AN APPLICATION OF DELAYED BORATE CROSSLINKED FRACTURING FLUIDS IN THE PEGASUS (DEVONIAN) FIELD

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A typical Devonian completion has a depth of 12,000 ft and bottomhole temperature of 200°F. The 1990 Pegasus (Devonian) program consisted of completing 11 wells and was the beginning of a major field development. The projected overall Devonian Program calls for drilling and completing approximately 93 wells over the next 8 to 10 years. Because the Devonian is a large developmental program, it was recognized that stimulation effectiveness would be a key factor in the project's success.

The fracturing fluid used in the Devonian prior to the 1990 program consisted mainly of titanate crosslinked HPG. Recent fracture conductivity data have indicated titanates can damage the proppant pack conductivity by as much as 90%. Borate crosslinked fracturing fluids have been demonstrated to be less damaging than the titanate fluid system. Fracture conductivity data for the borate crosslinked fluid systems show only 10 to 20% proppant pack damage. A delayed borate fluid system was formulated that provided the desired viscosity, proppant transport, and break characteristics for successful stimulation of the Devonian formation.

This paper will discuss the design/fluid parameters used to formulate the delayed borate fluid system. Laboratory testing techniques and resultant data will be provided and reviewed. Included in this discussion will be a review of the test techniques associated with delayed release breakers (encapsulated breakers). On-site quality control testing of the fluid system will be discussed and important fluid parameters that can be monitored will be identified. Case histories with production results will be provided.

The importance of pretesting and on-site quality control testing as related to borate crosslinked fracturing fluids also is discussed. Many engineers have the opinion that borate crosslinked fracturing fluids are simplistic fluids. This results in many unsuccessful borate treatments.

INTRODUCTION

The Pegasus Devonian Field, which is located approximately 20 miles south of Midland, TX, on the Midland/Upton County line, was discovered June 19, 1952 with the completion of the J.D. Windham "16" #4 (Fig. 1). Based on an initial low gas oil ratio (GOR), the Pegasus Devonian was classified as an oil reservoir. Early development of the field consisted of drilling six producers from 1954 to 1963, resulting in a total production rate of 200 barrels of oil per day (BOPD).

By 1963, the Devonian was recognized as a gas condensate reservoir and re-cycling of produced gas resulted in greater ultimate recovery of condensate. As a result, the field was reclassified as a nonassociated gas reservoir, a unit was established, and two wells were converted to gas injection. From 1964 to 1966, five additional gas injection wells were drilled to form a 320-acre inverted nine-spot pattern. During this time, several wells were also recompleted to the Devonian from other producing horizons.

From the mid-1960's to 1989, there was little additional development within the Devonian. During 1987, Mobil's Geology and Reservoir Engineering Department initiated a field characterization study of the Devonian which included remapping the field using porosity logs and a fluid characterization study. As a result of this study, additional pore volume was identified and an 80-acre inverted five-spot pattern was chosen for full field development.

The development of the Devonian reservoir to an 80-acre (per well) inverted five-spot pattern began in 1989 with the drilling of two gas injection wells. Data gathered from these wells confirmed the findings of the study. Based on the positive results from the first two wells, six additional producers and five gas injection wells (Fig. 2) were proposed for 1990. The six producers were completed during the first half of 1991 and initial potentialed (IP) at an average rate of 133 BOPD and 2.61 million standard cubic feet per day (MMSCFPD).

FORMATION LITHOLOGY

Prior to 1987, the Pegasus Devonian reservoir was presumed to be a homogeneous, laterally continuous, fractured chert. The current 1987 to 1991 reservoir description and simultaneous drilling program indicate that the Devonian reservoir is more complex than originally assumed. There is substantial lateral and vertical discontinuity in the Pegasus Devonian section because of faulting, porosity truncation, and permeability variation.

Core data show that the Devonian interval is a vertically stratified section of limy chert that comprises Brown Chert, Transitional Banded Chert, Mottled Blue Chert, and White (Tripolitic) Chert facies. Nearly all of the net pay is found in the Brown and White Chert lithologies which are composed of chert with high intercrystalline microporosity and very low lime content.

The Devonian structure map (Fig. 3) shows an elongated high that is oriented roughly north to south, with major high-angle faults along the east and west flanks. Lateral sealing capacity of these faults has not been determined. The structure can be divided into north, central, and south domes.

FIELD POTENTIAL

The reservoir is proposed to be developed on an 80-acre (per well), five-spot pattern to maximize areal sweep efficiency and the amount of continuous pay from injector to producer. This will consist of drilling and/or recompleting 93 producers and injectors over the next 8 to 10 years. The closer spacing would also reduce the time to injection response. Analogous reservoirs in the area have been developed on 80-acre spacing with sweet spots drilled to 40-acre spacing. The infill drilling program of both analogous projects has been successful, with many of the infill wells yielding good production rates with nearly original GOR's and pressures.

DEVONIAN STIMULATION BACKGROUND

Approximately 50 wells were completed and fracture stimulated in the Pegasus Devonian from the late 1950's to the early 1970's. The fracture stimulations consisted primarily of gelled brine water carrying a maximum of 1 1/2 lb/gal of 20/40 sand.

Recent completions occurred in 1989 when two pilot wells were drilled. The Brown and White Chert were fracture stimulated together in one well, while in the other, they were treated individually. Titanate and zirconate crosslinked systems were used along with a 50 lb HPG gel system. Recent fracture conductivity studies[1-6] indicate that titanate and zirconate crosslinked fluid systems are more damaging than borate crosslinked fluid systems. With this data in mind, a borate system was examined for use in the Pegasus Devonian 1990 program.

PRE-FRAC FLUID DESIGN PARAMETERS

Numerous authors have recently published results from laboratory studies regarding the chemistry of borate fluids.[6-12,14] The viscosity of borate crosslinked fluids is affected by the following parameters: (1) concentration of polymer, (2) concentration of crosslinking agent, (3) final crosslinked fluid pH, (4) addition of gel stabilizer, (5) addition of gel breakers, and (6) temperature. With regard to the Pegasus Devonian stimulation treatment, two criteria had to be established before the borate fluid would be considered for use:

1. All fluids had to contain adequate concentrations of breaker to be sure that the crosslinked fluid would be reduced to the viscosity of less than 10 centipoise (cp).

2. It had to be demonstrated that the delayed borate crosslinked fluid system containing breakers maintained 200 centipoise viscosity at 170 seconds^{-1} shear rate after two hours at 200°F.

LABORATORY TEST PROCEDURES

Equipment and Instrumentation

Borate crosslinked fluids are difficult to evaluate in the laboratory because of their shear thickening, viscoelastic behavior. Various investigators have used pipe viscometers,[11] capillary viscometers,[13] dynamic oscillatory measurements,[12,15] and rotational viscometers[10,16] in attempting to describe the rheological characteristics of borate crosslinked fluids. In this investigation, a rotational viscometer (Fann Model 50 viscometer) was used to describe the viscosity of the crosslinked borate fluids. The Fann Model 50 viscometer is a computerized unit which provides ease of test control and accurate data acquisition. The Fann Model 50 viscometer is equipped with a B5 extended bob and R1 sample cup. The B5 extended bob minimizes the fluid below the bob and appears to reduce the introduction of crosslinked fluid into the bob-cup gap during the testing.

The experimental setup also included the use of a Jabsco pump preconditioning device to simulate the shear induced in the fluid while it is being mixed and pumped downhole through the tubular goods. The preconditioning time with the Jabsco pump arrangement was four minutes with the crosslinker addition occurring after 25 seconds of initial circulation. The crosslinker was added over a five-second interval.

Selection of Fluids and Test Conditions

The polymer gelling agent type and concentration chosen were 40 lb guar/Mgal in 2% KCl Duncan, OK tap water. The polymer was added as liquid gel concentrate and not in dry powder form because a liquid gel concentrate will be used in field operations. A weak acid was selected to hydrate the base gel and was used at a concentration of 0.15 gal/Mgal. This typically reduced the base gel fluid pH to approximately 6.8. Sodium hydroxide (25% by weight solution) was used at a concentration of 0.5 to 0.75 gal/Mgal to achieve a final base gel pH of 11.0 to 11.1. The delayed borate crosslinker was added at a concentration of 1.2 gal/Mgal. Upon addition of the borate crosslinker, the final fluid pH decreased to the desired pH range of 10.0 to 10.2. Delayed release breakers (DRB) were evaluated at concentrations ranging from 0.1 to 0.5 lb/Mgal.

Fluid Testing Procedures

A 1000 ml volume of the base gel (minus the breaker) using the chemicals listed above was prepared with a Waring blender arrangement. The base gel was allowed to hydrate for a minimum of 30 minutes. After the 30-minute hydration period, the viscosity was measured with a Fann Model 35 viscometer, and the pH was measured with a portable pH meter to ensure that the desired base gel fluid properties were achieved. A 250 ml volume of the base gel was then circulated through the Jabsco pump equipment to remove any impurities or contaminants (residual water, etc.) from the system. The remaining 750 ml base fluid was then placed in the Jabsco pump setup. The DRB was sprinkled in the reservoir containing the base fluid at this point in the initial investigations. Later, during these laboratory studies, the breaker was added 15 seconds before completing the preconditioning of the crosslinked fluid system. In the final test series, the DRB were added directly into the R1 sample cup of the Fann Model 50 viscometer.

The Jabsco pump system was purged to remove all excess air, and the motor speed was set at the 100% setting. The base gel was circulated for 30 seconds and then the delayed borate crosslinker was added. An additional three minutes and 30 seconds of shear on the Jabsco pump was conducted. The borate crosslinked fluid was discharged from the Jabsco pump assembly into a large beaker. Immediately, 35 ml of fluid was withdrawn by means of a 60 ml syringe, placed in a R1 sample cup, and placed on a Model 50 Fann viscometer. The cup RPM was set to 95, and the heating bath, which had been preheated to 200°F, was raised or placed around the sample. The fluid remained on the instrument for four hours or until the fluid was broken. A broken fluid was defined as a fluid having an apparent viscosity value of less than 10 centipoise at 170 seconds.$^{-1}$ The authors felt that a fluid with this viscosity would be broken under downhole conditions following dilution with connate water and chemical interactions with formation, etc., to lower the pH of the fluid system.

RESULTS AND DISCUSSION

Several delayed borate fluid formulations were examined. Initially, problems with obtaining reproducible data were observed when the DRB was added to the base fluid on the Jabsco pump. In the 750 ml volumes, the amount of DRB added when concentrations of 0.1 to 0.5 lb/Mgal were required meant the addition of 0.009 to 0.0045 g of solids. Weighing out such minute quantities of particles ranging in size from 20 to 30 mesh was difficult; however, the problem was further aggravated by the fact that only 35 ml of borate crosslinked fluid was used in the Fann Model 50 viscometer studies. The removal of the 35 ml from the 750 ml volume resulted in some severe sampling errors. Figures 4 and 5 illustrate how difficult this sampling problem was. With two different experiments containing DRB's, the fluids appeared to have little or no DRB present when compared to a delayed borate crosslinked fluid containing no breakers. At 200°F, fluids containing

0.2 and 0.4 lb/Mgal of DRB should have shown a more significant decrease in fluid viscosity after four hours.

The alternate procedural method used when evaluating the DRB was to add the material directly to the R1 sample cup used in Model 50 testing. With a fluid volume of 35 ml this meant that 2 to 4 granules would be required to be placed in the cup with the fluid to be evaluated. Thus, 17 ml of the preconditioned fluid were placed in the R1 sample cup followed by the addition of the DRB and then the remaining 18 ml of borate crosslinked fluid. Using this technique, one may not have exactly 0.1, 0.2, or 0.4 lb/Mgal DRB; however, the effect of increasing concentration of DRB under a given set of conditions may be observed. Figure 6 illustrates the fluid viscosity curves obtained with the different loadings of DRB.

From the data in Fig. 6, it was decided that 0.1 lb/Mgal DRB would be added to the PAD fluid. As the fluid in the fracture cooled, the amount of DRB would be increased, and at the end of the stimulation treatment a minimum of 0.4 to 0.5 lb DRB would be incorporated in the fracturing fluid.

JOB TREATMENT/QUALITY ASSURANCE PROGRAM

Pretesting on Location

Mobil has a strong commitment to a quality assurance program and requires testing and evaluations on location before and during a stimulation treatment. The pretesting in the laboratory indicated the importance of proper base gel and crosslink fluid pH and crosslinker and breaker concentrations. Before performing the stimulation treatment, source water needed to be obtained to determine the appropriate buffer concentrations required to obtain similar base, crosslink, and final pH values, as with the Duncan, OK tap water used in the laboratory tests. Table 1 contains the complete water analysis conducted on waters before determining the buffer concentrations. Samples of water were obtained from the 14 frac tanks on location at the Pegasus (Devonian) field as they were being filled with the fresh water. There appeared to be nothing out of the ordinary noticed with the waters in the respective frac tanks. Tanks 13 and 14 were noted to have significantly higher chloride contents than the other tanks; however, no problems were expected from this level of chlorides. Fourteen tanks were batch mixed on location before the stimulation treatment. All tanks were monitored for fluid temperature, pH level before buffer and polymer addition, pH level of base gel fluid after buffer and polymer addition, and Fann Model 35 viscometer values after base gel preparation. The data have been summarized in Table 2. The crosslink or vortex close time was also determined for each tank of base fluid and recorded in Table 2. Useful information from Table 2 is as follows:

- After addition of all buffers to base fluids the base gel pH is consistently between 11.0 to 11.3. This matched results observed in the laboratory testing where base gel pH was 11.0.

- Base gel viscosities of the 40 lb guar base fluid/Mgal were consistent for the 12 frac tanks mixed. Apparent viscosity values were 47 centipoise +/- 3 centipoise with the exception of Tank 1.

- Crosslink times for the 12 frac tanks were also consistent with the exception of Tank 1. One should expect a longer crosslink time with the lower viscosity fluid when using the vortex close test. This was observed with Tank 1 where the crosslink time was 3:20 compared to an average of 2:27 for the 11 other tanks.

Testing During Actual Stimulation Treatment

Fluid samples were obtained during the actual stimulation treatment for the purpose of visually observing the crosslink nature of the borate fluid system, monitoring crosslinked fluid pH to ensure that the pH remained high enough to maintain stability throughout the desired treatment schedule, and measuring viscosity declines vs. time in a 190°F water bath to monitor proper breaker performance. Tables 3 to 6 provide information on the crosslinked fluid behavior of the delayed borate fluid system containing breaker. Four different samples were caught during the PAD and monitored for the remainder of the stimulation treatment. The crosslinked fluid pH was 10.6 +/- 0.2 for the four samples collected. The pH of the fluids decreased with time at temperature, which is an indication that the fluids were breaking and some hydrolysis was most likely occurring. The viscosity of the fluids was significantly reduced after 90 minutes, which suggests that the DRB was performing as desired. The break profiles on location substantiated the laboratory findings that 0.1 lb/Mgal DRB should adequately break the fluids at 200°F.

Monitoring During Actual Treatment

Mobil's Quality Assurance Program requires that any additives that are run "on-the-fly" be monitored during the treatment. The two additives that were run "on-the-fly" were the DRB and the delayed borate crosslinker.

The DRB was run at low concentrations of 0.1 to 0.5 lb/Mgal. A dry additive chemical pump was added to the blender to accurately deliver the breaker into the fluid. Lab testing has suggested that an excess of 0.05 to 0.1 lb/Mgal can lead to premature gel degradation and a possible screenout.

The other key was addition of the delayed borate crosslinker to the gel system at the proper concentration. The physical handing of this crosslinker was difficult because of the high viscosity of the liquid crosslinker. A positive displacement pump was added to the blender to solve this problem.

A continuous monitoring of these two chemicals was recorded on a VAX computer system. The computer also monitored and recorded the standard treatment variables (rate, pressure, sand concentration, and calculated bottomhole treating pressure). Postevaluation may be completed at a later time.

The Mobil personnel in the van monitored the concentrations of these critical additives. Mobil also had an engineer on the blender to verify that the monitored values were physically correct. This helped the service company and Mobil to work as a team to be sure that a quality job was performed.

1990 DRILLING PROGRAM ANALYSIS

The first 1990 well spudded during September 1990. To date, the results associated with the 1990 capital program have been very encouraging. All the wells have been completed. The 6 producers were IP'd from 1/15/91 through 4/3/91 ranging from 268 to 1 BOPD with an average IP of 133 BOPD and 2.6 MMSCFPD. Comparisons between prefrac estimates and actual results are provided. A total of 11 wells were completed in the Pegasus Devonian during the 1990 capital program. Table 7 summarizes the fracture treatments for the 11 wells. Each well was stimulated using a delayed borate 40 lb guar system and 64,000 to 361,000 lb of 20/40 intermediate strength proppant. All the fracture treatments were successfully placed.

Typical pre- and post-fracturing production data are illustrated in Fig. 7 for the Pegasus (Devonian) #1-58. Note the prefracture production averaged 40 BOPD, and gas had stabilized at 1100 MCFD. Postfracture production (when not choked back) averaged 260 BOPD and 4800 MCFD. After 16 months of production, this well is still flowing at 80 BOPD and 3500 MCFD. Based on the success of the 1990 capital program, the Pegasus RMT plans to drill several additional producers and injectors over the next 2 years.

CONCLUSIONS

The project started with the fallacy that borates are a "simple" fluid system. They are like any other completion fluid, correct fluid testing procedures are important to achieve consistent results. The chemistry and formation parameters must be known for a successful completion.

The goal of this project was to establish a completion program for use in the future. A delayed borate fracturing fluid, with higher retained fracture conductivities, was successfully developed fur use in the Devonian. This illustrates borates with proper pretesting can work at higher temperatures.

Pretesting and on-site quality control are essential for successful borate stimulation treatments. There were several jobs where procedures were changed due to pretesting, showing that the operator and service company can work together as a team to achieve the highest quality job possible.

REFERENCES

1. Penny, G.S.: "Evaluation of the Effects of Environmental Conditions and Fracturing Fluids on the Long-Term Conductivity of Proppants," paper SPE 26900 presented at the 1987 SPE annual Technical Conference and Exhibition, Dallas, Sept. 27-30.

2. Parker, M.A. and McDaniel, B.W.: "Fracturing Treatment Design Improved by Conductivity Measurements Under In Situ Conditions," paper SPE 16901 presented at the 1987 SPE Annual Technical Conference and Exhibition, Dallas, Sept. 27-30.

3. McDaniel, B.W. and Parker, M.A.: "Accurate Design of Fracturing Treatment Required Conductivity Measurements at Simulated Reservoir Conditions," paper SPE 17541 presented at the 1988 SPE Rocky Mountain Regional Meeting, Casper, WY, May 11-13.

4. Parker, M.A.: "Effect of Gelled Fracturing Fluids on the Conductivity of Propped Fractures," paper CIM/SPE 90-92 presented at the 1990 International Technical Meeting of the CIM and SPE, Calgary, Canada, June 10-13.

5. Brannon, H.D. and Pulsinelli, R.J.: "Evaluation of the Breaker Concentrations Required to Improve the Permeability of Proppant Packs Damaged by Hydraulic Fracturing Fluids," paper SPE 19402 presented at the 1990 SPE Formation Damage Control Symposium, Lafayette, LA, Feb. 22-23.

6. Brannon, H.D. and Ault, M.G.: "New, Delayed Borate-Crosslinked Fluid Provides Improved Fracture Conductivity in High-Temperature Applications," paper SPE 22838 presented at the 1991 SPE Annual Technical Conference and Exhibition, Dallas, Oct. 6-9.

7. Sinton, S.W.: "Complexation Chemistry of Sodium Borate with Poly(vinyl alcohol) and Small Diols," AB "NMR Study," *Macromolecules* **(1987)**, 20, 2430-2441.

8. Penny, G.S., Conway, M.W., and Klem, R.C.: "Laboratory Tests to Determine Parameters for Hydraulic Fracturing of Coalbed Methane," presented at the 1991 Rocky Mountain Regional Meeting and Low Permeability Reservoir Symposium, Denver, April 15-17.

9. Norman, L.R., Hollenbeak, K.H, and Harris, P.C.: "Fracture Conductivity Impairment Removal," paper SPE 19732 presented at the 64th 1989 SPE Annual Technical Conference and Exhibition, San Antonio, TX, Oct. 8-11.

10. Harris, P.C.: "Chemistry and Rheology of Borate Crosslinked Fluids," Technical Report from Halliburton Services.

11. Tan, H.C. and Shah, S.N.: "Field Application of Laboratory Friction Pressure Correlations for Borate Crosslinked Fluids," paper SPE 21034 presented at the 1991 SPE International Symposium on Oilfield Chemistry, Anaheim, CA, Feb. 20-22.

12. Dawson, J.C.: "A Thermodynamic Study of Borate Complexation with Guar and Guar Derivatives," paper SPE 22837 presented at the 1991 SPE Annual Technical Conference and Exhibition, Dallas, Oct. 6-9.

13. Prud'homme, R.K., Ellis, S., and Constien, V.G.: "Reproducible Rheological Measurements on Crosslinked Fracturing Fluids," paper SPE 18210 presented at the 1988 SPE Annual Technical Conference and Exhibition, Houston, Oct. 2-5.

14. Laramay, S.B., Shelley, R.F., and Hatcher, W.B.: "New Technology Improves the Performance of Borate Fluids in Low Temperature Zones of the Belridge Field," paper SPE 24064 presented at the 1992 Western Regional Meeting, Bakersfield, CA, March 30-April 1.

15. Kramer, J., Prud'homme, R.K., Wiltziu, P., et al.: "Comparison of Galactomannan Crosslinking with Organotitanates and Borates," *Accepted Polymer and Colloid Science* **(1987)**.

16. Gdanski, R.D., Harris, P.C., Lord, D.L., Reidenbach, B., and Shah, S.N.: "Analysis of Fann Model 50 for Fracturing Fluid Rheology," paper SPE 21647 presented at the 1991 Production Operations Symposium, Oklahoma City, OK, April 7-9.

Table 1
Water Analysis

Tank No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Resistivity @ 65°F (ohms/m^2/m)	9.63	10.25	9.76	9.61	5.86	8.76	10.32	8.78	10.22	10.58	10.49	10.12	1.34	3.94
Specific Gravity @ 60°F	1.002	1.002	1.002	1.003	1.003	1.003	1.003	1.003	1.002	1.003	1.002	1.002	1.007	1.005
pH	7.3	7.2	7.5	7.6	7.5	7.6	7.5	7.5	7.6	7.3	7.4	7.5	7.4	7.5
Calcium (Ca)	150	150	140	150	170	140	130	150	140	130	150	140	170	150
Magnesium (Mg)	40	30	40	45	25	45	50	40	70	30	45	70	80	65
Chlorides (Cl)	70	100	90	110	290	90	110	140	80	100	80	90	3400	600
Sulfate (SO4)	240	200	230	195	330	225	295	265	200	195	170	180	230	270
Bicarbonates (HCO3)	175	220	205	210	205	205	220	190	220	210	195	200	205	220
Iron (Fe)	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Potassium (K)	trace	10	trace	trace	trace	trace	trace	5	trace	10	trace	10	trace	20

NOTE: ion concentration in miligrams per liter.

Table 2
Pre-treatment Fracture Fluid Analysis

Tank No.	Guar Polymer Concentration (lbs/Mgal)	Fluid Temp. (°F)	Before Buffer pH	After Buffer pH	Viscosity at 511/sec (cp)	Vortex Close Time (min)
1	40 lb.	60	7.0	11.1	36.0	3:20
2	40 lb.	59	8.6	11.1	44.0	2:10
3	40 lb.	58	7.7	11.1	48.0	1:50
4	40 lb.	60	8.6	11.0	46.0	2:50
5	40 lb.	60	7.6	11.3	46.0	2:10
6	40 lb.	59	7.3	11.0	46.0	2:40
7	20 lb.	50	6.8	n/a	20.0	flush
8	30 lb.	59	8.8	11.1	34.0	prepad
9	40 lb.	59	7.7	11.0	48.0	2:20
10	40 lb.	59	7.7	11.0	46.0	2:50
11	40 lb.	59	7.6	11.3	49.0	2:40
12	40 lb.	59	7.4	11.0	50.0	2:30
13	40 lb.	59	6.7	11.1	46.0	2:20
14	40 lb.	59	6.8	11.1	47.0	2:40

Table 3
Break Test Analysis During Actual Stimulation Treatment Fann Model 35 Viscometer, B_2 bob, 38/sec

PAD Sample 1a				
Test Time (min)	Time (hr:min)	Fluid Temp. (°F)	Visc. (cp)	pH
0	10:08	60		10.6
10	10:18	120	5000	9.8
20	10:28	150	3250	9.4
40	10:48	170	4000	9.2
60	11:08	180	3250	9.3
80	11:28	180	150	9.3
100	11:48	180	25	9.3

Table 4
Break Test Analysis During Actual Stimulation Treatment Fann Model 35 Viscometer, B_2 bob, 38/sec

PAD Sample 1b				
Test Time (min)	Time (hr:min)	Fluid Temp. (°F)	Visc. (cp)	pH
0	10:10	62		10.4
10	10:20	120	5200	9.6
20	10:30	150	3500	9.3
40	10:50	170	2750	9.2
60	11:10	180	2500	9.3
80	11:30	180	140	9.3
100	11:50	190	25	9.3

Table 5
Break Test Analysis During Actual Stimulation Treatment Fann Model 35 Viscometer, B_2 bob, 38/sec

PAD Sample 1c				
Test Time (min)	Time (hr:min)	Fluid Temp. (°F)	Visc. (cp)	pH
0	10:15	62		10.8
10	10:25	115	7500	10.2
20	10:35	140	5500	9.8
40	10:55	170	4000	9.4
60	11:15	180	2000	9.2
80	11:35	180	875	9.2
100	11:55	180	25	9.3

Table 6
Break Test Analysis During Actual Stimulation Treatment Fann Model 35 Viscometer, B_2 bob, 38/sec

PAD Sample 1d				
Test Time (min)	Time (hr:min)	Fluid Temp. (°F)	Visc. (cp)	pH
0	10:20	62		10.8
10	10:30	120	6000	10.2
20	10:40	150	3500	9.4
40	11:00	160	3250	9.3
60	11:20	180	2250	9.2
80	11:40	180	1750	9.2
100	12:00	190	200	9.3

Table 7
Summary of Fracture Treatments

		1990 PEGASUS DEVONIAN FRACTURE DATA										
		PRODUCERS						INJECTORS				
Well No.	Avg. Producer	1-58	1-59	16-11	25-3	49-9	50-3	8-12G	*25-22G	9-3G	1-80G	49-1G
Prefrac Test (BCD/MMCFD)	13/0.51	40/1.10	33/1.40	7/0.55	0/0	0/0	0/0	-	-	-	-	-
Date Frac'd		12-12-90	12-17-90	01-07-91	01-16-91	01-30-91	02-04-91	02-13-91	03-07-91	03-29-91	04-15-91	05-11-91
IP (BCD/MMCFD)	133/2.48	268/4.40	164/3.70	102/2.60	193/3.60	1/0.400	70/0.200	-	-	-	-	-
Date	-	01-15-91	01-15-91	04-01-91	02-16-91	03-15-91	03-03-91	-	-	-	-	-
Net Pay (ft)	114	208	134	109	174	5	44	116	44	108	132	176
BHP (psi)	4127	3736	2887	3435	4980	5270	4455	3382	2499	-	4061	-
No. Holes	168	356	205	71	176	143	58	52	51	91	57	247
Limited Entry	-	No	No	Yes	No	**No	**No	Yes	Yes	Yes	Yes	**No
PAD Vol (Mgals)	117	141	141	141	120	80	80	80	65	80	80	30
% PAD	69	68	69	66	66	75	70	59	62	64	70	70
ISP (M#'s)	243	229	361	321	301	115	132	213	209	160	210	64
Highest Conc. (ppg)	6	6	8	8	6	5	5	8	6	8	8	6
Avg TP (psi)	4258	2800	4100	4200	6350	5300	2800	3000	4200/5000	4300	3700	6200
Avg Rate (BPM)	60	61	61	64	42	67	65	63	61/62	60	60	38
Conductor		5-1/2'	5-1/2'	5-1/2'	3-1/2'	5-1/2'	5-1/2'	5-1/2'	5-1/2'	4-1/2'	5-1/2'	3-1/2'

* NOTE: 25-22 was refrac'd due to mechanical failure on 1st job.

** NOTE: Limited entry not req'd - no white chert present.

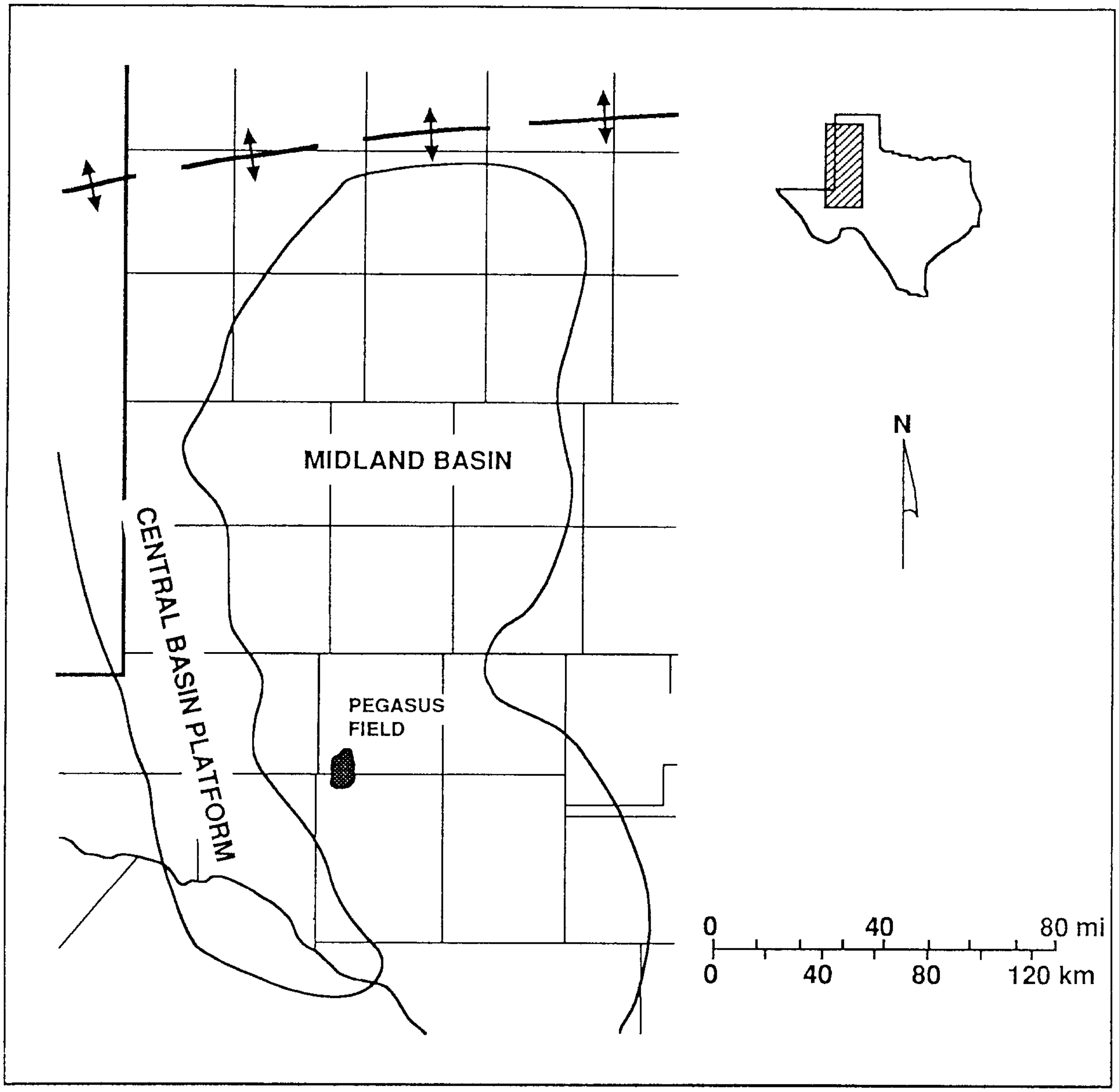

FIGURE 1: **LOCATION MAP** Pegasus Field is located 25 miles south of Midland in Midland and Upton Counties, Texas. The field lies in the southwestern portion of the Midland Basin, about 20 miles east of the Central Basin Platform.

Figure 1 - Location of the Pegasus (Devonian) Field

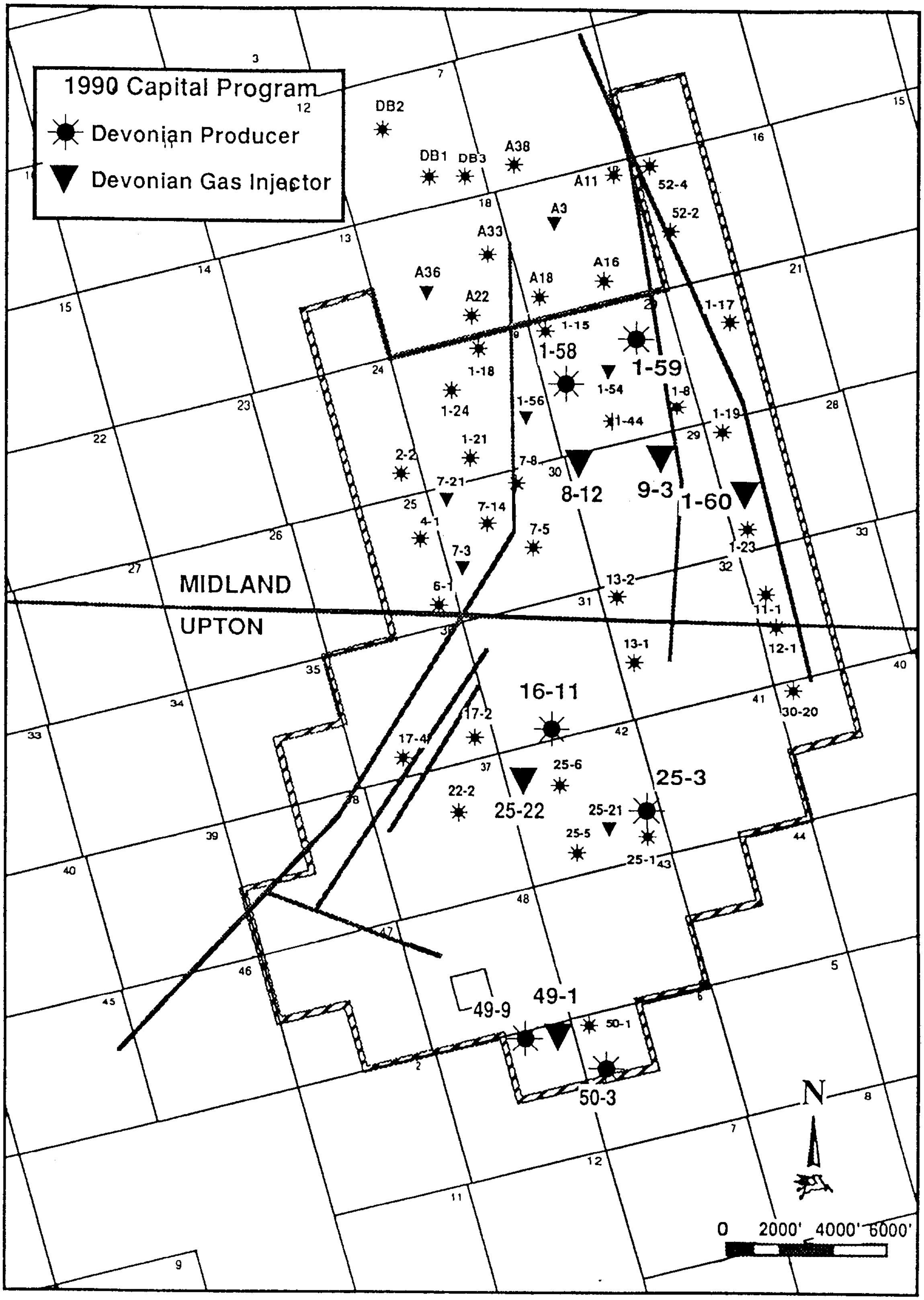

Figure 2 - 1990 Pegasus (Devonian) Capital Program

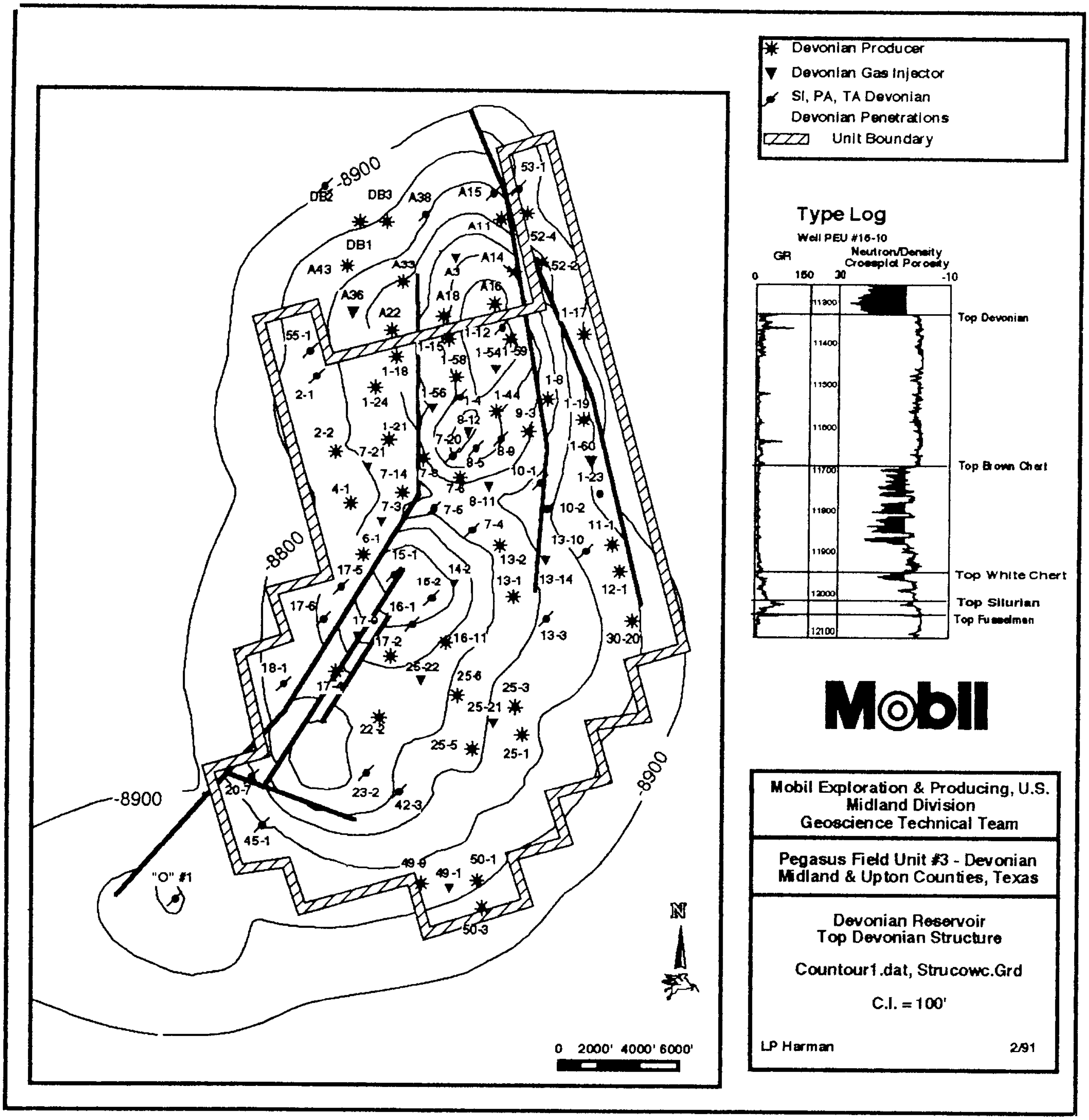

Figure 3 - Top Devonian structure map

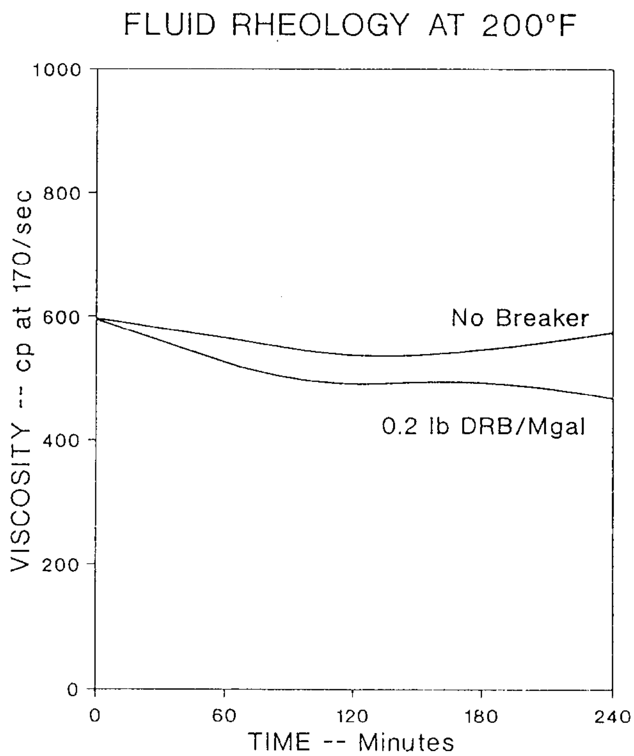

Figure 4 - Questionable Fann Model 50 test results due to sampling errors

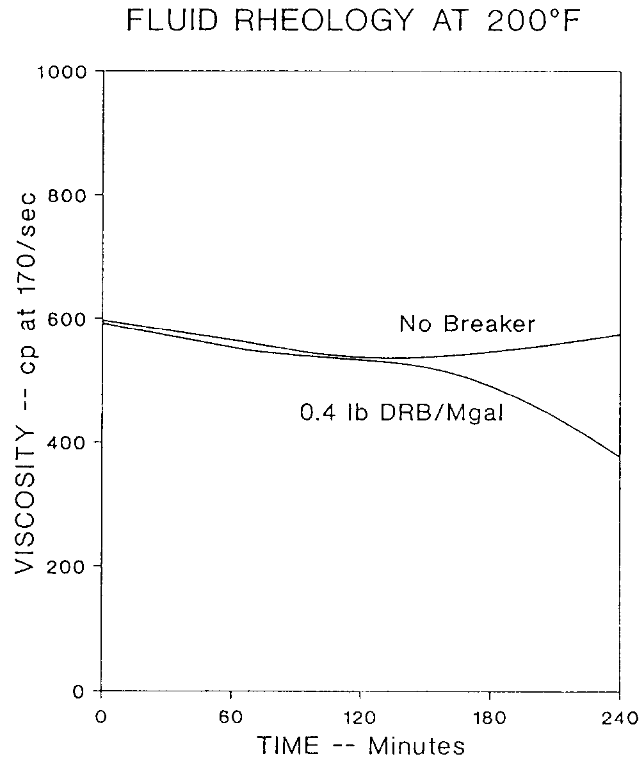

Figure 5 - Questionable Fann Model 50 test results due to sampling errors

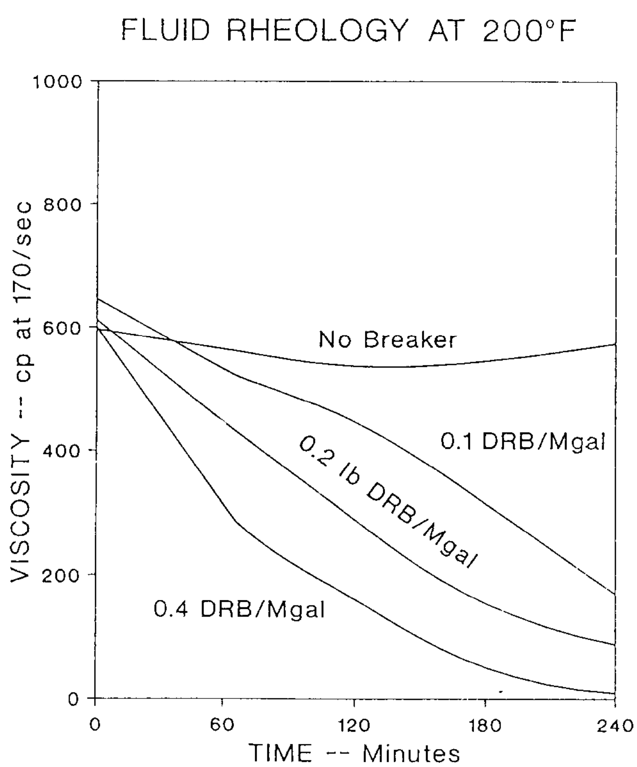

Figure 6 - Borate fluid viscosity profiles with different loadings of delayed release breaker

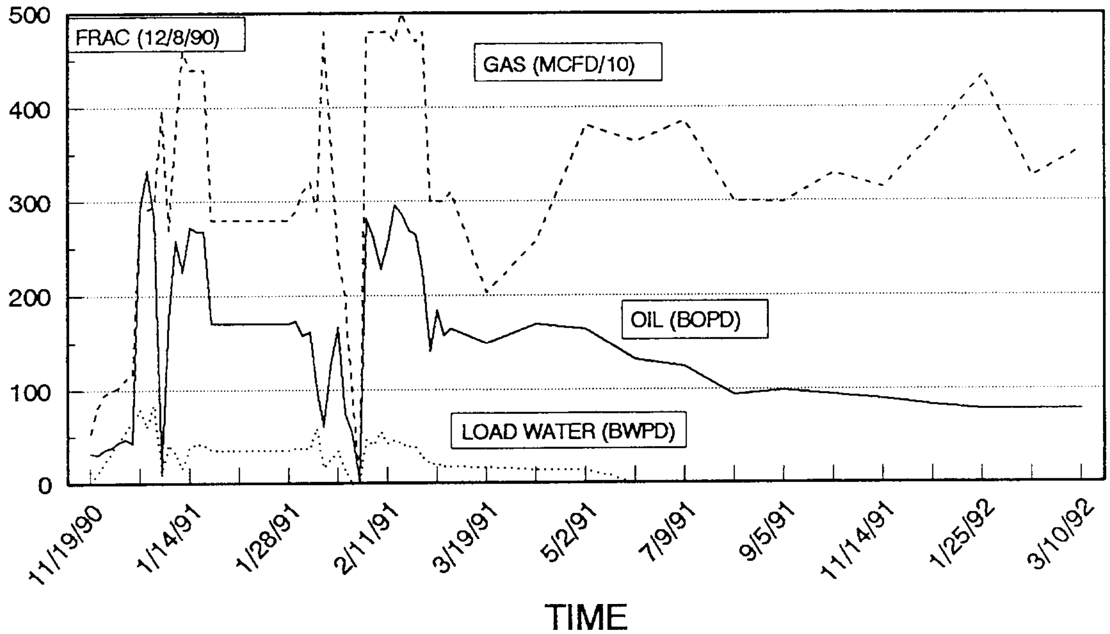

Figure 7 - Pre-and post-frac production
Pegasus (Devonian) #1-58