L06-3

LABORATORY REPORT No. T12-D005-85

IMPROVE FRACTURING OF DIRECTIONAL WELLS

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HALLIBURTON SERVICES
DUNCAN, OKLAHOMA

LABORATORY REPORT

No. T12-D005-85

To Mr. R. Leyton
Halliburton
Buenos Aires, Argentina

Date July 16, 1985

We give below results of our examination of submitted well logs, BELCO's Perforating and Fracturing Report on the Upper Mogollon and the Rio Bravo Formations, offshore Peru.

Submitted by Mr. R. Leyton for BELCO

Marked

Well:	Z2A-15-614-D-5N3	and	Z2A-21-615-D-L06 (L06-3)
Location:	Pena Negra Area		Lobitos Offshore Area
Formation:	Upper Mogollon		Rio Bravo
Depth:	4601 to 5414 Feet		4071 to 5083 Feet
Date Received:	May 2, 1985		

PURPOSE

The submitted logs and BELCO's Perforating and Fracturing Reports were used to examine BELCO's practices in the propped stimulation treatment of these wells. Also information obtained in discussions with various personnel familiar with BELCO's operation was used.

DISCUSSION

The examination of the submitted information on the stimulation treatment of the Upper Mogollon and the Rio Bravo Formations indicates there are apparently problem areas. These areas are as follows: (1) these wells were directionally drilled, (2) the proppant carrying fluid was a 30 pound WATERFRAC, (3) two different sizes of proppant were used, and (4) the amount of proppant placed was not sufficient. Each of these areas will be discussed separately with a possible solution to each problem.

Problem Area No. 1 - Directionally Drilled Wells

According to stimulation information on wells drilled offshore in the North Sea, the fracture stimulation treatments appeared to be inconsistent. The early stimulation procedures were similar to those performed on land wells and this appeared to be the reason for the inconsistency. That is, the directionally drilled wells did not stimulate in a consistent manner as one would expect for wells drilled onshore. For example, the first well drilled off of a platform is usually a straight hole. The wells (straight holes) that were fractured with proppant had a good sustained production increases. However, wells that were drilled later (all directional) and were stimulated by a propped fracture treatment were not as successful as the first well (straight hole) off the platform. In searching for a cause for this difference in fracture stimulation treatment results, the "Theory of Fracturing" had to be enlarged to cover the directionally drilled wells and the possible results. The following are the conclusions drawn from a study of stimulation treatments in directionally drilled wells.

Fracturing a Directionally Drilled Well

One of the basic rules of creating a fracture is that the fractures are usually vertical and they are created normal (perpendicular) to the least principal stress. Also, for any one field, the created vertical fractures are all parallel to each other as dictated by tectonic stresses.

A directionally drilled well presents problems in stimulation treatments that are not encountered in straight holes.

A directionally drilled well whose direction (azimuth) is normal (perpendicular) to the least principal stress in the producing interval and intersect the interval at an angle (not vertical) will have one vertical fracture created.

A directionally drilled well that is not normal (perpendicular) to the least principal stress in the producing interval and intersects the interval at an angle (not vertical) will have multiple vertical fractures. These multiple fractures could be very small and could be ineffective for all practical purposes.

Mr. B. B. Barfield, Halliburton at The Hague, did a study of this phenomenon in the North Sea area. His findings were that where a stimulation treatment of a straight hole was excellent, the same stimulation treatment on a directionally drilled well was creating

DISCUSSION (Cont'd)

multiple vertical fractures and that the total treatment was ineffective. This phenomenon has been somewhat supported by the placement of a large amount of proppant in a 2.5 foot perforated interval in an attempt to limit the amount of fractures created. The results of the treatment were excellent.

Recognizing that the multiple fractures can be created in a directionally drilled well which intersects the producing interval at an angle and planning treatments that control the amount of multiple fractures is of the utmost importance in stimulating these wells by either fracture acidizing or by fracturing with proppant. Since the azimuth direction of the fractures is usually not known, then all directionally drilled wells should be considered potential candidates for having multiple fractures created.

The two formations (Upper Mogollon and Rio Bravo) are found to be sands, bounded top and bottom by shales. The logs and perforating reports show that from 1 to 9 perforations per interval were used. Where 1 perforation per interval exists, the results will be similar to Figure 4, Insert 1. Where two or more perforations per interval occur, the results will be similar to Figures 3, 5, or 6, Insert 1. The conclusion is probably that each perforation will have its own fracture, and that the fractures created in some of the intervals will be ineffective.

A possible solution is to place all perforations in the same one foot section of casing to treat any one interval, whether or not the interval takes two or more perforations to stimulate it. (Using Limited Entry Techniques assumes each perforation has the same rate of flow through it.) This method would tend to create one vertical fracture per interval.

Problem Area No. 2 - Proppant Carrying Fluid

The formations were treated using a 30 pound WATERFRAC. The proppant settling velocity, in feet per second, for a 30 pound WATERFRAC (viscosity = 22 cp) is approximately 0.095 for 20/40 Ottawa and approximately 0.27 for 10/20 Ottawa (see Figure 1, Insert 2). The profile of a proppant grain entering the fracture is illustrated in Figure 2, Insert 2. M is the proppant grain, Uf is the horizontal velocity of the proppant in the fracture, and U is the settling velocity. Figure 3 shows the trajectories of the proppant at the levels of entering the fracture and the points of contact with the bottom of the fracture. The proppant usually will not move once it has been deposited on the bottom of the fracture. Figure 4 illustrates the building of the proppant bed. T1 is time initial and T2 is some time after T1. The proppant bed will continue to grow as illustrated by Figure 5 and Figure 6. At some point the proppant bed height will reach a height that the horizontal velocity will not allow the settlement of new proppant on the top of the bed. Then the proppant will be carried to the "front" of the proppant bed and deposited. The "front" of the

DISCUSSION (Cont'd)

proppant bed is at the angle of repose (ϕ) for the proppant, usually 30 degrees. Figure 7 diagrams this process. The maximum bed height probably does not occur in the stimulation treatment of the formations as performed according to the BELCO's Perforating and Fracturing Report. The proppant is deposited on the bottom of the fracture using the 30 pound WATERFRAC as the proppant carrying fluid and does not prop the interval through its entire height. This does not allow the best possible production from the interval. One solution to this problem area is to use a heavy gel or a crosslinked fluid to carry the proppant. Figure 10 illustrates a good crosslinked fluid with only one proppant, while Figure 11 illustrates a heavy gelled fluid with two proppants. In either case the carrying fluid should suspend the proppant until closure of the fracture occurs to obtain maximum fracture conductivity for the better production.

Problem Area No. 3 - Two Sizes of Proppant

The BELCO's Perforating and Fracturing Report shows that both 20/40 and 10/20 Ottawa sand proppant was used on each interval. The 20/40 size was used first followed by the 10/20 size in an attempt to have more fracture conductivity near the wellbore. However, using a 30 pound WATERFRAC as the proppant carrying fluid, a proppant deposition bed type occurred that is illustrated by Figure 8 and Figure 9, Insert No. 2. The larger 10/20 sized proppant is deposited on top of the 20/40 size proppant and also in "front" of the 20/40 size proppant if the maximum proppant bed height is reached. It is doubtful if the maximum proppant bed height is reached in the wells treated. The solution is the use of a heavily gelled or a crosslinked proppant carrying fluid which should give a proppant profile as illustrated by Figure 10 and Figure 11.

Problem Area No. 4 - Amount of Proppant

BELCO's Perforating and Fracturing Report shows that an average of 1320 pounds or 13 sacks of proppant were used per perforation. This amount of proppant will establish good fracture conductivity only in the very bottom of the interval fractured. The top of the interval will not have any fracture conductivity because no proppant is placed in the fracture to prop the top open. This condition is caused by using the 30 pound WATERFRAC. However, if a crosslinked proppant carrying fluid is used with the same amount of proppant, the fracture conductivity will be poor to medium throughout the entire height. The net result would be approximately 0.5 to 1.0 pounds per square foot of proppant in the fracture at the wellbore. The better production results should occur if the proppant bed concentration of the closed fracture exceeded 1.5 pounds per square foot in the fracture.

SUMMARY

The basic procedures, used presently, in the propped fracture stimulation treatment in the upper Mogollon and the Rio Bravo Formations are not the present "State of the Art" method. The following changes are presented for the customer's consideration.

(1) Treat all the wells that are directional drilled as if multi-vertical fractures will occur. To help create only one possible fracture, concentrate the perforations of any one interval in a 1 foot section.

(2) Use a crosslinked proppant carrying fluid, such as VERSAGEL LT 1300 or 1400. The break time for the fluid should exceed the expected closure time of the fracture.

(3) If a crosslinked proppant carrying fluid is not used, use only one size of proppant. If a crosslinked fluid is used, two sizes of proppant can be used. However, the amount of the large proppant should be an optimum amount to prevent a fracture cutoff (see Insert No. 3) from occurring. (This figure was prepared using a low to medium gelled proppant carrying fluid to exaggerate the cut off of the fracture.)

(4) Increase the amount of proppant used to improve the conductivity of the propped fracture.

(5) Perforate for the propped fracture stimulation treatment first, and then, at a later date, perforate for production, if so desired.

The above summary is based on the author's assessment of the information supplied, discussions with various personnel who are familiar with BELCO's operation, and the authors understanding of the "State of the Art" in propped fracture stimulation.

DATA

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Field Data Supplied by BELCO

Well No. : ZZA-15-614-D-PN3
BELCO NO. : PN3-23
Location : Pena Negra Area
Formation : Upper Mogollon

Stage No. 1

Interval : 5,104 to 5,414 feet
Measured Depth : 105 feet True Vertical Depth : 94 feet

Interval (feet) Top	Bottom	Total Measured	True	No. Shots	Perforation Depth (feet) 0.49 inch dia. a 0 deg phasing		
5,100	5,142	42	38	9	5,139	5,133	5,128
					5,126	5,120	5,116
					5,111	5,107	5,104
5,149	5,162	13	12	2		5,159	5,151
5,195	5,201	6	5	2		5,200	5,196
5,238	5,244	6	5	2		5,239	5,243
5,246	5,244	6	5	1		5,249	
5,304	5,312	6	5	2		5,310	5,305
5,317	5,324	7	6	1		5,319	
5,324	5,328	4*	4	1		5,326	
5,330	5,336	6	5	1		5,331	5,335
5,343	5,348	5	5	1		5,346	
5,354	5,363	7	6	1		5,360	
5,408	5,417	9	8	2		5,409	5,414

Total Perforations = 26

Treatment

	Total	Units	Amount per perforation
Total Treatment Volume :	28,220	Gallons	1,085
Pad Volume :	6,000	Gallons	240
Proppant Carry Volume :	17,020	Gallons	655
Flush Volume :	300	Gallons	
Displacement Volume :	4,900	Gallons	
Proppant; 20/40 sand :	11,200	Pounds	431
10/20 sand :	25,000	Pounds	962
Rate:	27.0	BPM	1.04

DATA (Cont'd)

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Field Data

Supplied by BELCO

Well No. : ZZA-15-614-PN3
BELCO NO. : PN3-23
Location : Pena Negra Area
Formation : Upper Mogollon

Stage No. 2

Interval : 4,978 to 4,834 feet
Measured Depth : 62
True Vertical Depth : 57

Interval (feet) Top	Bottom	Total Measured	True	No. Shots	Perforation Depth (feet) 0.49 inch dia. a 0 deg phasing	
4,830	4,845	15	13	4	4,834 4,841	4,827 4,844
4,896	4,898	2	2	0		
4,902	4,904	2	2	1	4,908	
4,913	4,929	16	14	4	4,926 4,922	4,918 4,926
4,932	4,944	12	11	3	4,941 4,933	4,937
4,951	4,961	10	9	2	4,953	4,959
4,964	4,969	5	5	1	4,965	
4,973	4,978	5	5	2	4,875	4,978

Total perforartions = 17

Treatment

	Total	Units	Amount per perforation
Total Treatment Volume :	19,070	Gallons	1,159
Pad Volume :	4,000	Gallons	235
Proppant Carry Volume :	10,600	Gallons	624
Flush Volume :	300	Gallons	
Displacement Volume :	4,710	Gallons	
Proppant; 20/40 sand :	9,000	Pounds	529
10/20 sand :	11,000	Pounds	647
Rate :	27.0	BPM	1.59

DATA (Cont'd)

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Field Data

Supplied by BELCO

Well No. : ZZA-15-614-PN3
BELCO NO. : PN3-23
Location : Pena Negra Area
Formation : Upper Mogollon

Stage No. 3

Interval : 4,797 to 4,601 feet
Measured Depth : 94
True Vertical Depth : 86

Interval (feet) Top	Bottom	Total Measured	True	No. Shots	Perforation Depth (feet) 0.49 inch dia. a 0 deg phasing	
4,597	4,614	17	15	3	4,601 4,609	4,605
4,616	4,637	11	10	2	4,619	4,624
4,652	4,672	20	18	4	4,675 4,665	4,664 4,669
4,675	4,680	5	5	1	4,690	
4,688	4,702	14	12	3	4,677 4,698	4,694
4,732	4,742	10	9	2	4,734	4,738
4,762	4,799	37	33	8	4,764 4,773 4,781 4,793	4,769 4,777 4,785 4,797

Total perforations = 23

Treatment

	Total	Units	Amount per perforation
Total Treatment Volume :	25,960	Gallons	1,129
Pad Volume :	4,000	Gallons	174
Proppant Carry Volume :	17,210	Gallons	748
Flush Volume :	300	Gallons	
Displacement Volume :	4,450	Gallons	
Proppant; 20/40 sand :	12,000	Pounds	522
10/20 sand :	25,500	Pounds	1,109
Rate :	28.0	BPM	1.22

DATA (Cont'd)

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Field Data

Supplied by BELCO

Well No. : Z2A-21-615-D-L06
BELCO NO. : L06-3
Location : Lobitos Offshore
Formation : Rio Bravo

Stage No. 1

Interval : 4,750 to 5,083 feet
Measured Depth : 93 feet
True Vertical Depth : 77 feet

Interval (feet) Top	Bottom	Total Measured	True	No. Shots	Perforation Depth (feet) 0.49 inch dia. a 0 deg phasing	
4,747	4,776	29	25	5	4,750	4,754
					4,758	4,763
					4,767	
4,780	4,784	4	3	1	4,782	
4,790	4,810	20	16	4	4,792	4,796
					4,804	4,808
4,819	4,824	5	4	1	4,821	
4,855	4,863	8	7	2	4,856	4,860
4,894	4,900	6	5	0		
4,919	4,931	12	9	2	4,923	4,927
5,074	5,092	18	14	3	5,079	5,080
					5,083	

Total Perforations = 19

Treatment

	Total	Units	Amount per perforation
Total Treatment Volume :	26,500	Gallons	1,472
Pad Volume :	8,000	Gallons	445
Proppant Carry Volume :	12,520	Gallons	751
Flush Volume :	300	Gallons	
Displacement Volume :	4,680	Gallons	
Proppant; 20/40 sand :	9,800	Pounds	545
10/20 sand :	18,600	Pounds	1,033
Rate :	28.0	BPM	1.47

DATA (Cont'd)

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Field Data

Supplied by BELCO

Well No. : Z2A-615-D-L06
BELCO NO. : L06-3
Location : Lobitos Offshore
Formation : Rio Bravo

Stage No. 2

Interval : 4,273 to 4,613 feet
Measured Depth : 89 feet
True Vertical Depth : 70 feet

Interval (feet) Top	Bottom	Total Measured	True	No. Shots	Perforation Depth (feet) 0.49 inch dia. a 0 deg phasing	
4,271	4,278	7	5.5	2	4,273	4,275
4,285	4,307	22	17	5	4,288	4,292
					4,296	4,300
					4,304	
4,318	4,340	22	17	4	4,320	4,328
					4,332	4,336
4,362	4,367	5	4	1	4,364	
4,396	4,411	15	12	2	4,402	4,404
4,425	4,428	3	2	1	4,443	
4,442	4,450	8	6	2	4,443	4,447
4,469	4,479	10	8	0		
4,462	4,464	2	1	0		
4,603	4,615	12	9	3	4,605	4,611
					4,613	

Total Perforations = 20

Treatment

	Total	Units	Amount per perforation
Total Treatment Volume :	24,130	Gallons	1,207
Pad Volume :	8,000	Gallons	400
Proppant Carry Volume :	11,620	Gallons	581
Flush Volume :	200	Gallons	
Displacement Volume :	4,210	Gallons	
Proppant; 20/40 sand :	10,000	Pounds	500
10/20 sand :	13,600	Pounds	680
Rate :	24.0	BPM	1.20

DATA (Cont'd)

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Field Data

Supplied by BELCO

Well No. : Z2A-21-615-D-L06
BELCO NO. : L06-3
Location : Lobitos Offshore
Formation : Rio Bravo

Stage No. 3

Interval : 4,071 to 4,241 feet
Measured Depth : 106 feet
True Vertical Depth : 82 feet

Interval (feet) Top	Bottom	Total Measured	True	No. Shots	Perforation Depth (feet) 0.49 inch dia. a 0 deg phasing	
4,047	4,053	6	4.5	0		
4,070	4,079	9	7	3	4,071	4,074
					4,077	
4,082	4,096	14	11	3	4,090	4,092
					4,094	
4,101	4,116	15	11.5	3	4,103	4,106
					4,109	
4,141	4,150	9	7	2	4,143	4,147
4,154	4,165	11	8.5	3	4,156	4,161
					4,163	
4,168	4,195	27	21	4	4,173	4,178
					4,182	4,186
4,203	4,225	22	17	5	4,206	4,210
					4,214	4,221
					4,223	
4,238	4,245	7	5.5	2	4,239	4,241

Total Perforations = 25

Treatment

	Total	Units	Amount per perforation
Total Treatment Volume :	27,210	Gallons	1,089
Pad Volume :	8,000	Gallons	320
Proppant Carry Volume :	15,030	Gallons	601
Flush Volume :	300	Gallons	
Displacement Volume :	3,880	Gallons	
Proppant; 20/40 sand :	11,300	Pounds	452
10/20 sand :	21,600	Pounds	864
Rate :	27.0	BPM	1.08

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Insert No. 1

Fig. 1. Created fractures extend away from the wellbore in two directions 180° apart.

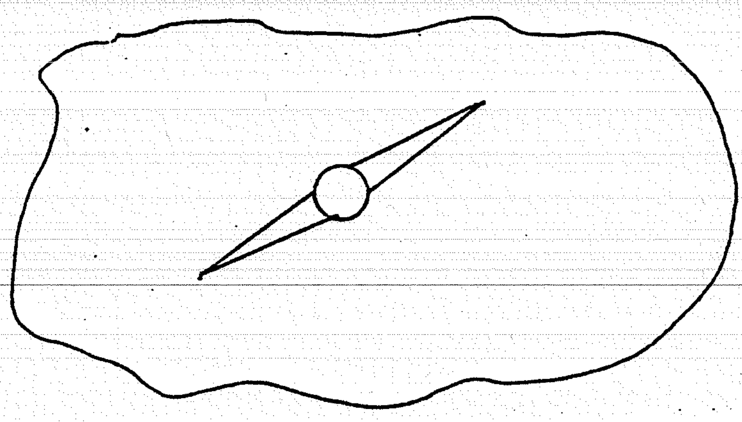

Fig. 2. Preferred fracture orientation is essentially the same for all wells in the same reservoir.

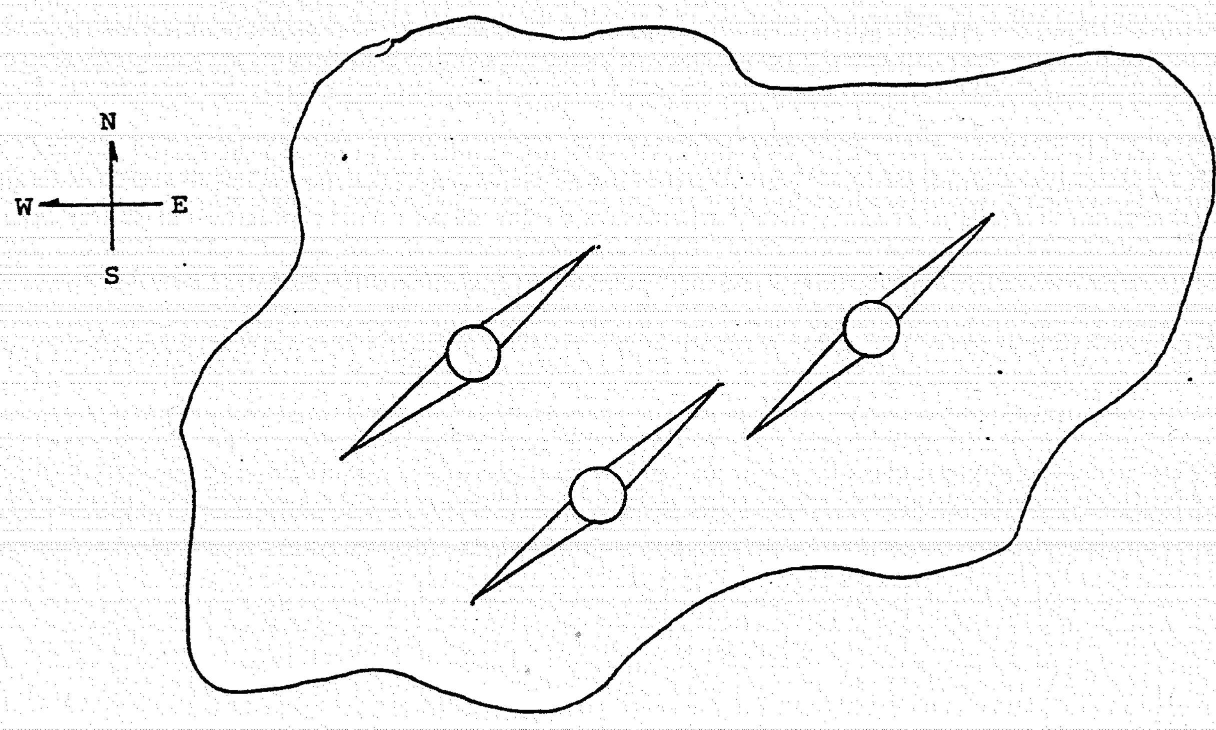

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Fig. 3. Multiple parallel fractures across and along the wellbore.

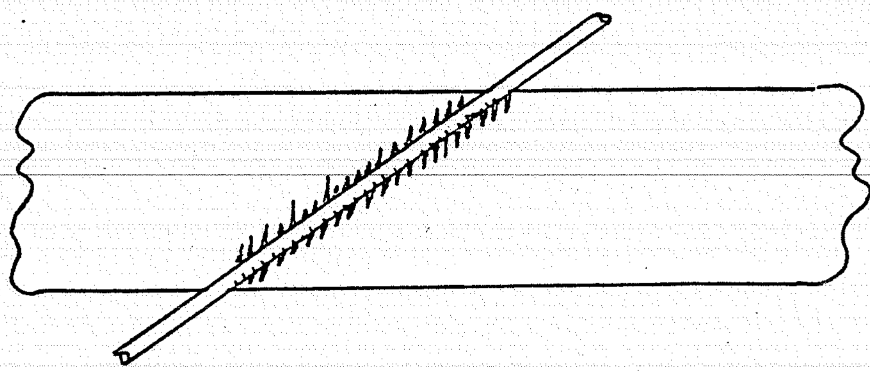

Fig. 4. A single fracture across the wellbore AT ANY POINT along the wellbore.

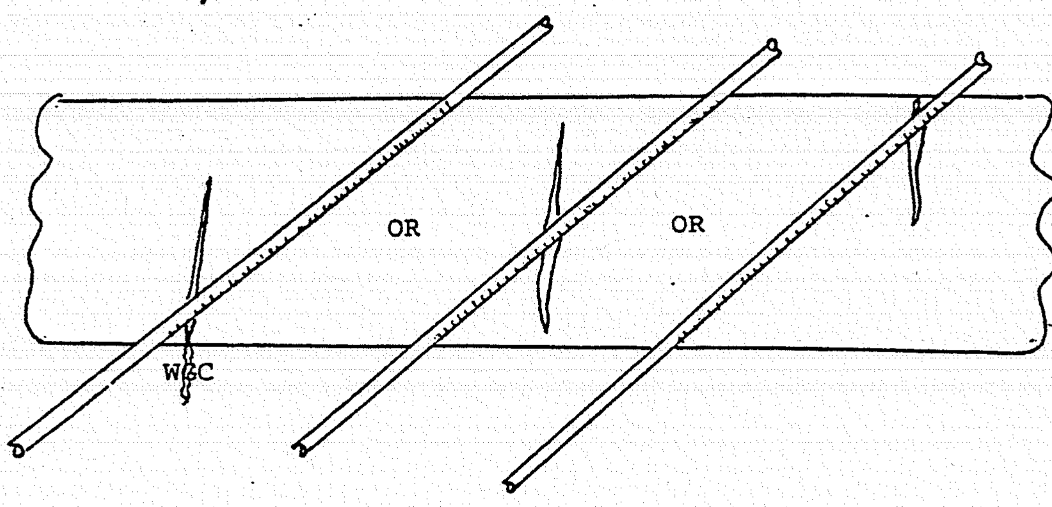

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Fig. 5. Several major and minor fractures across and along the wellbore.

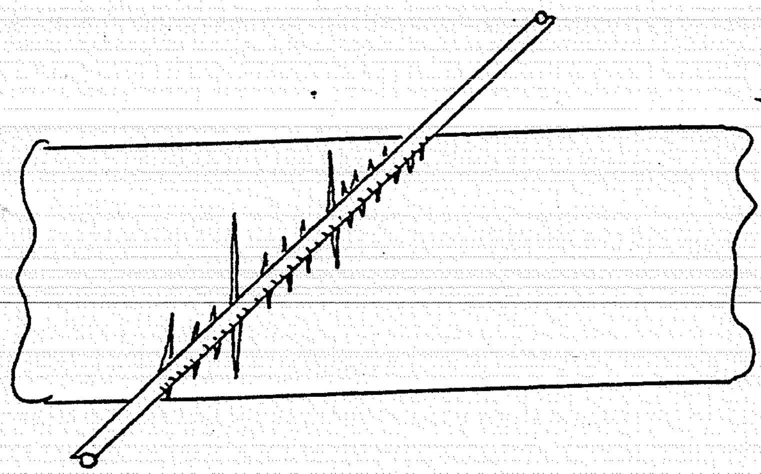
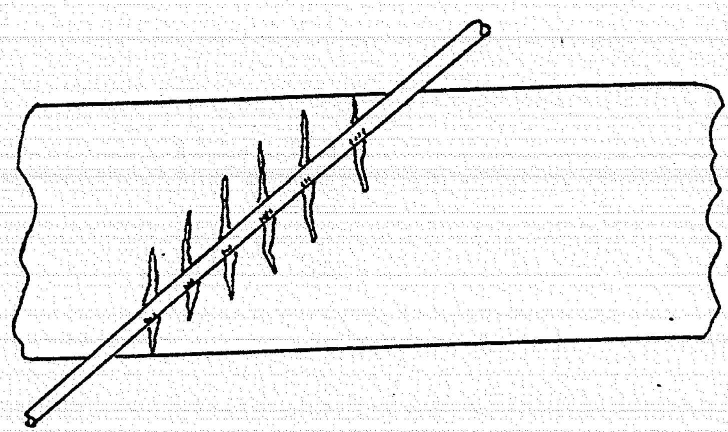


Fig. 6. Limited entry creating six (6) properly spaced fractures across and along the wellbore.



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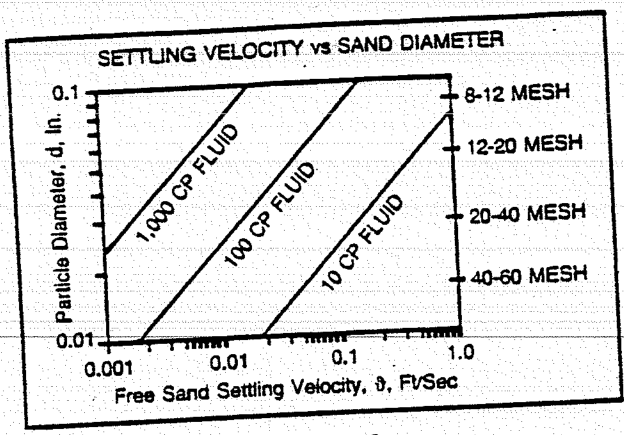

Figure 1

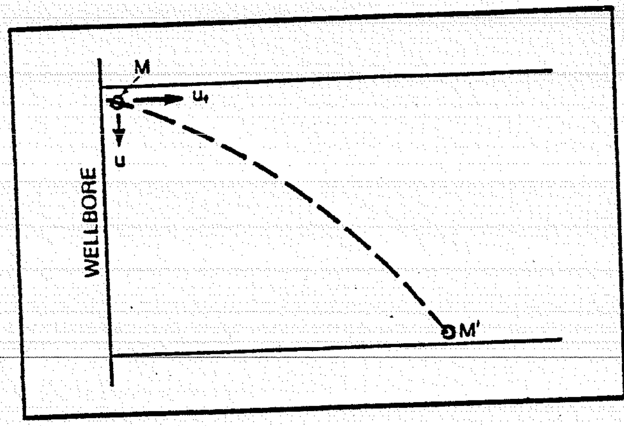

Figure 2

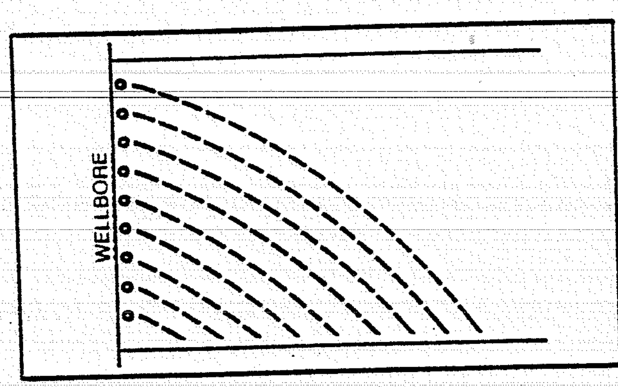

Figure 3

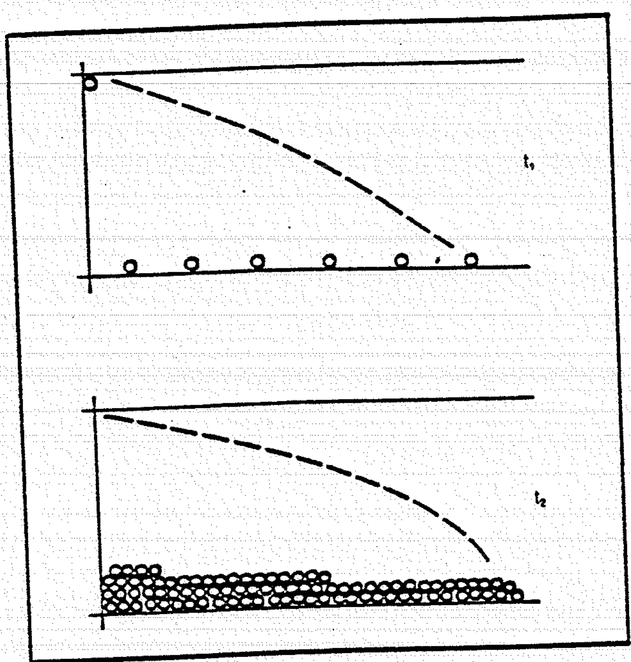

Figure 4

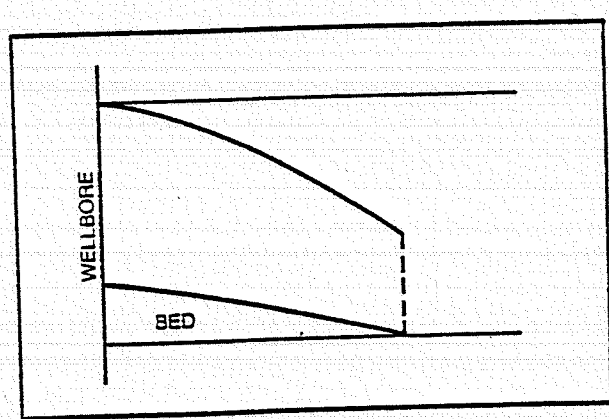

Figure 5

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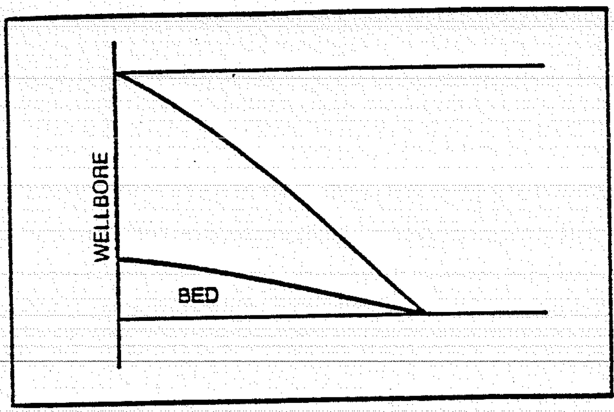

Figure 6

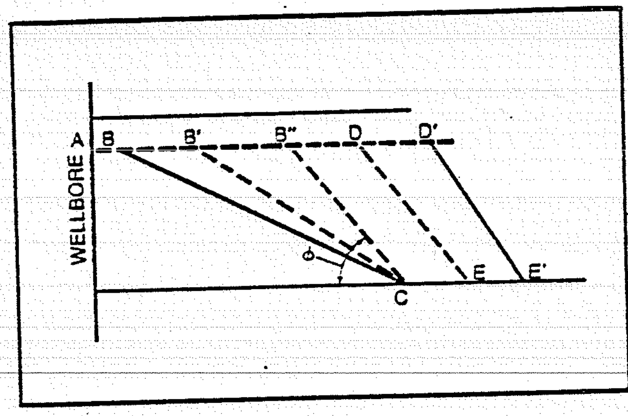

Figure 7

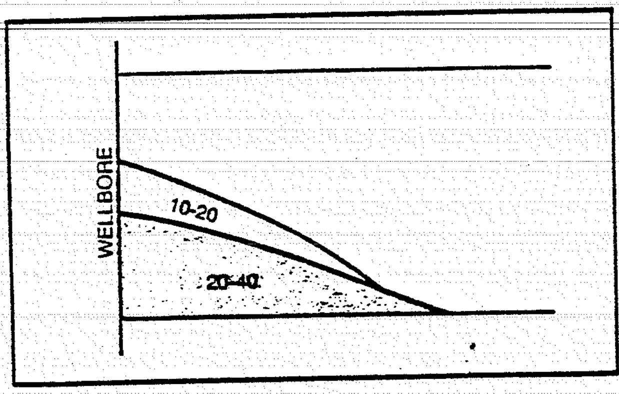

Figure 8

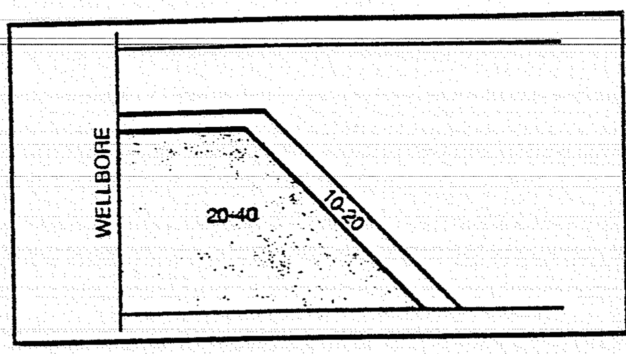

Figure 9

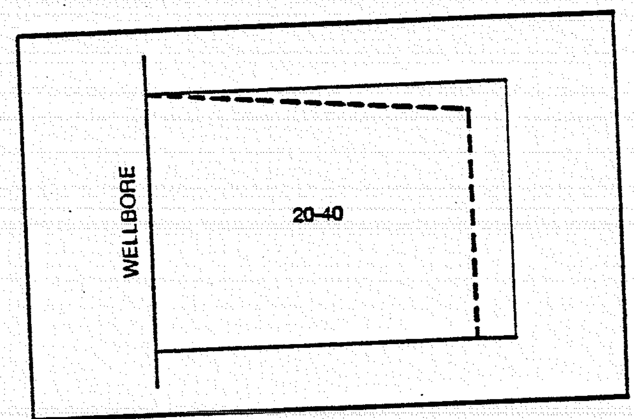

Figure 10

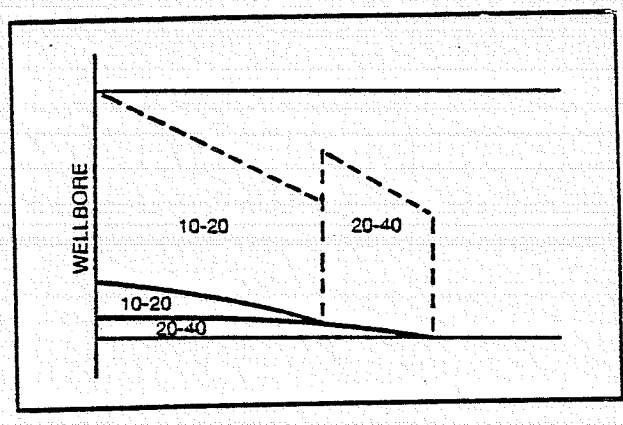

Figure 11

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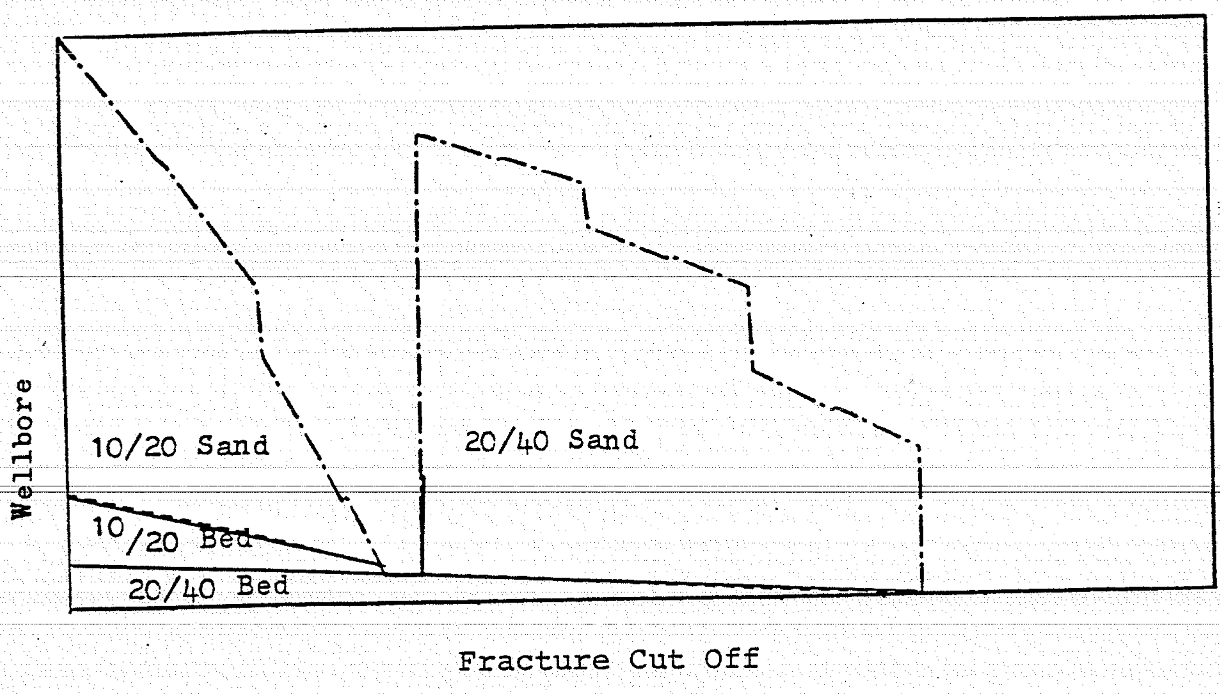
Insert No. 3



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