ENVIRONMENTALLY PREFERRED SYSTEM PROVIDES CONTROL OF RETURNS DURING DRILLING AND PRIMARY CEMENTING OPERATIONS

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ABSTRACT

Partial or total lost circulation is prevalent in the Permian Basin of West Texas during many drilling and cementing operations. Whether losses are due to highly vugular or cavernous intervals or due to low fracture gradients, the problem is recurrent over the entire region. The common practices for fighting these losses are foamed mud sweeps, foamed cements, lost circulation pills and high-viscosity gel spacers containing lost circulation materials.

This paper presents case histories representing more than 100 wells in which a new environmentally preferred system has been employed. Specifically, instances during drilling are discussed where partial or total losses in returns have occurred and have been restored by pumping 40 to 50 bbls of this new material. These same wells after restoring circulation resume drilling to total depth without any further losses. In addition, cases are presented where the system is used as a spacer pumped ahead of cement, resulting in the circulation of cement in an area where this has not occurred before. Another example resulted in the improvement of bonding by the cement. Additional scenarios demonstrate that pumping this material on a single stage cementing job, could replace the normal two stage job.

INTRODUCTION

Lost circulation in well operations is simply the loss of fluids during drilling, cementing and/or completions. The causes for the losses are based on simple physics of the "overbalance of pressure favoring the migration of the fluid from the well-bore to the formation".[1] The reasons for this overbalance can be excessive mechanical or hydrostatic pressures and can happen without the fracture initiation pressure of the formation being exceeded. Losses during any well operation cost money in rig time and replacement of fluids as well as presenting very possible safety issues. The safety issues primarily center around the potential for a blowout which would put all persons on location in danger. Additional problems that can occur are hole sloughing, and stuck drill pipe or tubing. The worst case results of a lost circulation problem could be the need to side track the well-bore, plug a potentially productive interval or well abandonment. When and where these losses occur dictates the preventive measures as well as the possible treatments to restore circulation.

When evaluating loss potentials it is best to begin with the properties of the formations to be penetrated. The nature of these formations as to fracture gradients, presence of caverns or vugs, permeability, presence of natural fractures and if the formations are susceptible to induced fracturing during the drilling operations. The severity of the losses and how long it will take to overcome them are a direct function of these formation properties.

Fracture gradient issues are dealt with generally by planning the drilling program and casing points to minimize the potential for fluid hydrostatics to exceed these pressures. However, in cases such as a "Wolfberry" well in the Permian Basin where the goal is to penetrate through the Wolfcamp and then to do a multi-stage frac of several zones to comingle production from all of them while minimizing costs this creates problems. The fracture gradient of the Spraberry intervals at the top of what will be the producing column is approximately 0.517 psi/ft and the Wolfcamp is 0.71 psi/ft.[2] This makes the drilling as well as the cementing operations a challenge.

Typically carbonate formations present the possibility of caverns and/or vugs. In general these problems are not common, however in several areas of the Permian this is an everyday occurrence. Losses associated with these conditions may occur suddenly and may be complete. Since they can be so severe they are the most difficult to control or restore. High permeability formations typically unconsolidated rock (>325md) will exhibit seepage losses in contrast to the complete losses associated with caverns and vugs. These losses can be 20 bbl/hr or more, so drilling can continue.

Fractured formations (either natural or induced) are the suspects for most severe lost circulation cases. These conditions are not restricted to particular formations (can occur in sandstone, carbonate and shale). Identified typically as the cause in fields where no pattern is apparent. Natural fractures in sandstone and shale typically need excessive pressure in the well-bore to cause them to open and therefore take fluid, while in carbonates they remain open and will accept fluid readily. The carbonate formation with natural fractures can have total losses if enough fractures are present in the well-bore. Induced fractures can be minimized through controlled drilling practices. Use mud weights that yield pressures equal to the pore pressure of the formation of concern plus 200 psi.

With an understanding of the formations and their properties the next step is to have a drilling program designed in accordance with this information. As a part of that program a predefined method to deal with lost circulation should be included. Control of downhole pressures is essential. Mud properties are key to this control. These include the density, viscosity and fluid loss. Density affects the hydrostatic pressure of the fluid in the well-bore while the viscosity and fluid loss characteristics influence the fluid friction. The Equivalent Circulating Density (ECD) is the measure of the combined effect of the hydrostatic pressure of the fluid in a well-bore plus the created friction while the fluid is being circulated.

$$ECD = \frac{P_{total}}{(0.052 \bullet TVD)}$$

$$P_{total} = P_{hydrostatic} + P_{friction}$$

During drilling operations to control or restore circulation reduced ECD's is a key. Reduction in ECD's involves reduce pump rate, lowered mud density and/or a change in the mud properties (plastic viscosity, yield point, fluid loss and/or gel strength). When ECD's have been reduced as far as safely possible pump bridging materials or some form of a plug. Bridging materials are numerous and over the years everything imaginable has been tried. **Table 1** lists the types of losses in returns possible during drilling along with what rate of loss characterizes this type. In **Table 1** also are possible remedies for these loss situations. **Table 2** lists some of the common bridging materials used today. One study conducted determined that the seal of a lost circulation zone must take place inside the opening not on the face of the well-bore.[3] It was further determined by this researcher that 15 pounds per barrel is the optimum quantity of lost circulation material to be added to a pill. If this pill doesn't work change the size or the distribution of the material instead of the concentration. Downside of using these materials is creation of problems with the mud, damage of a productive interval or limited by bit nozzle size. If circulation is still not under control pulling out of the hole and leaving the well-bore static for 8 to 24 hours the formation may heal allowing resumption of drilling operations (some areas 75% success rate).

Other forms of control or restoration include pills, soft plugs and hard plugs. All are meant to strengthen the well-bore. Pills pump as sweeps during circulation carrying lost circulation materials help to avoid losses before they occur. Plugs can be either soft or hard. The soft plugs are used to stabilize and the hard plugs to form barriers to pressure changes in the well-bore. Among soft plugs is the reactive system options where chemical reactions in the well-bore provide the resultant material desired.

During cementing operations the same causes of lost circulation during drilling also apply. The problems created by lost circulation during primary cementing operations are insufficient fill behind casing, Inter-zonal communication, formation damage and corrosion of exposed pipe[4]. Bridging materials are also used in these operations to control losses similar to the efforts in the drilling operations. In addition, mechanical methods, such as cement baskets, external casing packers, multistage tools and liners are employed in an effort to obtain a good cement job. Other methods include foaming with nitrogen mud ahead of cement and/or the cement slurries themselves. Spacers or pre-flushes ahead of cement slurries can be used for control.

This paper presents a case history representative of several cases where a natural material has been used as a pill during drilling operations to restore circulation. Case histories are also presented where the same material has been used ahead of cement to provide control allowing circulation where unable to achieve and where better bonding needed. Lastly two case histories are presented where the use of this material has made it possible to remove the use of a multistage tool.

Environmentally Preferred System

The environmentally preferred system that was utilized in the following case histories is a water based system with a natural polymer added. The typical blend for a spacer ahead of a cement job where losses are minor is 15 ppb of the polymer. If loss conditions are worse then additional polymer is added. In addition, to the base system a solid lost circulation material may be added. This is added at anywhere from 15 to 25 ppb of the system. This lost circulation material is composed of another natural polymer and silicate particles. The system has been weighted up with barite. The system can either be batch mixed or mixed "on-the-fly".

The system pumped ahead of a cement slurry provides excellent control of leak-off by absorbing onto the rock face to minimize penetration. In addition to keeping the system intact, the absorbed layer assists in the leak-off control of the cement slurry which maintains the slurry properties designed for the job. It has been found to provide improved bonding with the formations.

CASE HISTORIES

Drilling Operations

Several wells drilled to produce the Wolfberry by an Operator in Glasscock County, Texas experienced complete loss in circulation of drilling fluid. This case history is just one of these wells in which these losses occurred. **Table 3** lists the descriptive parameters of the well-bore. During the drilling of the production hole on this Wolfberry completion, returns were lost completely at 5800 feet. For three days various pills and sweeps with all different kinds of lost circulation materials (paper, cottonseed hulls, etc.) were pumped with no success. The fourth day a 50 bbl pill of an all natural polymer carrying 30 pounds per barrel of a lost circulation material, also compose of a natural polymer and silicate particles was pumped down the drill string and through the PDC bit. The pill was weighted to 8.8 ppg to maintain wellbore pressure control as well as be compatible in density to the mud in the hole. The pill was pumped at two barrels per minute or slightly less and was followed by drilling fluid. The rig continued to pump at the 2 barrels per minute and within nine hours 60% returns had been established and 70% returns were achieved within 12 hours. At the attainment of 70% of the circulation volume drilling was resumed. The well was drilled to total depth (20 additional days) without any further losses.

All the other wells on which this has been applied under similar conditions of complete loss a minimum of 60% circulation has been achieved within 12 to 18 hours and most 100% within 18 to 24 hours. The quantity of polymer, lost circulation solids added and the volume of the pill varied. Pump rates were always 2 BPM or less until circulation reestablished.

Cementing Operations

Circulation

Southeastern New Mexico has many areas known for the inability to circulate cement to surface. In one area of Lea County one operator has used this natural polymer system as a spacer ahead of his cement with great results. **Table 4** lists the results of four of these wells. Three of the four wells used the same lead slurry composition, 35:65:6 Pozzolan:Cement:Bentonite mixed at 12.5 ppg, while the fourth used 50:50:10 mixed at 11.8 ppg. All four wells used the same tail slurry composition. **Table 5** gives the wellbore configuration variances for the four wells.

Bond Logs

An operator in Andrews County, Texas was looking for improved bonding in his wells. In order to achieve this improved bond the new spacer system was utilized. **Figure 1** is a portion of a bond log on a well where the spacer system was not used. At 4540 feet is the top of the tail cement slurry. **Table 6** lists the well information. The lead slurry consisted of 800 sacks of a 50:50:10 Pozzolan:Cement:Bentonite system with additives mixed at 11.8 ppg and the tail was 200 sacks of a 50:50:2 system with additives mixed at 14.2 ppg. The slurries were mixed and pumped 4.5 to 7 BPM and displacement was at 3 to 7 BPM. The spacer ahead of the lead was 10 barrels of fresh water. 61 sacks of cement were circulated to the pit.

Table 7 lists the values for the second well where 20 bbls of the new spacer system was pumped ahead of the cement. The cement slurries composition and volumes were identical to those used on the offset. All rates were also nearly the same. **Figure 2** illustrates the same section in the well where the top of the tail slurry should be. The bonding is significantly improved. This job also had an additional 25 sacks of cement circulated to the pit.

Two Stage Cementing Replaced by One

Southeast New Mexico Case History

In Southeast New Mexico there are numerous areas which have lost circulation zones. Drilling and cementing in these areas that have loss circulation zones is usually difficult and have numerous costly conventional solutions (if they work). Most operators choose to perform 2-stage jobs in order to bypass loss circulation zone and to keep from fracturing into formation with cement due to weaker zones. A new environmentally preferred spacer has been utilized in the cementing system which has yielded excellent results. By studying past job failures and recent successes, a solution to many of the lost circulation problems has been obtained by incorporating this spacer.

In this case study the operator drills grayburg wells to an average depth of 4000-4200 feet and has problems with loss circulation in the area of 3200-3400 feet. In the past few years several different approaches have been made to solve the problem of getting cement returns to surface with a good bond from casing to formation through out the well. Several wells were one staged with varying results using thixotropic cement ahead of the lead slurry to try to create a seal between the loss area and formation so that cement would then be able to be circulated to surface. A few wells were then cemented, removing the thixotropic slurry ahead with less than acceptable bonds above the interest zone and less bonding than previous wells in the interest zone. Findings concluded that few wells circulated cement only to have it fall back and some not to circulate cement at all, with the top of cement at 1600. 2 stage jobs were also pumped with better results. Cement was circulated most of the time but logs had indicated that there were gas cuts in the production area.

The next step was to perform 2 stage jobs with better slurry on the production zone that would hold down the gas. A 14.8 ppg slurry with good fluid loss numbers and with bonding agents added was used as the slurry for the first stage. The DV tool was then set at about 3200, just above the loss area. Second stage cement was an 11.8 ppg filler slurry with a 14.8 ppg neat cement as a tail around tool and loss area. An environmentally preferred spacer was then added to the two stage jobs resulting with full returns during cementing. Results for these slurries and job design were very successful. Cement is always circulated to surface and bond is 88% to 95% average over interest area.

Following the 2 stage jobs that were very successful, a one stage job was performed with DV tool in hole. Throughout the cementing operation circulation to surface was maintained. This demonstrated that the spacer accomplished sealing off the loss area. The one stage job was pumped with good results as demonstrated by the case studies below (Well #2).

Well #1

First case well was cemented using 40 Bbls of the environmentally friendly Spacer 190 sacks (14.8) @ 1.36 cu/ft per sack which is 258 cu/ft on the first stage. 99 sacks of the slurry were circulated. On the second stage the lead 375 sacks (11.8) @ 2.1 cu/ft with a tail 150 (14.8) @ 1.34 cu/ft for 1247 cu/ft of cement pumped on the second stage. 75 sacks of the lead were circulated. A total of 296 cu/ft were circulated during job. There was no fall back, the top of cement was at surface. This well was 45 ft deeper than the one stage that followed. Interest zone shows an average bond of 95% (**Figure 1**)

Well #2

Second case well was cemented by utilizing a one stage job and pumping 40 Bbls of the environmentally friendly spacer. Lead was 425 sacks (11.8) @ 2.1 cu/ft and a tail of 190 sacks (14.8) @ 1.36 cu/ft. 1151 cu/ft of cement was pumped. 101 sacks of the lead was circulated which was 212 cu/ft. Top of cement was at surface with no fall back as previously noted with one staged wells in this field. Bond is 96% throughout the interest zone (**Figure 2**). Bond throughout the well from TD to surface was excellent. Both wells are located in same area of the field.

Elimination of the two stage job saved the customer time and money. Monetary savings included tools and an operator ($11,220), and rig time ($3,750). Total cost savings of using the new spacer ahead of the cement to eliminate the second stage cementing operation was $19,600. In addition, a bond log run on the well shows improved bonding over the two stage offset. Another positive point is that cement is being circulated to surface with no fall back.

Alaska

In Alaska, the Cook Inlet area operator will typically drill to a 7,000’ TVD Tyonek/Beluga formation target with a stage tool set around 3,500’ to 4,000’ due to the depleted Sterling formation. This formation has proven notorious for hole sloughing, differential sticking, and lack of zonal isolation due to poor cement coverage. With the two stage method it is not uncommon to have to perform top out jobs and/or squeeze jobs to satisfy the state's requirement for top of cement. With the two stage process, the Alaska operator was finding results much like that in New Mexico. Lack of cement circulation, cement fallback, poor bond logs, and expensive operating costs were the norm.

The first well out of a six well campaign was identified as a candidate an attempt at alleviating remedial cement work. It would include this new spacer, in conjunction to new ultra light weight, high strength cement. The well was a planned two stage with plans for future single stages if the products pumped successful.

Well #1

First case well was cemented in two stages. Stage #1 was cemented with 24 bbls of the environmentally friendly spacer weighted to 10ppg and 238 sacks of single gas tight slurry yielding 712 ft^3 weighted to 10.5ppg. 168 ft^3 was circulated. Stage #2 was cemented with 24 bbls of environmentally friendly spacer weighted to 10ppg and 56 sacks of the same cement slurry weighted to 10.5ppg Both stages went as planned with no cement fallback. The operator was very pleased with the execution, and cement placement of the job. The bond yielded questionable results but still better than typical past with excellent zonal isolation. Enough time was not given to the curing to the cement up the wellbore as well as to the lack of pipe movement during the job and the proper calibration of the logging tool to the nature of the light weight cement.

Well #2

Second case well was cemented as a single stage job pumping 24 bbls of the environmentally friendly spacer weighted to 10ppg and 284 sacks of single 10.5 ppg gas tight slurry yielding 848 ft^3. Cement was circulated to surface and no fall back was observed. The rig reciprocated and rotated the casing during cementing. Proper compressive transit and acoustic impedance data was supplied to the logging company providing a much improved bond log over Well Case #1. The remainder of the wells was cemented in a very similar fashion.

To date, all two stage jobs in the Alaskan Cook Inlet area have been eliminated by virtually all operators in the area in response to this new spacer.

CONCLUSIONS

1. Severe losses (100% Loss) during drilling can be restored to 60% of circulation within 9 to 12 hours using a new environmentally preferred system and in most cases to 100% within 18 to 24 hours.
2. Using the new system as a spacer ahead of a primary cement operation gave one operator circulation of cement to surface in area known for not getting circulation.
3. Improved bonding of cement systems is shown as a result of pumping the natural polymer spacer ahead of cement.
4. A substantial cost savings to operators has been found where using this spacer can eliminate a two stage operation.

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NOMENCLATURE

BPM	Barrels Per Minute
ppg	Pounds Per gallon
ECD	Equivalent Circulating Density
Bbls	Barrels
OD	Outside Diameter
Sks	Sacks
BPH	Barrels Per Hour
Ppb	Pounds Per Barrel

REFERENCES

1. Jordan, A, 2009, Lost Circulation, Tomball, Texas, USA (July 6, 2009).
2. Coronado, J. A. and Metcalf, A. S.: "Permian Basin Wolfberry: Stimulation Evolution and Economic Optimization," paper SPE 140724 presented at the SPE Production and Operations Symposium, Oklahoma City, Oklahoma, 27-29 March, 2011.
3. Green, B. Q.: "New Tests Show Which Lost-Circulation Materials to Use and How to Use Them," Oil and Gas Journal, (March 1959) 110-115.
4. Metcalf, A. S., Purvis, D. and Stilwell, S.: "Wellbore Re-entries and Repairs: Practical Limits of Cementing New Casing Inside Existing Casing," paper SPE 124381 presented at the 2009 SPE Annual Technical Conference and Exhibition, New Orleans, La., 4-7 October, 2009.

Table 1 – Amount of losses during drilling and remedies

Amount of Loss in Returns	Rate of Loss, BPH	Remedy
Seepage	1 – 15	Continuously add 1 – 2 sks of fine cellulosic fiber and 1 – 2 sks Gilsonite per drilling hour
Partial	15 - 30	Pump 40 – 60 bbl sweeps w/ 10 ppb each of fine and coarse cellulosic fiber plus 10 ppb medium Kwik-Seal
Continued Partial	15 – 30	Pump reactive silicate (20 bbls) and calcium chloride water to set up the silicate w/ fresh water spacers
Severe or Complete	30+	Pump 40 – 60 bbl sweeps w/ 10 ppb each of fine and medium Kwik-Seal + ½ -1 ppb XC polymer + 5 ppb Gilsonite + 5 ppb fine cellulosic fiber and barite as needed to weight
Continued Severe or Complete	30+	Pump reactive silicate (20 bbls) and calcium chloride water to set up the silicate w/ fresh water spacers

Table 2 – Commonly used bridging materials to combat lost circulation

Screened Sawdust	Spun Mineral Fiber
Shredded Cedar Bark	Shredded Rubber
Cellophane Flakes	Sized Graphite
Cottonseed Hulls	Sized Laminate
Shredded Paper	Mica
Walnut Shells	Granular Thermoset Rubber
Pecan Shells	Shredded Cane Fiber

Table 3 – Drilling case history well description

Parameter	Value
Bit	8.75 inch PDC with 316 and 312 nozzles
TD	10850 feet
Production Casing	4.5 inch 16.6 pounds per foot
Surface Casing	8.625 inch 24 pounds per foot
Depth Surface Casing	1100 feet

Table 4 – Wells cemented using new spacer				
Well	Volume Lead Slurry	Volume Tail Slurry	Spacer Volume (% Additional Polymer)	Sacks Cement Circulated
1	950	700	60 (25)	313
2 – First Stage	600	400	60 (25)	274
3 – First Stage	300	650	65	300
4	350	330	60 (25)	181

Table 5 – Wellbore differences for the four wells where cemented circulated for first time				
Well	Hole Diameter, inches	Depth, feet	Casing OD, inches	Casing Weight, pounds per foot
1	8.75	7628	5.5	17
2	8.75	7708	5.5	17
3	7.875	7000	5.5	17
4	7.875	7315	5.5	17

Table 6 – Well cemented without spacer	
Parameter	Value
Hole Diameter	7.875 inches
Casing OD	5.5 inches
Casing Weight	15.5 pounds per foot
Depth	4757

Table 7 – Well cemented with spacer	
Parameter	Value
Hole Diameter	7.875 inches
Casing OD	5.5 inches
Casing Weight	15.5 pounds per foot
Depth	4925

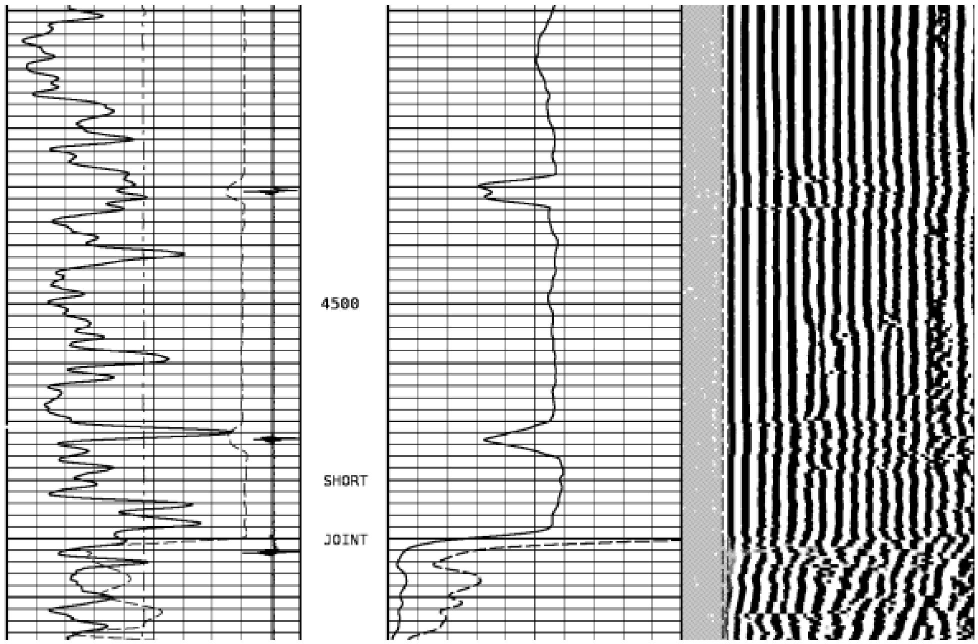

Figure 1 – Bond log section at top of tail slurry on well without new spacer ahead of cement.

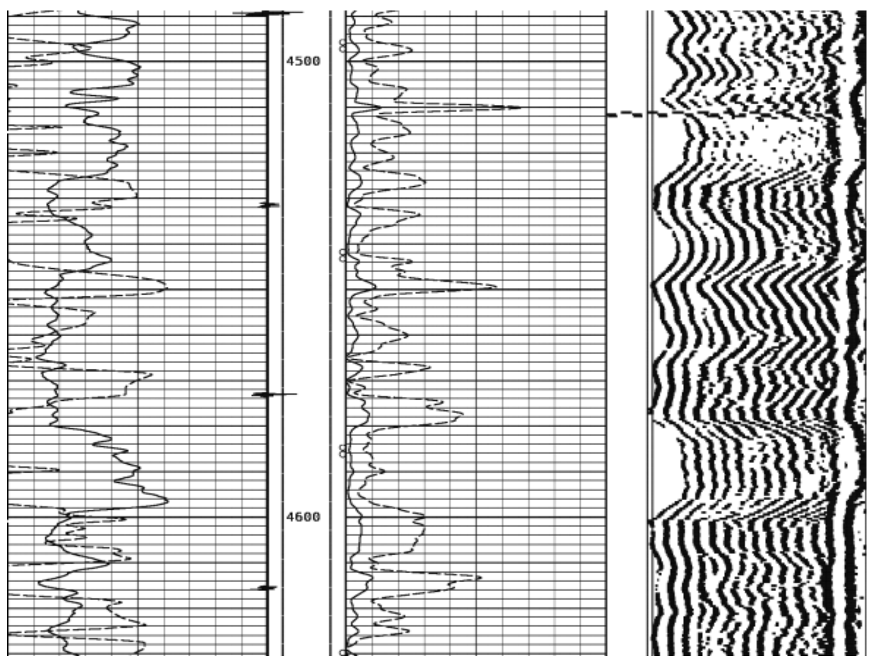

Figure 2 – Bond log section at top of tail slurry on well without new spacer ahead of cement.

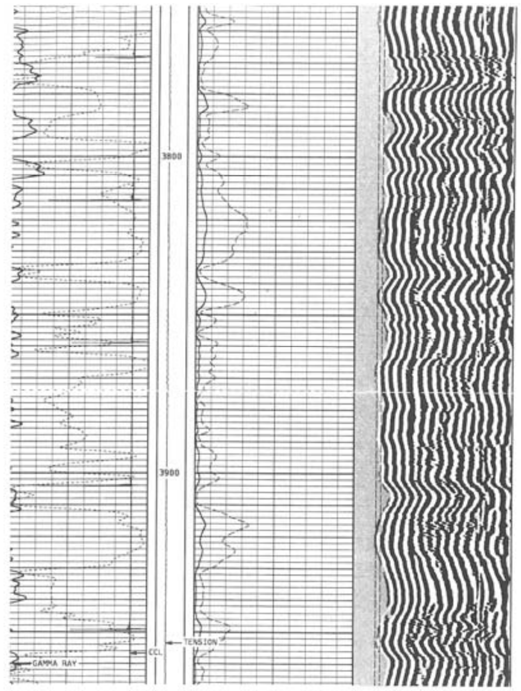

Figure 3 – Bond log across zone of interest in Well #1

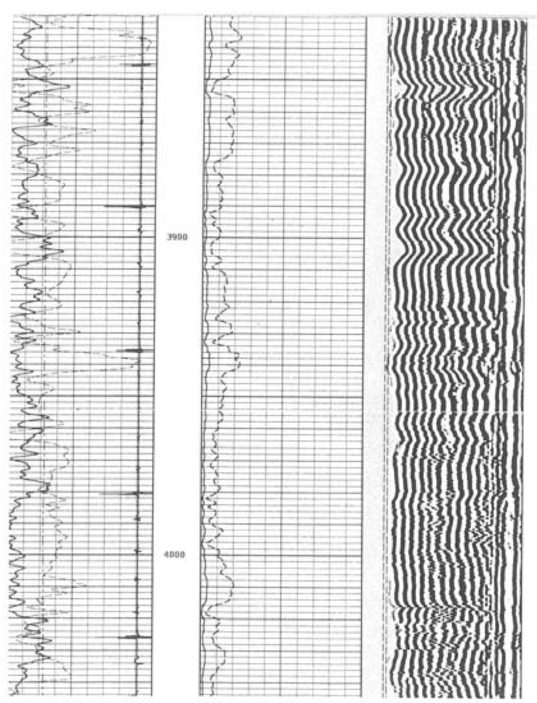

Figure 4 - Bond log across zone of interest Well #2