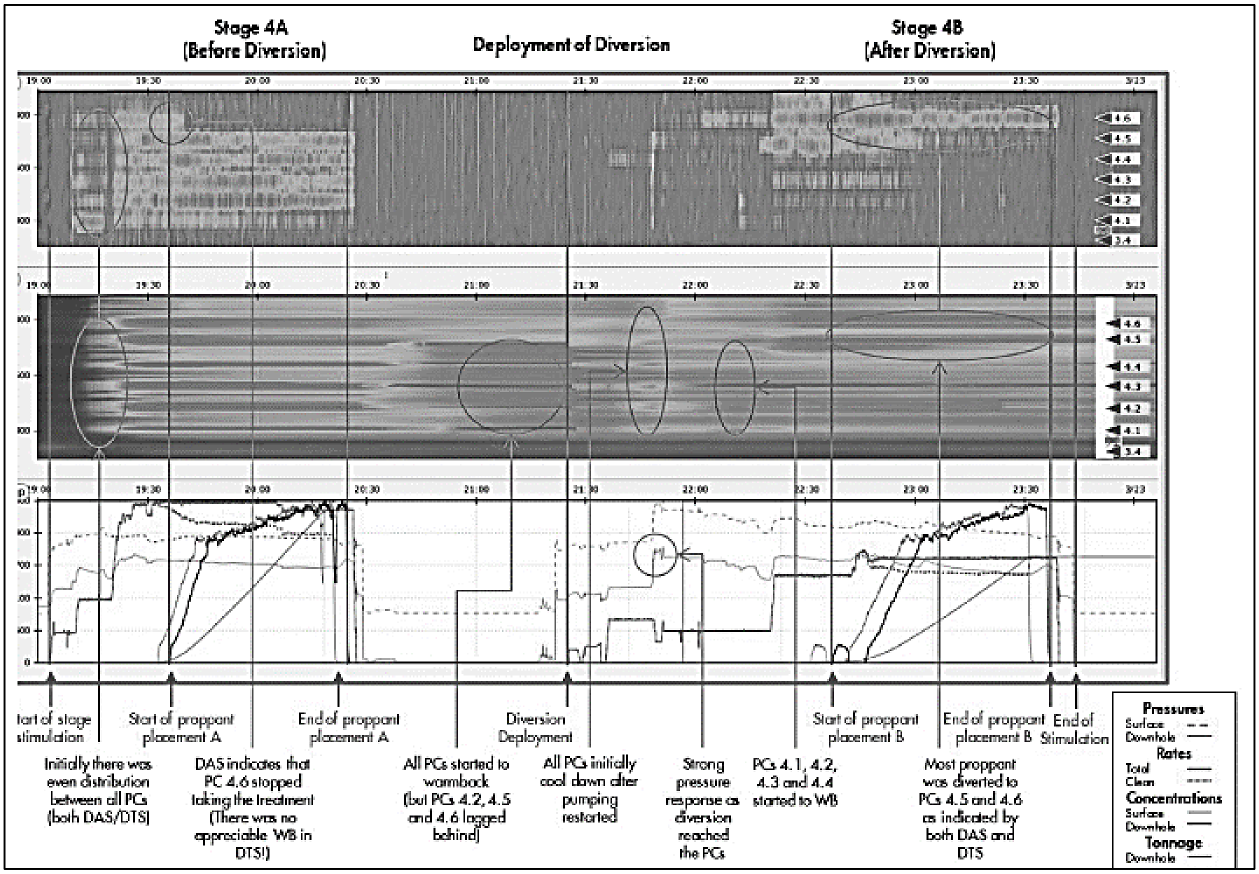

Figure 1 Fiber Optics analysis taken from Ugueto et al (SPE 173348). Image shows how diverter moved fluid from 5 active clusters to 2 active clusters

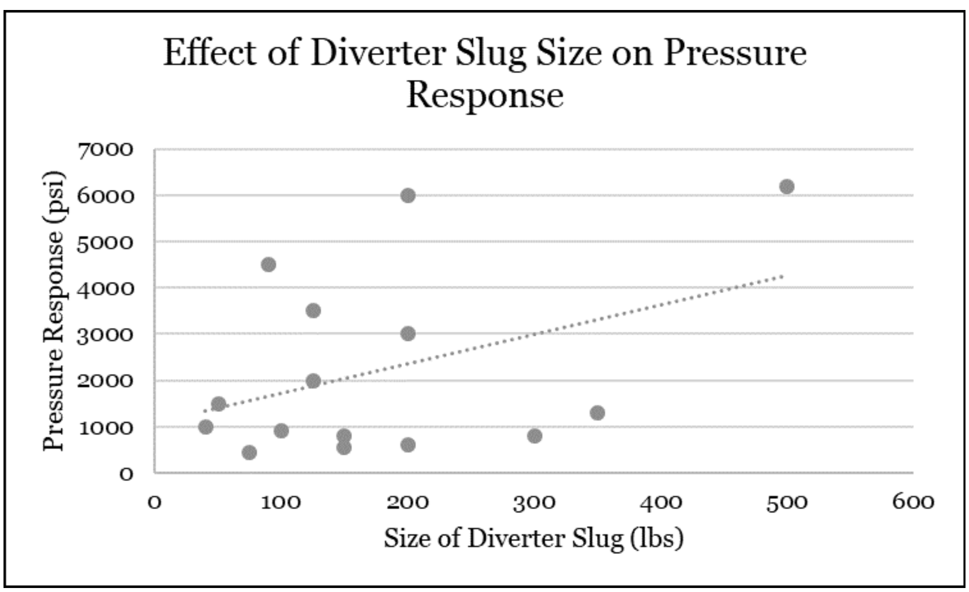

Figure 2 The amount of pressure increase obtained after each diverter drop. Ideal pressure response should be between 700psi and 3000psi

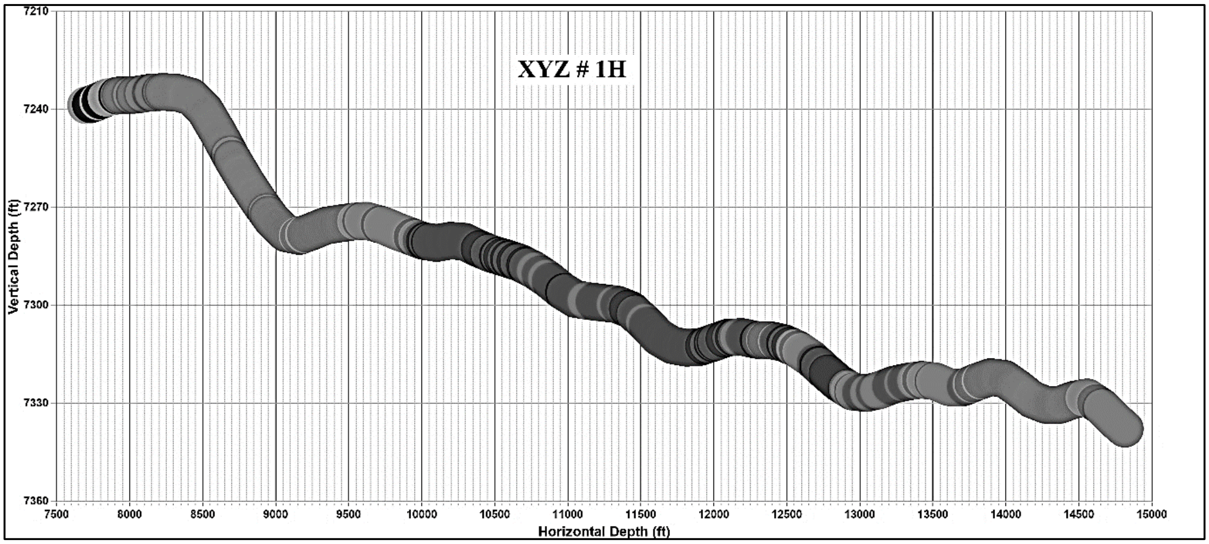

Figure 3 Example of mechanical properties as calculated from drilling data plotted along a wellbore trajectory

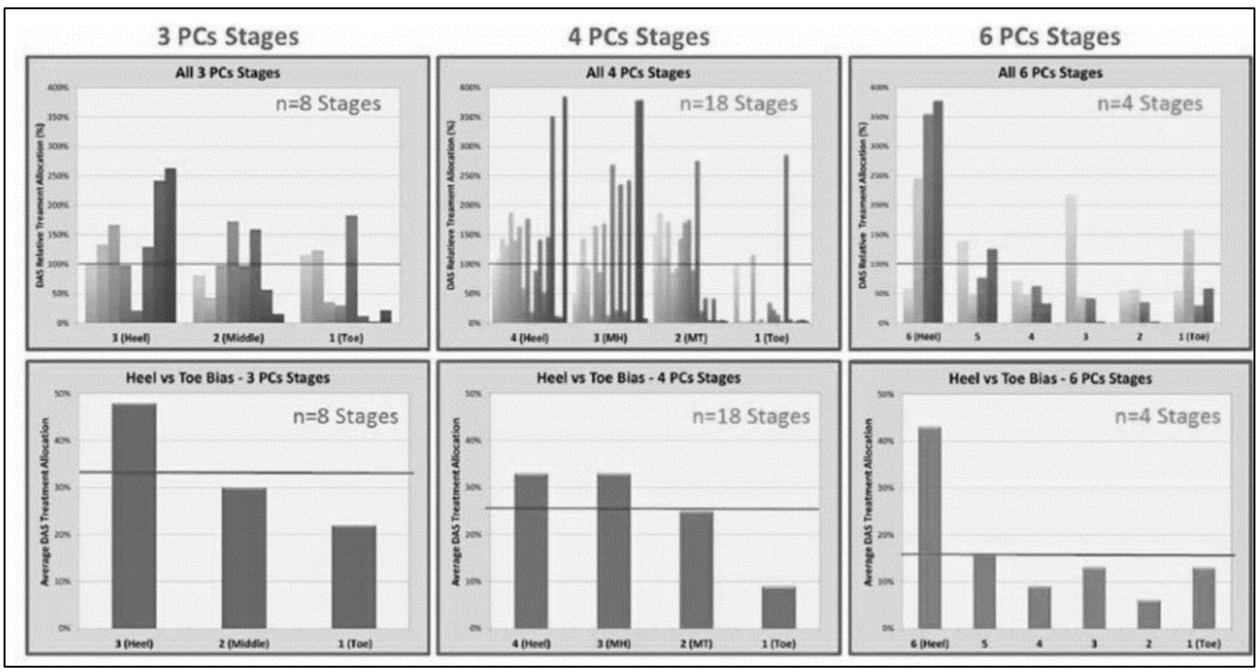

Figure 4 Plot obtained from SPE 173348 shows how fiber optic analysis consistently showed more fluid preferentially going to the heel cluster over the toe. Examples are for stages with three, four and six perforation clusters

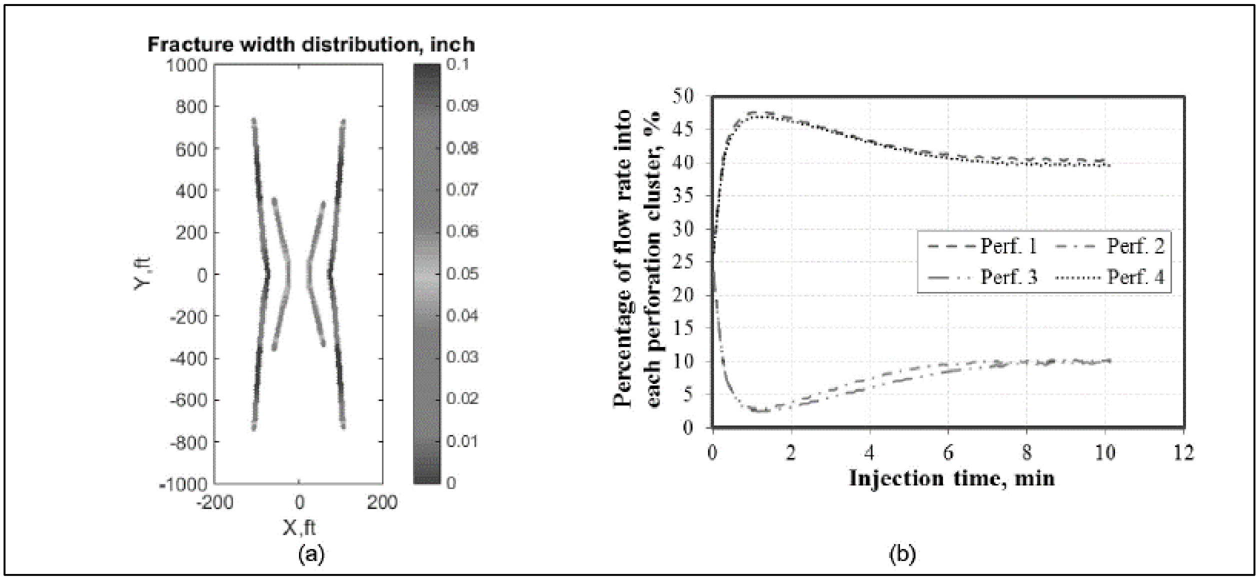

Figure 5 Taken from SPE 174869. (a) Propagation paths for four fractures, twofold exaggeration on x-axis scale; (b) Percentage of flow rate splitting into each fracture vs. injection time

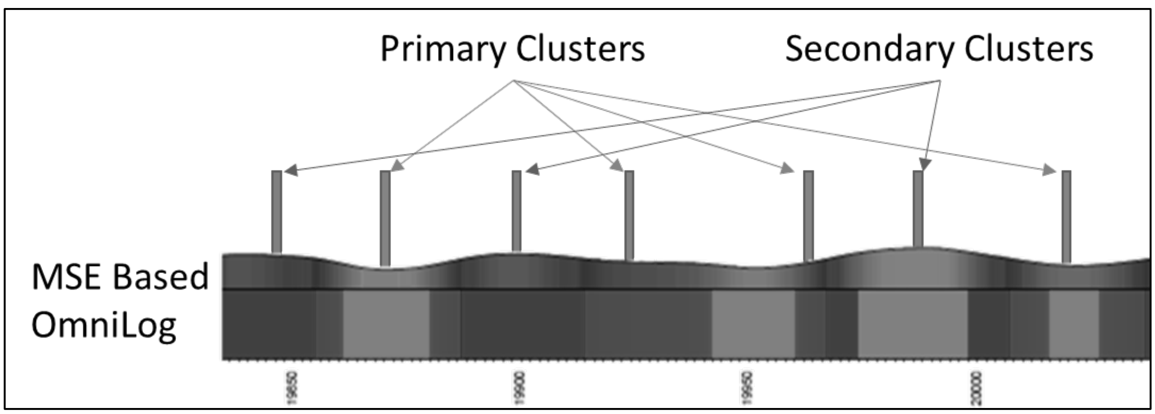

Figure 6 Example of how an engineered diversion strategy can use drilling based MSE logs to place clusters for effective diversion

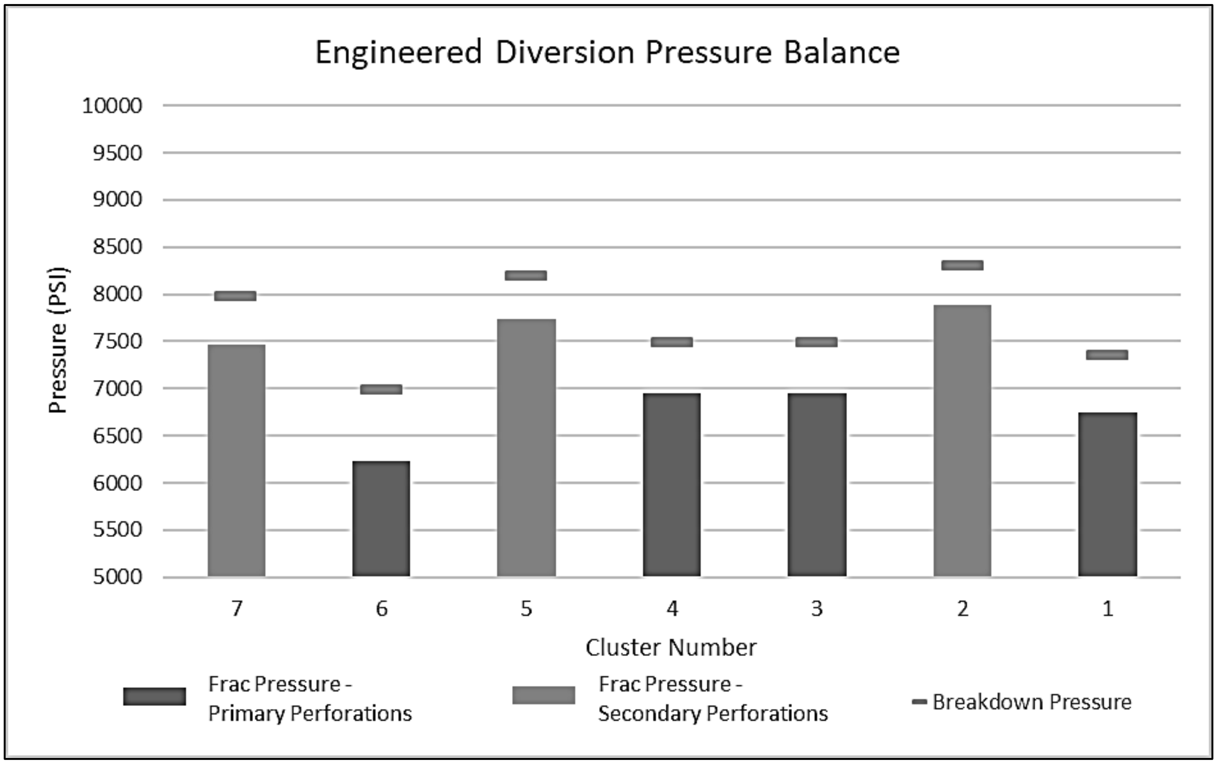

Figure 7 Engineered Diversion Pressure balance plots the minimum insitu stress plus stress shadow for each cluster. This allows for the calculation of Breakdown Pressures

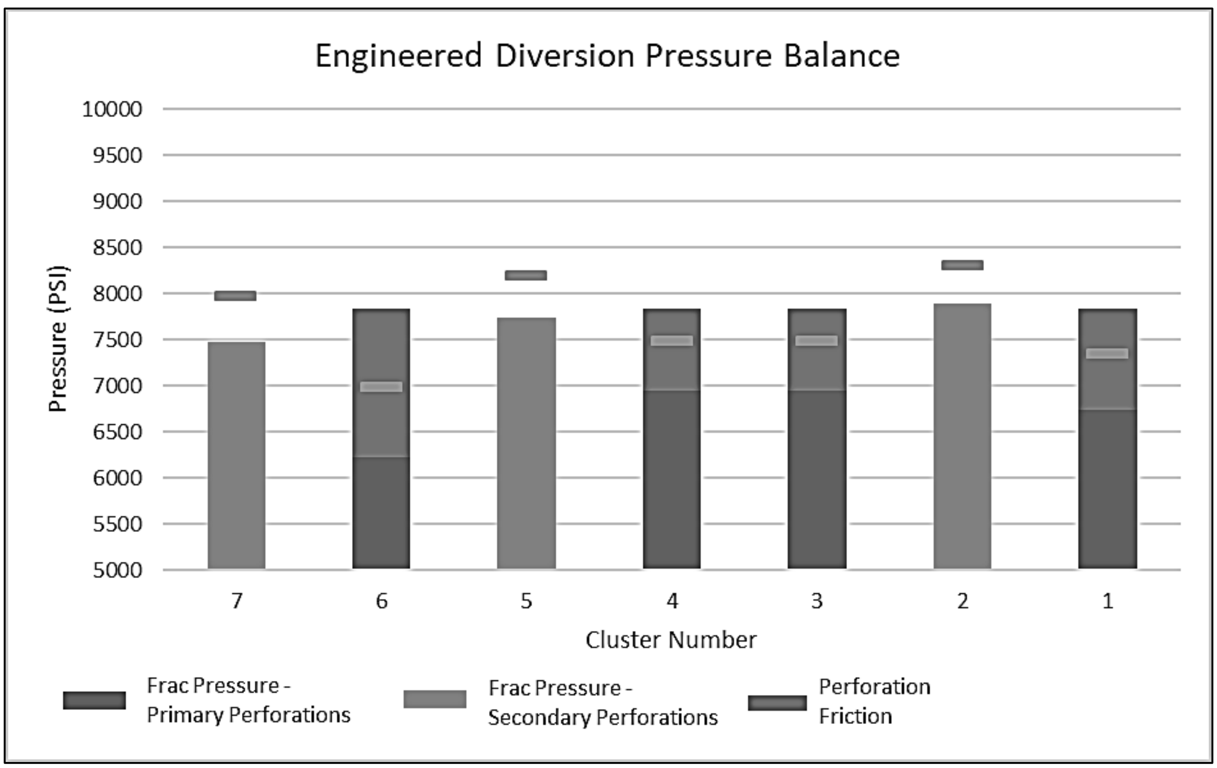

Figure 8 Engineered Diversion Pressure Balance at the point when fluid is flowing into primary clusters before diverters are applied

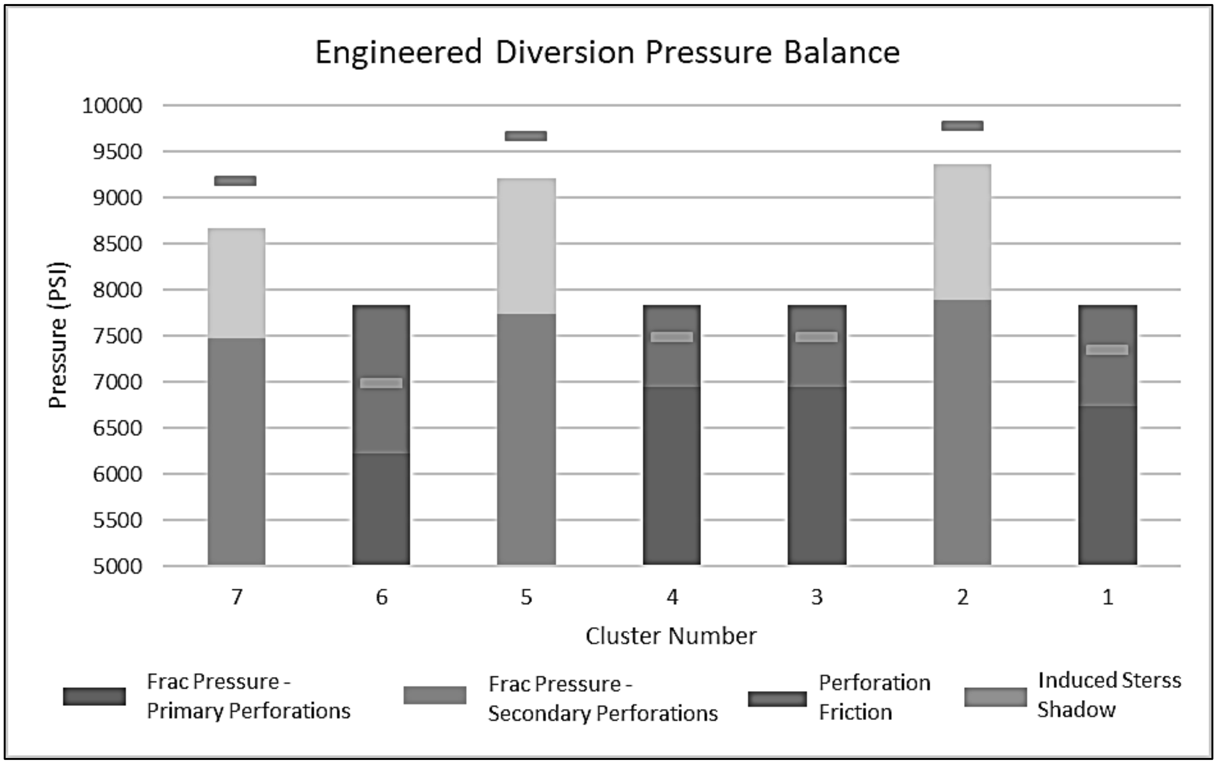

Figure 9 Engineered Diversion Pressure Balance at point right before diverter is applied downhole

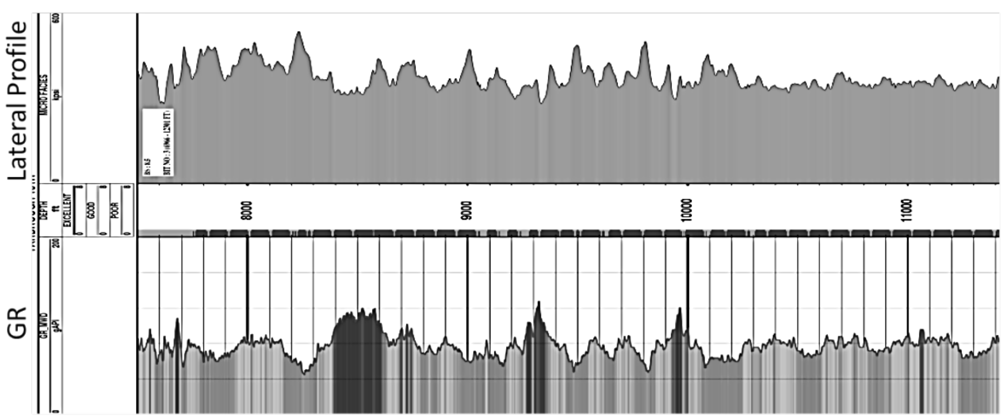

Figure 10 Lateral mechanical properties profile derived from drilling data compared to gamma ray

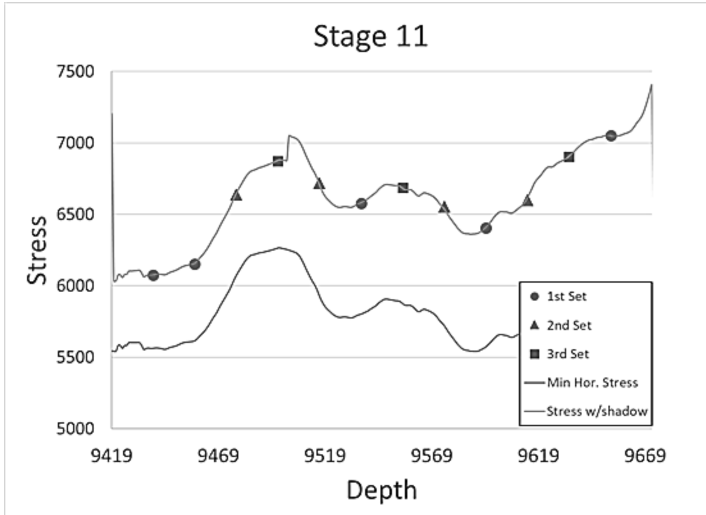

Figure 11 Sample stage showing perforation picks on an engineered diversion strategy

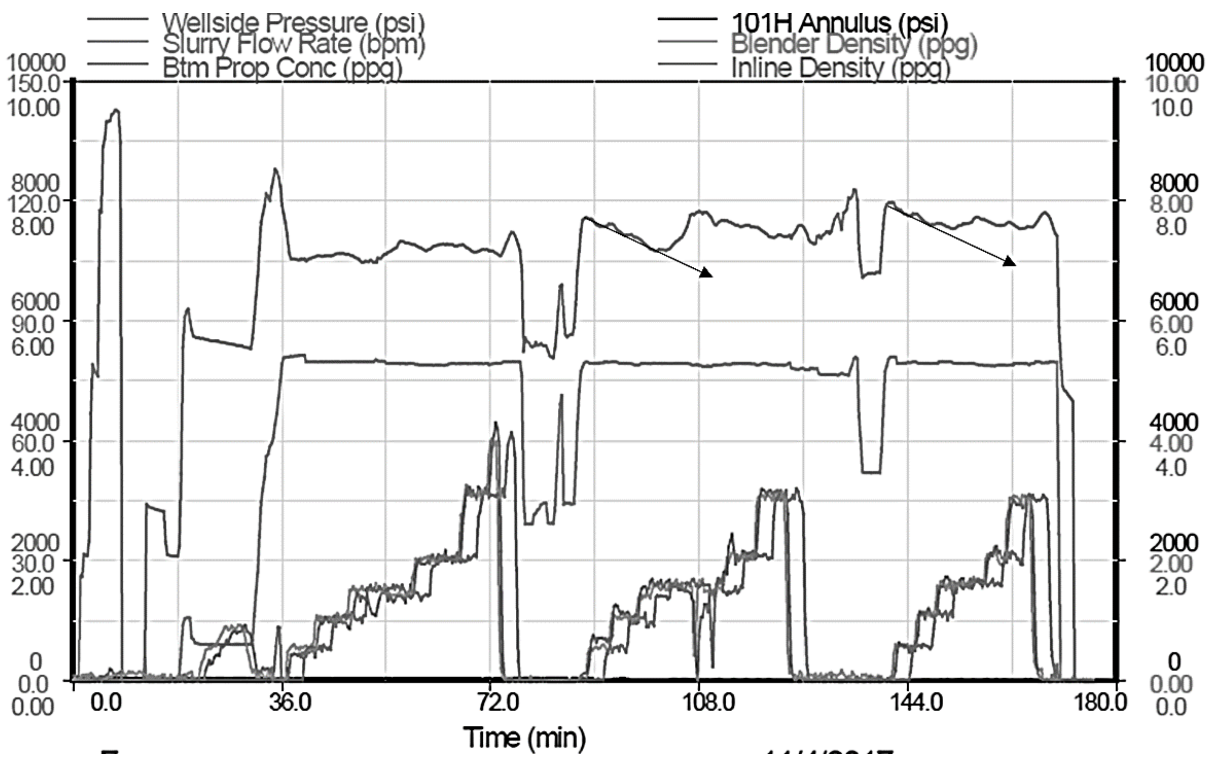

Figure 12 Sample stage where a fully engineered diverter strategy was applied using Perforation Pods as the sealing mechanism

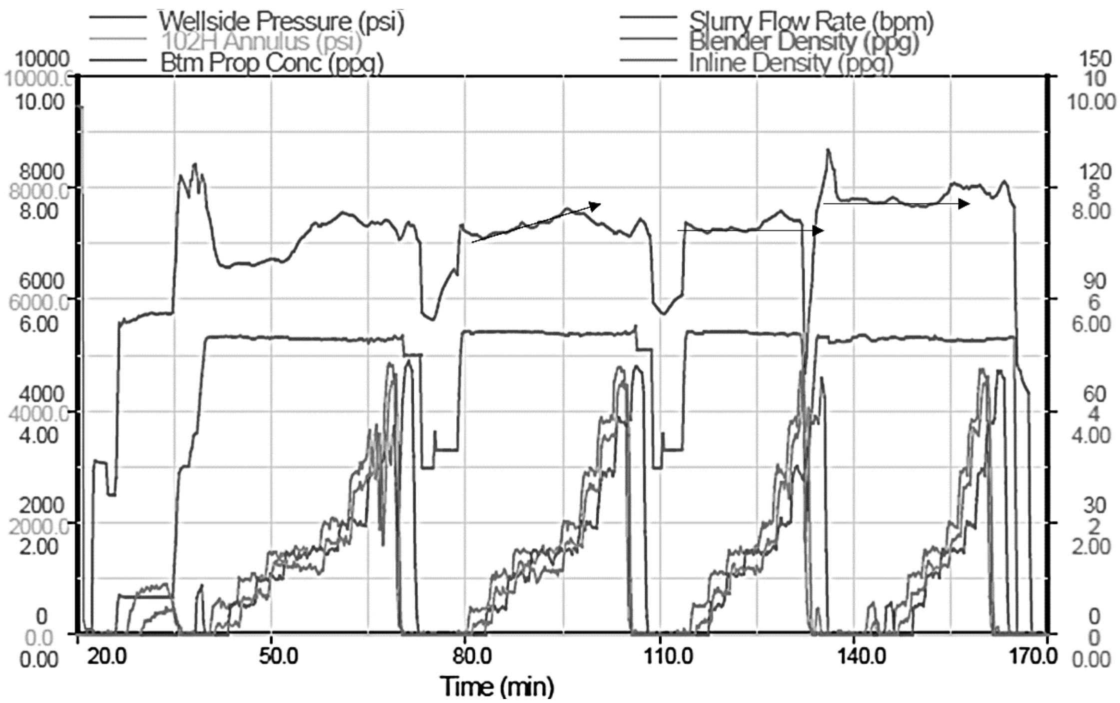

Figure 13 Sample stage where an engineered diverter strategy was not applied using Perforation Pods as the sealing mechanism