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CREATION AND CHARACTERIZATION OF HORIZONTAL HYDRAULIC FRACTURES IN OIL SHALE

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CREATION AND CHARACTERIZATION OF
HORIZONTAL HYDRAULIC FRACTURES
IN OIL SHALE

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ABSTRACT

Sandia Laboratories, in support of the Department of Energy Laramie Energy Technology Center's (LETC) in situ oil shale programs, conducted a true in situ oil shale experiment to evaluate the porosity and permeability produced by detonating a slurry explosive in one or more previously formed hydraulic fractures. The experiment involved the creation and characterization of three closely spaced horizontal hydraulic fractures, followed by the insertion and detonation of a slurry explosive in two of these fractures. Initial site evaluation, explosive evaluation tests, and numerical analyses provided guidance to the hydrofracturing procedure. Numerous diagnostic and evaluation measurements were made before, during, and after the hydrofracturing process for evaluation of the fractures. The results showed that three closely spaced fractures satisfactory for subsequent explosive fracturing had been created in essentially horizontal planes.

INTRODUCTION

The need for the development of technical and economical methods of extracting hydrocarbons from oil shale has long been recognized. Recoverable synthetic crude oil in the form of kerogen found in oil shale formations is one of our most abundant energy sources, potentially as large as all the world's known petroleum reserves.⁽¹⁾ The extraction of the hydrocarbons by true in situ processing techniques is attractive from an environmental standpoint.⁽²⁾ With such techniques, the only linkage between the underground shale bed and the surface is through a series of wellbores. The mining, crushing, and disposal of large quantities of raw shale are eliminated. Demands upon surface water resources and the disfigurement of the earth's surface are significantly reduced.

In the bed preparation phase of in situ processing, sufficient porosity and permeability must be obtained throughout the naturally impermeable shale bed to permit process gases to flow from the injection wells to the flame front and product fluids from the pyrolysis zone to the production wells. The main problem associated with in situ processing is that of developing technically and economically feasible methods of fracturing the oil shale to achieve the necessary porosity and permeability. Past experiments^(3,4) have examined variations in the two basic explosive fracturing approaches. A borehole springing method,⁽⁵⁾ in which explosives are detonated in adjacent boreholes to fracture the shale in the nearby region, shows promise where the shale is sufficiently close to the surface to achieve the necessary porosity and permeability by surface heaving. The second method, in which fracturing of the formation is achieved by the detonation of slurry explosive emplaced in previously formed, sand-propped, horizontal hydraulic fractures, may be feasible where the shale is deeper underground.

This paper describes the hydraulic fracturing portion of a hydraulic/explosive fracturing experiment recently conducted at Site 12 of the LETC field laboratory near Rock Springs, Wyoming. The objective of the fracturing experiment was to (1) create three closely spaced horizontal sand-propped hydraulic fractures in the Tipton Member of the Green River Oil Shale Formation, and (2) characterize the fractures sufficiently to permit judicious placement of instrumentation designed to monitor the subsequent explosive fracturing experiment. A discussion of the hydrofracturing processes, diagnostic and other measurement techniques employed, and the post-hydraulic fracturing formation evaluation are presented.

EXPERIMENT DESIGN

Fracturing of oil shale by inserting and detonating slurry explosives in previously formed hydraulic fractures offers the potential of affecting the formation over a much larger distance from the injection/detonation well than is possible using well-bore springing methods. Its success is contingent upon the ability to create fractures sufficiently parallel to act as impedance-mismatched interfaces to reflect the compressive wave as a fracture producing tensile wave. A detailed computer-simulated analysis by Boade⁽⁶⁾ indicated that fracturing of oil shale sufficient for retorting might be achieved by detonating an explosive in closely spaced parallel cracks of substantial width (1/4"). Lithology and stratigraphy studies⁽⁷⁾ of the Tipton Member of the Green River Formation shows a lateral uniformity of the oil shale with the bedding planes essentially horizontal, suggesting that hydraulic fractures could be formed in a horizontal plane.

Thomas, et.al.,⁽⁸⁾ investigated the feasibility of creating horizontal hydraulic fractures in the Tipton Member near Green River Wyoming. A subsequent experiment at the Rock Springs Site 9⁽⁴⁾

consisted of creating three horizontal hydraulic fractures for use in a subsequent true in situ experiment. The Site 12 experiment was to build on the knowledge gained by these two earlier experiments by the extensive use of diagnostic measurements made to evaluate each step in the sequence of operations producing the fractured bed.

The horizontal fractures would be created by cutting a horizontal notch in the formation at the desired depth, pressurizing the notched wellbore to achieve crack initiation, and pumping sufficient fluid into the initiated crack to propagate it the proper distance. Since horizontal fractures were required for this experiment, the crack initiation/propagation pressures could not equal that required to create a vertical fracture. Using material properties for Tipton Member oil shale⁽⁹⁾ and the planned well geometry, predictions of the pressures required for initiation of horizontal cracks from a notched well ⁽¹⁰⁾ (Fig. 1) were compared to the pressures required to generate vertical cracks⁽¹¹⁾ (Fig. 2). For example, a 600 psi pressure was predicted for initiation of a horizontal fracture in a 150 mm (6 in) diameter well with a 25 mm (1 in) notch at a depth of 61 m (200 ft), while the pressure required to create a vertical fracture ranged from 2100 psi with no flaws in the wellbore to 540 psi for a well with a 6 mm (.25 in) vertical flaw (Fig. 3). Results of calculations made for the 150 mm (6 in) and 250 mm (10 in) diameter hydrofracing wells for this experiment showed that the hydrofracing operation should be conducted from cased wells to minimize the probability of creating vertical fractures.

Figure 4 shows the plan view of the Site 12 experiment. The original well pattern consisted of three central wells used in the creation of the three hydrofractures (these wells would later serve as explosive emplacement/detonation wells), and two rings of observation

wells for monitoring fracture growth and extent. Instrumentation wells were also drilled prior to the hydrofracturing to increase the number of diagnostic measurement locations. Figure 5 shows a section view along an East-West line of the wells.

EXPERIMENT RESULTS

A. Site Preparation

Cores were extracted from the center well (A) and four outlying observation wells (1, 3, 5 and 7) for lithology and stratigraphy studies.⁽¹²⁾ The cores showed that the significant "markers" (tuff lenses, etc.) were located at essentially the same depth over the experiment area and at the same relative position within the Tipton Member as at nearby experiment sites.⁽⁷⁾

The observation wells were drilled and cased to the top of the Tipton Member (55 m (180 ft)) to seal off any aquifers which might exist between the surface and the Tipton Member and then drilled to their final depth. The hydrofracturing wells were drilled and cased to their total depth.

Air acceptance and tracer gas flow tests were conducted to establish the initial formation permeability. A loss of air from the experiment site was noted; investigation disclosed communication between this site and previous experiment sites. Air flow logs were obtained which disclosed existing horizontal fractures at approximately 58.5 m (192 ft) and 65.5 m (215 ft) depths. Depths of 60 m (197 ft), 61.5 m (202 ft) and 63 m (207 ft) were selected for the hydraulic fractures, based on the core analyses and the locations of the natural fractures.

Explosive evaluation tests⁽¹³⁾ were conducted to determine the detonation characteristics of three candidate explosives* in simulated open and sand-propped fractures. The results showed that none of the

*The three candidate explosives tested prior to this experiment were TAL 1005E, GOI-4, and Teledex.

candidate explosives would either detonate or burn when inserted in sand-propped cracks up to 9.4 mm (0.375 in) wide or in open cracks 1.5 mm (1/16 in) wide. The proppant design was therefore modified to include only a partial monolayer of 6-8* sand in the lower two hydraulic fractures. This proppant would hold the cracks open for beginning of the explosive insertion. The cracks would be widened further by the insertion of the explosive under pressure.

B. Hydraulic Fracturing

The three horizontal hydraulic fractures were created using procedures developed in consultation with an oil field service company. The wellbore casing was notched with a 4.8 mm (3/16 in) diameter orifice hydra-jet tool using high velocity gelled water and fine mesh sand. This provided a horizontal cut about 6.3 mm (1/4 in) wide through the casing, grout, and for some distance into the formation. High pressure water was then pumped into the wellbore and through the notch to initiate crack propagation (formation breakdown). Gelled water carrying proppant sand was pumped into the formation according to a predetermined procedure. A "pre-pad" of fine sand was inserted followed by larger sand according to the hydrofracing schedule established for that fracture. The upper fracture was totally propped with sand and the two lower adjacent fractures were propped with a partial monolayer.

Hydrofrac No. 1 - The first hydrofracture was created from Wellbore C at a depth of 61.5 m (202 ft). Formation breakdown (crack initiation) parameters were not recorded but were estimated to have been ≈ 600 psi wellhead pressure and 0.5 bbl/min flow rate. The hydrofracturing continued (the following day) at a pumpline pressure of ≈ 520 psi resulting in a bottom hole pressure of 600 psi. The planned hydrofracing schedule is shown in Table 1. Difficulties with the

*Sand graded in size to pass through a #6 sieve but will not pass through a #8 sieve resulting in sand whose diameter is between about .125 in. and .170 in.

sand-gel blender caused several delays in the hydrofracing, but the total scheduled volumes and flow rates were adhered to.

Diagnostic instrumentation consisting of wellhead pressure gages, pressure gages and flow rate meters in the injection pump lines, in-well hydrophones, and resistivity networks were utilized to determine the growth rate and shape of the hydrofracture. The observation wells were maintained full of water, causing the pressure in each well to rise rapidly when the crack front intersected that well. The wellhead pressure histories, together with the flow rate data permitted "tracking" the growth of the hydrofracture through the intersection of observation wells. The frac fluid flow rate and pumpline pressure versus time are shown in Figures 6 and 7. A composite plot showing the time at which the hydrofrac intersected the outlying wells is shown in Figure 8.

Contours of the fracture front at selected times, Figure 9, show that the growth pattern was nearly circular with a slight preference for more rapid growth to the North. Correlation between fracture extent and accumulative flow indicates that at the time of intersection with the outer wells, the average fracture width was 0.034 inches.

Hydrophones were placed in three of the observation wells to determine whether the arrival of the crack front would generate a unique response. The data showed that the arrival of the crack front with that well could be detected; the results were found to agree with the wellhead pressure data. The resistivity experiment, which has been successfully used in the past to observe hydrofracture growth, was not successful in the test. The well casings were electrically interconnected at the surface by metal plumbing, thus masking the changes in formation resistivity caused by the movement of a conductive fluid through the fracture.

Hydrofrac No. 2 - The second (lower) horizontal hydraulic fracture was made through Wellbore B at a depth of 63 m (206.5 ft).

Difficulty was experienced in achieving an adequate notch in this casing because the crookedness of the wellbore forced the hydrojet against one side of the casing. Initial attempts at hydrofracturing were unsuccessful because of the poor notch and because the bottom of the wellbore became filled with sand to a level above the notch as a result of a limited amount of "rathole". A successful hydrofracture was obtained (i) by using a centralizer to hold the hydrojet tool in the center of the well thereby obtaining a uniform cutting of the casing, grout, and shale; (ii) extending the cutting period, and (iii) by flushing all sand from the wellbore, including that held in suspension, prior to the hydrofracturing process.

Formation breakdown pressure at the 63 m (206.5 ft) level was ≈ 1400 psi compared to the ≈ 600 psi breakdown pressure for the 61.5 m (202 ft) level hydrofracture. Pumpline and frac well pressures were nearly identical--as shown in Figures 10-A and 10-B. Communication with outlying wells was established during the formation breakdown; the communication between outlying wells through the 61.5 m (202 ft) level hydrofracture resulted in essentially identical pressure-time responses at all wells (Fig. 11).

Continuation of the hydrofracturing operation followed the same procedure as for the first hydrofrac, except that the pumping pressure during fracture extension was greater (Fig. 12). Pressures in the observation wells were recorded during the hydrofracing; the presence of the previously made fracture and the establishment of communication during formation breakdown masked the growth rate (Fig. 13). Following creation of the hydrofrac, the formation was shut in overnight; leakage of frac fluid from the immediate area was shown to be negligible (Fig. 14).

Hydrofrac No. 3 - The third (top) hydraulic fracture was formed and sand propped per the schedule of Table II through Wellbore A at a level of 60 m (197.5 ft). A centralizer was again used during the

notching of the well casing. Difficulty was again experienced in obtaining formation breakdown (crack initiation). What was considered to be adequate breakdown pressure was applied several times with no results. A slow crack growth was finally achieved by cycling the pressure from 400 to 1900 psi until a flow rate of 0.5 barrels per minute could be achieved. The flow rate indicated in Table II was maintained until 1200 gallons of fluid had been displaced. Pressure cycling to 1800 psi was then required to attain the desired flow rate of 20 bbl/min. The scheduled fracturing procedure was then resumed and the hydrofracturing continued. The frac fluid flow rate is shown in Figure 15. Pumpline and frac well pressures v.s. time are shown in Figures 16 and 17.

Pressure sensors were again used at outlying wellheads in an attempt to monitor the areal extent of the fracture versus time. The presence of the two previous fractures with the resulting communication between fractures through the wellbores and the slow early crack growth rate again masked the crack growth. Response times at outlying wells are given in Figure 18. Hydrophones were placed in Wells 1 and 9, and the travel of the crack front was monitored acoustically. The results of these hydrophone observations again demonstrated the viability of this measurement technique as a means of observing fracture arrival at outlying wells. Following completion of the hydrofracturing, wellhead pressures were again monitored at outlying wells; frac fluid loss was again shown to be negligible (Fig. 19).

An experiment was conducted during the creation of the third (top) hydrofracture to determine the effectiveness of surface tiltmeters in tracking the crack propagation. An array of tiltmeters was placed around the site for measuring surface tilt during the fracturing procedure. Surface lift (Fig. 20) was obtained from the measured tilt shown in Figure 21. The width of the crack at the wellbore was also determined from the surface lift data (Fig. 22). The shape of the crack growth contours is shown by the directional vectors of the tiltmeters. Using

these data and the accumulative fluid volume injected, the crack growth was predicted. Preliminary results⁽¹⁴⁾ showed that the crack propagation indicated by the tilt measurements was nearly circular with emphasis toward the North.

C. Formation Evaluation

Air acceptance and flow tests and tracer flow tests were conducted following the creation of each hydrofracture to determine the change in airflow characteristics. Air was found to flow freely through the hydraulic fractures between all wells except Wells 5, 6, and 7, where nearly all the flow was through the pre-existing "natural" fracture at a depth of 65.5 m (215 ft). No evidence was noted of increased permeability between the horizontal fractures which would indicate the presence of branched and/or vertical fractures.

Airflow logging of the observation wells was performed following the first (61.5 m (202 ft) level) hydrofracture using an impeller type tool with a photo-optic sensor to measure the level at which air flowed into each wellbore from the fractures. Poor determination of the crack levels was achieved because of leakage of air around the wiper system and slippages in the cable counter used to determine the crack level each time the tool was moved. Water flow logging of the wells was performed following the second hydrofracture. More accurate determination of the fracture levels was achieved by measuring and mechanically marking the wireline and using a rubber wiper system. Crack locations were determined from the change in the accumulative flow rate. The presence of two hydraulic fractures plus the pre-existent fracture at a lower level led to the need for very large total flow in order to obtain a measurable differential flow at a given crack level. The depths of the first two hydraulic fractures were located with reasonable accuracy in all observation wells except Wells 5, 6, and 7, where virtually all the flow was again observed to be through the pre-existent lower level fracture.

The flow logging tool wiper system was modified so that the flow coming into the well between two wipers could be measured directly, while the flow from lower cracks bypassed the sensor (Fig. 22). The flow from a particular entry point was thus isolated. This system was useful for identifying entry points with low flow. Absence of entry flow between the horizontal fracture locations indicated the absence of a vertical fracture. Water flow logging using the differential flow wiper system was repeated following the creation of the third hydrofracture. The intersection of the three hydrofractures and the two pre-existent fractures were found in nearly all the wells and no evidence of vertical fractures were noted.

A television camera lowered into the wellbore was also used to locate the hydrofractures and to resolve ambiguous flow logging results. Forcing air through the hydrofracture from the hydrofracing well increased the visibility of the hydrofractures. No vertical fractures were noted by TV logging.

Impression packers were used in three wells to obtain a more accurate determination of the crack levels and widths. Multiple and angle cracks noted during TV logging were confirmed by the impression packers.

An auxiliary experiment was conducted to determine whether the depth of the intersection of the lower fractures with Well A could be accurately located through the casing. A background gamma log was made of Well A prior to hydrofracturing. Near the end of the propping operations of the first two hydrofractures, a small amount of 8-12* mesh sand coated with Scandium 41 was inserted into the fractures. Post-fracture gamma logs clearly showed the presence of the radioactive sand outside the well casing (Figs. 24 & 25). The fracture depths were determined within ± 19 mm (0.75 in).

The results of the logging were collated to establish the hydrofracture profiles through the test area. The three hydraulic fractures were found to be reasonably horizontal. No significant branching was noted.

*Sand graded in size to pass through a #8 sieve but will not pass through a #12 sieve resulting in sand whose diameter is between .08 in. and .125 in.

The hydrofractures did not intersect each other or the pre-existing horizontal cracks in the vicinity of the well pattern. A section view of the hydrofractures in the East-West direction is shown in Fig. 26.

CONCLUSIONS

The results of the experiment show that:

1. Closely spaced horizontal hydraulic fractures can be created in an oil shale formation.
2. Hydrofracing from cased wells minimizes the likelihood of initiating vertical fractures because of wellbore flaws.
3. A combination of special logging procedures are required to characterize the hydrofractures and evaluate the fractured formation.
4. The experiment objectives of creating three closely spaced horizontal fractures and of characterizing the fractures sufficiently to permit accurate placement of instruments for the next phase of the program were met.

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TABLE I
FLUID-PROPPANT SAND SCHEDULE FOR
THE PARTIAL MONOLAYER TYPE HYDROFRACTURES

VOLUME GAL.	DESCRIPTION	--PROPPANT--		--ADDITIVES--	
		SIZE	CONC. #/GAL	TYPE	CONC. #/M GAL
1,200	Pre-Pad @ 0.5 BPM	--	--	MYF-1 GBW-3	25 0.125
4,200	Pre-Pad @ 20 BPM	--	--	MYF-1 GBW-3 70-170 Sand	25 0.125 2000
6,000	Pad (MY-T-GEL ^R I Fluid) @ 20 BPM	--	--	WAC-9 GBW-3	25 0.5
1,000	MY-T-GEL @ 20 BPM	8-12	1.0	WAC-9 GBW-3	25 0.5
2,000	MY-T-GEL @ 20 BPM	8-12	2.0	WAC-9 GBW-3	25 0.75
1,000	MY-T-GEL @ 20 BPM	6-8	1.0	WAC-9 GBW-3	25 1.0
2,000	MY-T-GEL @ 20 BPM	6-8	2.0	WAC-9 GBW-3	25 1.0
<u>800</u>	Flush	--	--	--	--
18,200					

TABLE II
FLUID-PROPPANT SCHEDULE FOR
THE SAND-PROPPED HYDROFRACTURE

VOLUME GAL.	DESCRIPTION	--PROPPANT--		--ADDITIVES--	
		SIZE	CONC. #/GAL	TYPE	CONC. #/M GAL
1,200	Pre-Pad @ 0.5 BPM	--	--	MYF-1 GBW-3	25 0.125
4,200	Pre-Pad @ 20 BPM	--	--	MYF-1 GBW-3 70-170 Sand	25 0.125 2000
5,200	Pad (MY-T-GEL ^R) @ 20 BPM	--	--	WAC-9 GBW-3	25 0.5
1,100	MY-T-GEL @ 20 BPM	10-20	1.0	WAC-9 GBW-3	25 0.5
1,100	MY-T-GEL @ 20 BPM	10-20	2.0	WAC-9 GBW-3	25 0.75
1,200	MY-T-GEL @ 20 BPM	10-20	3.0	WAC-9 GBW-3	25 0.75
1,200	MY-T-GEL @ 20 BPM	8-12	2.0	WAC-9 GBW-3	25 1.0
1,200	MY-T-GEL @ 20 BPM	8-12	3.0	WAC-9 GBW-3	25 1.0
1,000	MY-T-GEL @ 20 BPM	8-12	4.0	WAC-9 GBW-3	25 1.0
<u>500</u>	Flush	--	--	--	--
18,000

FIGURE 1. SIMULATION OF THE NOTCHED WELLBORE USED FOR THE INITIATION OF HORIZONTAL HYDRAULIC FRACTURES (FROM KERR(10)).

FIGURE 2. BOUNDARY COLLOCATION METHOD FOR PREDICTION OF VERTICAL CRACK PROPAGATION (FROM NEWMAN(11)).

FIGURE 3. PRESSURES REQUIRED TO INITIATE VERTICAL AND HORIZONTAL FRACTURES V.S. FLAW SIZE AT A DEPTH OF 61 m (200 ft.) IN A 150 mm (6 in.) DIAMETER UNCASD WELLBORE.

FIGURE 4. PLAN VIEW OF SITE 12 WELLBORE PATTERN

FIGURE 5. SECTION VIEW ALONG EAST-WEST LINE OF THE SITE 12 WELLBORE PATTERN.

FIGURE 6. FRAC FLUID FLOW RATE V.S. TIME, CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE 7. PUMP LINE PRESSURE V.S. TIME
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 AM), DAY 138

FIGURE 8. COMPOSITE PLOT WELLHEAD PRESSURE V.S. TIME
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 $T_0 = 640$ MINUTES (10:40 AM) DAY 138

CONTOUR ID	TIME (MINUTES)	
	FROM START	FROM START PRE-PAD
a	6.50	0.83
b	7.17	1.50
c	8.00	2.33
d	10.10	4.43
e	10.42	4.75
f	10.77	5.10
g	11.67	6.00
h	13.00	7.33
i	14.09	8.42
j	17.84	12.17
k	18.00	12.33
l	19.00	13.33

FIGURE 9. CRACK GROWTH CONTOURS FOR
FIRST (61.5 M) SITE 12 HYDROFRACTURE

FIGURE 10A. PUMP LINE PRESSURE V.S. TIME
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE 10B. WELLHEAD PRESSURE V.S. TIME - WELL E
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE 11. COMPOSITE PLOT WELLHEAD PRESSURE VS TIME
FORMATION BREAKDOWN-LOWER (206.5 FT) HYDROFRAC
START TIME AT T=1200 MINUTES (8:00 AM) DAY 161

FIGURE 12A. PUMPLINE PRESSURE V.S. TIME-CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE 12B. WELLHEAD PRESSURE V.S. TIME-WELL B, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE 13. COMPOSITE PLOT WELLHEAD PRESSURE V.S. TIME
 CREATION OF LOWER (206.5 FT) HYDROFRAC
 START TIME A T = 500 MINUTES (8:20 AM) DAY 162

FIGURE 14. COMPOSITE PLOT WELLHEAD PRESSURE VS TIME
FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC
START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE 15. FRAC FLUID FLOW RATE V.S. TIME
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 P.M.) DAY 179

FIGURE 16. PUMP LINE PRESSURE V.S. TIME
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 PM)
DAY 179

FIGURE 17. WELLHEAD PRESSURE V.S. TIME, WELL A
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE 18. COMPOSITE PLOT WELLHEAD PRESSURE VS TIME
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE 19. COMPOSITE PLOT WELLHEAD PRESSURE VS TIME
FORMATION SHUTIN FOLLOWING CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE 20. SURFACE UPLIFT RESULTING FROM 200 psi PRESSURE ABOVE LITHOSTATIC.

FIGURE 21. SURFACE TILT MEASURED AT VARIOUS TIMES (PRESSURE) DURING THE HYDROFRACTURE AT SITE 12.

FIGURE 22. METHOD OF INFERRING FRACTURE WIDTH FROM SURFACE LIFT, DEPTH OF FRACTURE, AND FRACTURE RADIUS. (FROM SCHMIDT)

FIGURE 23. FLOW LOGGING TOOL SCHEMATIC ILLUSTRATING ACCUMULATIVE AND DIFFERENTIAL FLOW MEASUREMENT.

FIGURE 24. RESULTS OF GAMMA LOGGING TO DETECT 61.5 m HYDROFRACTURE LEVEL AT WELL A.

FIGURE 25. FRACTURE LOCATION BY GAMMA LOGGING

FIGURE 26. HYDRAULIC FRACTURE ELEVATIONS IN EAST-WEST DIRECTION DERIVED FROM WELLBORE LOGGING DATA.

APPENDIX A

61.5 m (202 FT) HYDROFRACTURE

The 61.5 m (202 ft) level hydraulic fracture was created from Well-bore C by cutting a notch through the well casing, grout, and out into the formation at the desired level, pressurizing the notched region sufficiently to achieve crack propagation (formation breakdown), and injecting gelled water carrying proppant sand into the fracture to continue the hydrofracturing procedure. Frac fluid flow rates, pumpline pressures, and wellhead pressures were recorded as a function of time during fracture creation on a PDP-11 minicomputer. Pressure at the outlying wellheads were also recorded manually as a means of direct observance of the fracturing progress. Plots of the data recorded during the hydrofracture creation are provided herein.

Formation breakdown events, performed the day prior to the creation of the hydrofrac, were not recorded. The breakdown pressure was estimated to be 600 psi. The data taken during hydrofracture creation indicated that limited communication had been established to Wells 9 and DD during formation breakdown.

Water pumping to pressurize the frac well (Well C) was started at $T = 645$ minutes (10:45 a.m.), on day 138 (May 18, 1977) (Figures A1 and A2). Fracturing was started at $T = 650.23$ minutes at an average rate of 0.5 bbls/min. The prepad sand was started at $T = 655.9$ minutes and continued at an average rate of 0.9 bbl/min until 1200 gallons of fluid had been inserted.

The intercept of the hydrofracture with each well was noted by a step increase in wellhead pressure. The hydrofrac was shown (Figs. A3 - A16) to have intersected all outlying wells during the pre-pad insertion. Correlation between fracture extent and accumulative flow

indicates that at the arrival of the hydrofrac with the outer wells, the average fracture width was 0.034 inches.

Fluctuations in the well pressures (with the exception of Wells 1, 3, 5 and 7 where the gage limit of 200 psi was exceeded) at later times correspond to pumping periods and shut-in periods caused by blender problems. The wellhead pressure data thus reflects the continuing events.

FIGURE A1. FRAC FLUID FLOW RATE V.S. TIME, CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A2. PUMP LINE PRESSURE V.S. TIME
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 AM), DAY 138

FIGURE A3. WELLHEAD PRESSURE V.S. TIME - WELL 2
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A4. WELLHEAD PRESSURE V.S. TIME - WELL 1
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A5. WELLHEAD PRESSURE V.S. TIME - WELL 4
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A6. WELLHEAD PRESSURE V.S. TIME - WELL 3
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A7. WELLHEAD PRESSURE V.S. TIME - WELL 6
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A8. WELLHEAD PRESSURE V.S. TIME - WELL 5
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A9.. WELLHEAD PRESSURE V.S. TIME - WELL 8
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A10. WELLHEAD PRESSURE V.S. TIME - WELL 7
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A11. WELLHEAD PRESSURE V.S. TIME - WELL AA
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A12. WELLHEAD PRESSURE V.S. TIME - WELL 9
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A13. WELLHEAD PRESSURE V.S. TIME - WELL CC
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A14. WELLHEAD PRESSURE V.S. TIME - WELL BB
 CREATION OF MIDDLE (202 FT) HYDROFRAC
 To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A15. WELLHEAD PRESSURE V.S. TIME - WELL EE
CREATION OF MIDDLE (202 FT) HYDROFRAC
To = 640 MINUTES (10:40 A.M.), DAY 138

FIGURE A16. WELLHEAD PRESSURE V.S. TIME - WELL DD
CREATION OF MIDDLE (202 FT) HYDROFRAC
To = 640 MINUTES (10:40 A.M.), DAY 138

APPENDIX B

63 m (206.5 FT) HYDROFRACTURE

The 63 m (206.5 ft) level hydrofracture was created from Well B following the same procedures as were performed from Well C (Appendix A), except that the pressure and flow data were recorded on a data logger. Figures B1 through B52 depict the responses recorded during the hydrofracturing events.

Formation breakdown was performed during the evening prior to hydrofracture creation. During formation breakdown, communication was established with at least one outlying well. The communication between all wells through the previously created 61.5 m (202 ft) level hydrofracture resulted in near identical pressure-rise times at all wellheads, as shown in Figures B3 - B18. Formation shut-in following breakdown showed only a slight pressure drop in the formation.

The 63 m (206.5 ft) level hydrofrac was started at T = 507 minutes (8:27 a.m.), on day 162 (June 9, 1977). An immediate increase in pressure at all wellheads was noted, followed by gradual rise in pressure indicating the uniform pressurization of the formation (Figs. B19 - B36). The hydrofracture growth could not be determined by the pressure-time histories. Pressures at Wells 1, 3, 5 and 7 exceeded the 200 psi gage limit; the pressure-rise times at all other wells were essentially identical.

Formation shut-in pressures were also recorded (Figs. B37 - B52). As shown, essentially no pressure drop was noted. This indicated that there was little, if any, leakage of frac fluid from the experiment area, i.e., no communication through the 61.5 m or 63 m fractures from this site to other experiment sites.

FIGURE B1. PUMP LINE PRESSURE V.S. TIME
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B2. WELLHEAD PRESSURE V.S. TIME - WELL E
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B3. WELLHEAD PRESSURE V.S. TIME - WELL C
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161.

FIGURE B4. WELLHEAD PRESSURE V.S. TIME - WELL 1
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B5. WELLHEAD PRESSURE V.S. TIME - WELL 2
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC.
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161.

FIGURE B5. WELLHEAD PRESSURE V.S. TIME - WELL 3
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B7. WELLHEAD PRESSURE V.S. TIME - WELL 4
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B8. WELLHEAD PRESSURE V.S. TIME - WELL 5
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B9. WELLHEAD PRESSURE V.S. TIME - WELL 6
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B10. WELLHEAD PRESSURE V.S. TIME - WELL 7
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B11. WELLHEAD PRESSURE V.S. TIME - WELL 8
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B12. WELLHEAD PRESSURE V.S. TIME - WELL 9
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B13. WELLHEAD PRESSURE V.S. TIME - WELL AA
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B14. WELLHEAD PRESSURE V.S. TIME - WELL BB
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B15. WELLHEAD PRESSURE V.S. TIME - WELL CC
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B16. WELLHEAD PRESSURE V.S. TIME - WELL DD
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B17. WELLHEAD PRESSURE V.S. TIME - WELL EE
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B19. WELLHEAD PRESSURE V.S. TIME - WELL A
FORMATION BREAKDOWN - LOWER (206.5 FT) HYDROFRAC
START TIME AT T = 1200 MINUTES (8:00 PM) DAY 161

FIGURE B19. PUMPLINE PRESSURE V.S. TIME-CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B20. WELLHEAD PRESSURE V.S. TIME-WELL B, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B21. WELL HEAD PRESSURE V.S. TIME-WELL C, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B22. WELL HEAD PRESSURE V.S. TIME-WELL I, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B23. WELL HEAD PRESSURE V.S. TIME-WELL 2, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B24. WELL HEAD PRESSURE V.S. TIME-WELL 3, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B25. WELL HEAD PRESSURE V.S. TIME-WELL 4, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B26. WELL HEAD PRESSURE V.S. TIME-WELL 5, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B27. WELL HEAD PRESSURE V.S. TIME-WELL 6, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B28. WELL HEAD PRESSURE V.S. TIME-WELL 7, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B29. WELL HEAD PRESSURE V.S. TIME-WELL 8, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B30. WELL HEAD PRESSURE V.S. TIME-WELL 9, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B31. WELL HEAD PRESSURE V.S. TIME-WELL AA, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B32. WELL HEAD PRESSURE V.S. TIME-WELL BB, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B33. WELL HEAD PRESSURE V.S. TIME-WELL CC, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B34. WELL HEAD PRESSURE V.S. TIME-WELL DD, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B35. WELL HEAD PRESSURE V.S. TIME-WELL EE, CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B36. WELL HEAD PRESSURE V.S. TIME-WELL A CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=500 MINUTES (8:20 AM) DAY 162

FIGURE B37. WELLHEAD PRESSURE V.S. TIME-WELL C, FORMATION SHUTIN
FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC
START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B38. WELLHEAD PRESSURE V.S. TIME-WELL 1, FORMATION SHUTIN
FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC
START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B39. WELLHEAD PRESSURE V.S. TIME-WELL 2, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162.

FIGURE B40. WELLHEAD PRESSURE V.S. TIME-WELL 3, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B41. WELLHEAD PRESSURE V.S. TIME-WELL 4, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162.

FIGURE B42. WELLHEAD PRESSURE V.S. TIME-WELL 5, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162.

FIGURE B43. WELLHEAD PRESSURE V.S. TIME-WELL 6, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162.

FIGURE B44. WELLHEAD PRESSURE V.S. TIME-WELL 7, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B45. WELLHEAD PRESSURE V.S. TIME-WELL 8, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162.

FIGURE B46. WELLHEAD PRESSURE V.S. TIME-WELL 9, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B47. WELLHEAD PRESSURE V.S. TIME-WELL AA, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B48. WELLHEAD PRESSURE V.S. TIME-WELL BB, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B49. WELLHEAD PRESSURE V.S. TIME-WELL CC, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B50. WELLHEAD PRESSURE V.S. TIME-WELL DD, FORMATION SHUTIN FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B51. WELLHEAD PRESSURE V.S. TIME-WELL EE, FORMATION SHUTIN
FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC
START TIME AT T=560 MINUTES (9:20 AM) DAY 162

FIGURE B52. WELLHEAD PRESSURE V.S. TIME-WELL A, FORMATION SHUTIN
FOLLOWING CREATION OF LOWER (206.5 FT) HYDROFRAC
START TIME AT T=560 MINUTES (9:20 AM) DAY 162

APPENDIX C

60 m (197.5 FT) HYDROFRACTURE

The lower two (61.5 m and 63 m levels) hydrofractures were created from Wells C and B and propped with a partial monolayer of sand to accept the explosive slurry that would be used to fracture the shale bed. This hydrofracture, created from Well A, was totally propped with standard propping sand. Pressures and flows were again recorded during the hydrofracturing; the responses are shown in Figures C1 through C32.

Formation breakdown and hydrofracture creation were executed as one operation. Difficulty was experienced in achieving formation breakdown; pressure was applied several times with no results. A very slow crack growth was finally achieved by cycling the frac well pressure up to about 1900 psi until the desired flow rate of 0.5 bbls/min was achieved. Pressure cycling was again required following the insertion of the prepad sand to increase the flow rate to 20 bbl/min. A nine-minute shut-in to adjust equipment was experienced soon after breakdown was established.

The pressure histories showed a similar gradual increase at all wells following the beginning of frac fluid flow (Figs. C4 - C18). This was caused by the wells being interconnected by the previously created hydrofractures. Thus, the hydrofracture growth could not be determined from wellhead pressure rise times.

Wellhead pressures were again recorded during post-fracturing formation shut-in. These data (Figs. C19 - C32) indicate that there was no loss of frac fluid and presumably no connection of the three hydrofractures with adjacent experiment sites.

FIGURE C1. FRAC FLUID FLOW RATE V.S. TIME
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 P.M.) DAY 179

FIGURE C2. PUMP LINE PRESSURE V.S. TIME
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 PM)
DAY 179

FIGURE C3. WELLHEAD PRESSURE V.S. TIME, WELL A
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C4. WELLHEAD PRESSURE V.S. TIME, WELL C
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C5. WELLHEAD PRESSURE V.S. TIME, WELL 1
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C6. WELLHEAD PRESSURE V.S. TIME, WELL 2
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C7. WELLHEAD PRESSURE V.S. TIME, WELL 3
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C8. WELLHEAD PRESSURE V.S. TIME, WELL 4
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C9. WELLHEAD PRESSURE V.S. TIME, WELL 5
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C10. WELLHEAD PRESSURE V.S. TIME, WELL 6
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C11. WELLHEAD PRESSURE V.S. TIME, WELL 7
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C12. WELLHEAD PRESSURE V.S. TIME, WELL 8
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C13. WELLHEAD PRESSURE V.S. TIME, WELL 9
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C14. WELLHEAD PRESSURE V.S. TIME, WELL AA
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C15. WELLHEAD PRESSURE V.S. TIME, WELL BB
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C16. WELLHEAD PRESSURE V.S. TIME, WELL CC
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C17. WELLHEAD PRESSURE V.S. TIME, WELL DD
 CREATION OF UPPER (197.5 FT) HYDROFRAC
 START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C18. WELLHEAD PRESSURE V.S. TIME, WELL EE
CREATION OF UPPER (197.5 FT) HYDROFRAC
START TIME AT T=740 MINUTES (12:20 PM) DAY 179

FIGURE C19. WELLHEAD PRESSURE V.S. TIME-WELL 1
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C20. WELLHEAD PRESSURE V.S. TIME-WELL 2
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C21. WELLHEAD PRESSURE V.S. TIME-WELL 3
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C22. WELLHEAD PRESSURE V.S. TIME-WELL 4
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C23. WELLHEAD PRESSURE V.S. TIME-WELL 5
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C24. WELLHEAD PRESSURE V.S. TIME-WELL 6
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C25. WELLHEAD PRESSURE V.S. TIME-WELL 7
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C26. WELLHEAD PRESSURE V.S. TIME-WELL 8
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C27. WELLHEAD PRESSURE V.S. TIME-WELL 9
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C28. WELLHEAD PRESSURE V.S. TIME-WELL AA
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C29. WELLHEAD PRESSURE V.S. TIME-WELL BB
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C30. WELLHEAD PRESSURE V.S. TIME-WELL CC
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C31. WELLHEAD PRESSURE V.S. TIME-WELL DD
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

FIGURE C32. WELLHEAD PRESSURE V.S. TIME-WELL EE
FORMATION SHUTIN FOLLOWING CREATION OF UPPER
(197.5 FT) HYDROFRAC.
START TIME AT T=860 MINUTES (2:20 PM) DAY 179

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