DEVELOPMENT OF BYPASSED OIL RESERVES USING BEHIND CASING RESISTIVITY MEASUREMENTS

Santa Fe Springs Field, Los Angeles County, California[1]

Semiannual Technical Progress Report

Reporting Period Start Date: February 14, 2004
Reporting Period End Date: August 14, 2004

Prepared By: Michael G. Conner, Terra Exploration and Production Company
Jeffrey A. Blesener PE, Consulting Petroleum Engineer

February 7, 2005

DOE Solicitation No.: DE-PS26-02NT15377
DOE Award Identification No.: DE-FG26-03NT15435

TERRA EXPLORATION AND PRODUCTION COMPANY
1250 E. 23RD – Second Floor
SIGNAL HILL, CALIFORNIA 90755-3502

DISCLAIMER

ABSTRACT

Tubing and rods of the S.P. Pedro-Nepple #1 well were pulled and the well was prepared for running of Schlumberger's Cased Hole Formation Resistivity Tool (CHFR) in selected intervals. The CHFR tool was successfully run and data was captured. The CHFR formation resistivity readings were compared to original open hole resistivity measurements. Separation between the original and CHFR resistivity curves indicate both swept and un-swept sand intervals. Both watered out sand intervals and those with higher remaining oil saturation have been identified. Due to the nature of these turbidite sands being stratigraphically continuous, both the swept and unswept layers have been correlated across to one of the four nearby offset shallow wells. As a result of the cased hole logging, one well was selected for a workover to recomplete high oil saturated shallow sand intervals.

During the second report period, well S.P. Pedro-Nepple #2 was plugged back with cement excluding the previously existing production interval, squeeze cemented behind casing, selectively perforated in the shallower "Bell" zone and placed on production to develop potential new oil reserves and increase overall well productivity. Prior workover production averaged 3.0 BOPD for the previous six-months. Post workover well production was marginally increased to 3.7 BOPD on average for the following six-months.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Potential oil reserves remain in selected turbidite sand sequences of the Santa Fe Springs Field in Los Angeles County, California. Many productive zones of the field have been waterflooded where more permeable sand layers have preferentially watered out. It is suspected the flood fronts have bypassed lower permeable, yet oil saturated sand intervals. Due to low salinity formation water, more conventional TDT logs are not suitable in detecting hydrocarbons behind cemented casing. The project uses cased-hole resistivity measurements to identify higher oil saturated sands. Up to four wells will be perforated and placed on production to develop behind-flood-front oil sands in marginal stripper production wells. If lower-sand potential exists, one well may be deepened.

There are five active producing wells in the “Pedro-Nepple” and “Fulton” leases of the Santa Fe Springs Field. Four of the five wells range in depth from 3,841 feet to 4,505 feet. The deep well, S.P. Pedro-Nepple #1, has a total depth of 10,152 feet, thereby penetrating all of the sand intervals of the four offsetting shallow production wells.

Tubing and rods of the S.P. Pedro-Nepple #1 well were pulled and the well was prepared for running of Schlumberger’s Cased Hole Formation Resistivity Tool (CHFR) in selected intervals. The CHFR formation resistivity readings were compared to original open hole resistivity measurements. Separation between the original and CHFR resistivity curves indicate both swept and un-swept sands. Both watered out sand intervals and those with higher remaining oil saturation have been identified. Due to the nature of the turbidite sands being stratigraphically continuous, both the swept and unswept layers have been correlated across to one of the four nearby offset shallow wells. As a result of the cased hole logging, up to four well workover projects have been identified. One of these four wells, S.P. Pedro-Nepple #2, is planned to be plugged out of the existing interval, selectively perforated and placed on production to develop potential new oil reserves and increase overall well productivity.

Approximately six potential pay zones were evaluated using the CHFR tool in the S.P. Pedro-Nepple #1 well. The following table outlines the zones, approximate CHFR logged footage and potential pay intervals:

Logged Zone	Logged Depths, Ft.	Potential Pay
Shallow Gas	2265-2329	Yes, 2282-2292
Terra	3060-3226	Yes, 3071-3120
Foix	3464-3625	Yes, 3478-3496
Bell	3858-3990	Yes, 3887-3935
Meyer	4311-4640	No
O-Connell	7344-7588	Possible, 7510-7520

Many, if not all, of the offset wells will require remedial circulation cement squeezes performed to isolate the proposed recompletion intervals prior to perforation. Many, if not all, of the offset wells did not have primary cementing displaced high enough to cover the potential recompletion zones that the CHFR log identifies.

In May 2004, a workover program to recomplete a shallow zone identified by the CHFR log was completed in well S.P. Pedro-Nepple #2. The well was plugged back with cement excluding the previously existing production interval in a deeper zone, squeeze cemented behind casing, selectively perforated in the shallower "Bell" zone and placed on production to develop potential new oil reserves identified by the CHFR log and increase overall well productivity. Since the well did not have primary cement behind casing high enough to exclude water sands, a circulation cement squeeze was attempted to isolate the target zone. Even though the circulation cement squeeze operation went well and according to program, an ensuing CBL showed less than desirable bonding across the target interval. It was decided to move forward without doing any additional secondary block squeeze cementing. Approximately 4, 0.4-inch holes-per-foot jet perforations were shot the two prospective intervals identified by the CHFR log from 3935' to 3927' and 3917' to 3912'.

Prior workover production averaged 3.0 BOPD for the previous six-months. Post workover well production was marginally increased to 3.7 BOPD on average for the following six-months. The project has resulted in an incremental cumulative production of approximately 77 barrels of oil with no significant increase in water production.

EXPERIMENTAL

In an active waterflood, determining the flood-front position usually requires the use of open hole resistivity logs. This method works well in a field that has an active infill-drilling program where new open hole log data can be obtained at regular intervals over time. Traditional cased-hole logs have been inconclusive as flood-front monitoring tools.

Pulsed neutron tools, such as the carbon/oxygen and thermal-decay rate tools (TDT), also have limited application and provide inconclusive results. The low salinity of the formation and injected water has made it difficult for the thermal-decay rate tools to discern oil from the water phase[2].

The Cased Hole Resistivity (CHFR) Tool

Schlumberger Well Services has developed a commercially available tool that measures formation resistivity in cased holes [3]. The resistivity measurement is made independently of the salinity of the formation fluid and porosity. The depth of investigation is substantially beyond the near wellbore, beyond the influence of flushing from drilling mud filtrate. Other applications include using this tool to log wells through casing in older wells where open hole logs were not available at the time.

The CHFR is a pad contact-type tool where the logging sonde must come to a complete rest within the well in order to establish electrical coupling with the existing well casing. As the tool stops at each depth, the contact pads couple with the casing and directly measure formation resistivity for that single depth. Each stop represents one resistivity measurement. Therefore, several stops must be made approximately 2–4 feet apart in selected intervals of interest in order to develop a potential pay zone resistivity profile. According to the tool vendor, each stop and respective measurement takes approximately 3-5 minutes to obtain a reading. The tool does not accurately measure behind casing resistivity at the casing collars, so the tool must be either raised or lower accordingly.

The CHFR log was run successfully on January 10-11, 2004. The logging engineer had some difficulties testing the tool on the surface, extending and contracting the contact pad apparatus. Following these difficulties, the tool had no other problems running in and out of the 7-inch cased hole.

Once logging commenced with a formation resistivity measurement at each stop of the tool, it became apparent the tool logging speed is slower than we anticipated. The time duration at each stop varied and required between 4-8 minutes for the tool to stabilize and measure consistent readings. There were numerous times the tool could not measure formation resistivity due to a stop that coincided at a casing collar. The tool would then be moved either up or down a couple feet and successfully measured.

Approximate Gross Footage of Logged Interval

Log Interval Depths	Feet	Potential Pay Interval	Feet	Zone	Original Resist. ohm-m
7950 - 7900	50	7940 - 7924	26	Hathaway	13.5
7560 - 7500	60	7552 - 7510	42	O'Connell	7 - 9.5
7450 - 7400	50	7447 - 7415	32	O'Connell	9.5
4620 - 4530	90	4607 - 4530	77	Meyer (M6)	8 - 40+
4515 - 4425	90	4508 - 4430	78	Meyer (M5)	11 - 16
4400 - 4320	80	4396 - 4335	61	Meyer (M3)	70 - 80
3975 - 3880	95	3920 - 3885	65	Bell	13.5 - 16
3515 - 3470	45	3511 - 3477	34	Foix	20
3180 - 3070	110	3172 - 3072	100	?	9 - 14
2310 - 2270	40	2305 - 2276	29	Gas?	11.5
	710		544		

Approximately 580 resistivity measurement stops were made to evaluate the 710 feet of intervals listed above. Some of the intervals include sections with numerous hard, cemented, calcareous sands commonly called ‘bones’ or ‘shells’ that are very resistive. Not having a porosity log for the original open hole, it is difficult to discern the higher resistivity intervals as these hard streaks from oil saturated pay sands. Given a choice, candidate well selection should include a well where porosity logs are available.

The CHFR formation resistivity readings were compared to original open hole resistivity measurements. Separation between the original and CHFR resistivity curves indicate both swept and un-swept sand intervals. Both watered out sand intervals and those with higher remaining oil saturation have been identified. Due to the nature of these turbidite sands being stratigraphically continuous, both the swept and unswept layers have been correlated across to one of the four nearby offset shallow wells.

Well S.P Pedro-Nepple #2 Workover

Since there are some unmapped faults in the area, a well nearest the S.P. Pedro-Nepple #1 well was to be recompleted into a shallow zone. The nearest offset well, S.P. Pedro-Nepple #2 has been plugged back with cement excluding the previously existing production interval in a deeper zone, squeeze cemented behind the 7-inch casing, selectively perforated in the shallower “Bell” zone and placed on production. Since the well did not have primary cement behind casing high enough to exclude water sands, a circulation cement squeeze was attempted to isolate the target zone. Even though the circulation cement squeeze operation went well and according to program, an ensuing CBL showed poor to fair bonding across the target interval. It was decided to move forward without doing any additional secondary block squeeze cementing. Approximately 4, 0.42-inch holes-per-foot jet perforations were shot in the two prospective intervals identified by the CHFR log from 3935' to 3927' and 3917' to 3912'. Schlumberger did the perforating immediately following the running of the CBL tool. Schlumberger used 4-inch “HEGS” guns with 22.0-gram charges. Specified penetration depth is 21.7 inches. The perforating job went well and all shots fired.

Prior workover production averaged 3.0 BOPD for the previous six-months. Post workover well production was marginally increased to 3.7 BOPD on average for the following six-months. The project has resulted in an incremental cumulative production of approximately 77 barrel of oil with no significant increase in water production.

RESULTS AND DISCUSSION

Tubing and rods of the S.P. Pedro-Nepple #1 well were pulled and the well was prepared for running of Schlumberger's Cased Hole Formation Resistivity Tool (CHFR) in selected intervals. The CHFR log was run successfully on January 10-11, 2004. The logging engineer had some difficulties testing the tool on the surface, extending and contracting the contact pad apparatus. Following these difficulties, the tool had no other problems running in and out of the 7-inch cased hole.

The CHFR formation resistivity readings were compared to original open hole resistivity measurements. Separation between the original and CHFR resistivity curves indicate both swept and un-swept sands. Both watered out sand intervals and those with higher remaining oil saturation have been identified. Due to the nature of the turbidite sands being stratigraphically continuous, both the swept and unswept layers have been correlated across to one of the four nearby offset shallow wells. As a result of the cased hole logging, up to four well workover projects have been identified.

Approximately six potential pay zones were evaluated using the CHFR tool in the S.P. Pedro-Nepple #1 well.

Approximate CHFR Logged Footage and Potential Pay Intervals

Logged Zone	Logged Depths, Ft.	Potential Pay
Shallow Gas	2265-2329	Yes, 2282-2292
Terra	3060-3226	Yes, 3071-3120
Foix	3464-3625	Yes, 3478-3496
Bell	3858-3990	Yes, 3887-3935
Meyer	4311-4640	No
O-Connell	7344-7588	Possible, 7510-7520

Many, if not all, of the offset wells will require remedial circulation cement squeezes performed to isolate the proposed recompletion intervals prior to perforation. Many, if not all, of the offset wells did not have primary cementing displaced high enough to cover the potential recompletion zones that the CHFR log identifies. In order to test the CHFR logging results, one of these four wells, S.P. Pedro-Nepple #2, is planned to be plugged out of the existing interval, selectively perforated and placed on production to develop potential new oil reserves and increase overall well productivity.

In May 2004, a workover program was performed to recomplete the shallower "Bell" zone sands where the CHFR log showed moveable hydrocarbons remaining. Since the well did not have primary cement behind the 7-inch casing high enough to exclude water sands, a circulation cement squeeze was attempted to isolate the target zone. Even though the circulation cement squeeze operation went well and according to program, an ensuing CBL showed poor to fair bonding across the target interval.

Approximately 4, 0.42-inch holes-per-foot jet perforations were shot in the two prospective intervals identified by the CHFR log from 3935' to 3927' and 3917' to 3912'.

Prior workover production averaged 3.0 BOPD for the previous six-months. Post workover well production was marginally increased to 3.7 BOPD on average for the following six-months. The project has resulted in an incremental cumulative production of approximately 77 barrel of oil with no significant increase in water production.

The resulting low production may be due to the following possibilities:

1. The secondary cementing operation damaged the formation and the perforations did not penetrate beyond the damaged zone.

2. The well continues to produce with 700 feet of FOP. Increasing pump displacement will draw the fluid down and increase fluid entry, thereby increasing oil production rate.

3. Even thought the test well was selected due to its proximity near the CHFR logged well, S.P. Pedro-Nepple #1, is may still be separated by minor faulting and in a different reservoir compartment.

4. The captured CHFR log data resistivities may be in error and has led to an incorrect interpretation.

CONCLUSION

In January 2004, the CHFR cased hole tool was successfully run and measured formation resistivity through 7-inch casing in an older Santa Fe Springs Field production well. The CHFR appears to have identified four potential pay intervals in shallower zones, above the existing production intervals in the existing lease wells. Potential pay intervals could be correlated stratigraphically to the offset wells where recompletion opportunities may increase reserves and overall productivity.

Initially, the tool had some mechanical difficulties, but this was addressed and no other problems occurred. The logging speed is slow as the tool is not continuously reading and recording. The tool must come to complete rest, making direct contact with the casing, measuring formation resistivity through the casing string.

When an infill drilling program is not practical to track flood fronts, the tool indicates it is capable of determining behind casing formation resistivity, therefore, water saturation. Some of the intervals include sections with numerous hard, cemented, calcareous sands commonly called ‘bones’ or ‘shells’ that are very resistive. Not having a porosity log for the original open hole, it is difficult to discern the higher resistivity intervals as these hard streaks from oil saturated pay sands. Given a choice, candidate well selection should include a well where porosity logs are available.

In May 2004, well S.P. Pedro-Nepple #2 was plugged back with cement excluding the previously existing production interval in a deeper zone, squeeze cemented behind casing, selectively perforated in the shallower “Bell” zone and placed on production to develop potential new oil reserves identified by the CHFR log and increase overall well productivity. Even though the results of the CHRF log indicated the presence of movable hydrocarbons, the resulting production from the workover is less than anticipated and, at the present oil rate, will not pay out the cost-shared investment in this well.

Further review of the resulting production performance indicates the well could be pumped at higher rates to reduce the FOP. The well currently has 700-feet of FOP that could reduce oil entry into the wellbore with the resulting head restriction. Attempts will be made by the operator to reduce the FOP and increase oil production rate.

REFERENCES

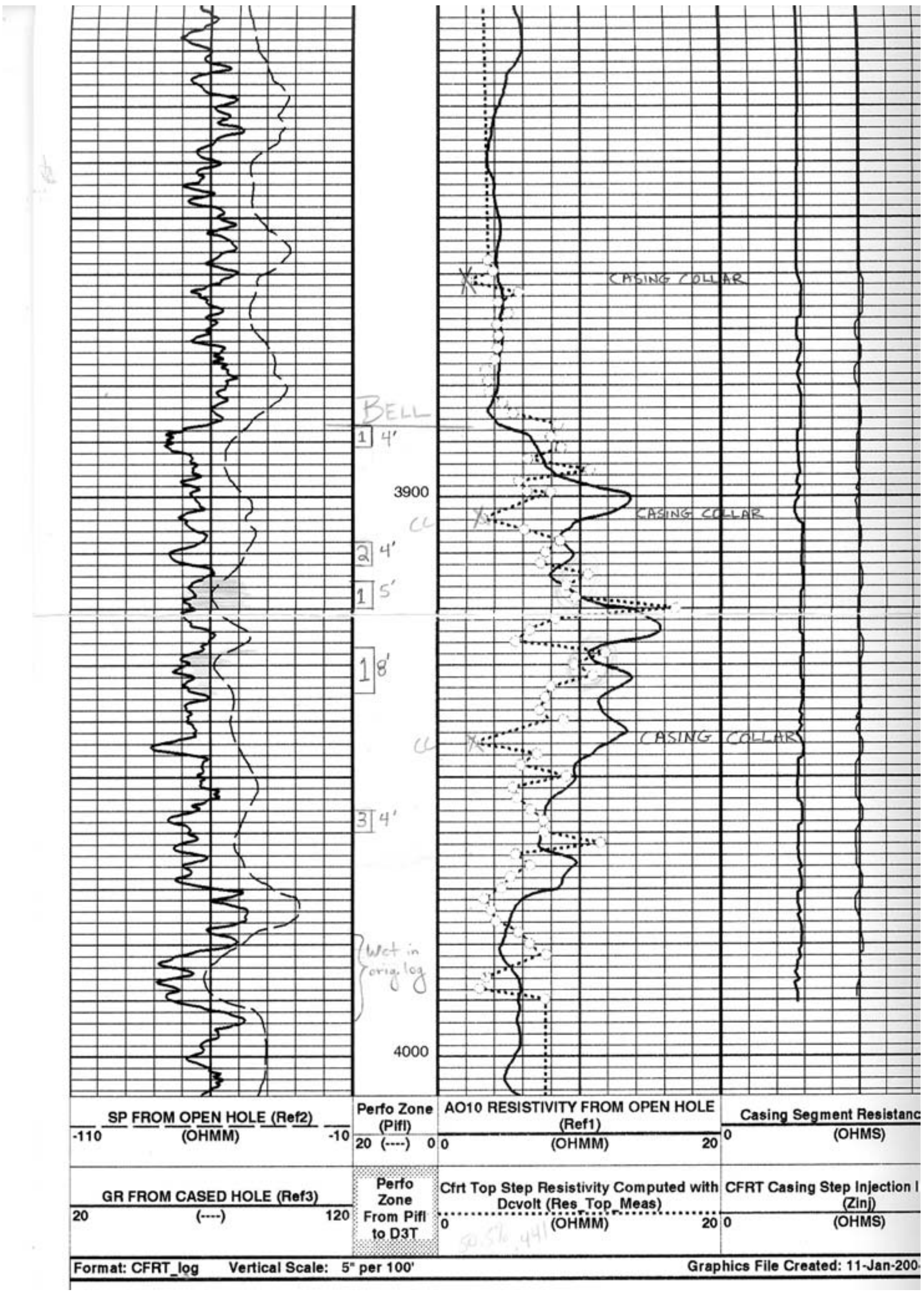
1. California Division of Oil, Gas and Geothermal Resources, Summary of Operations - California, Vol. 43, No.2, 1957.
2. M. Starcher, D. Mut, M. Fontanarosa, B. Davis, C. Presmyk. "Waterflood Surveillance: Behind Casing Resistivity Measurement at Elk Hills", Society of Petroleum Engineers, *Journal of Petroleum Technology*, October 2002.
3. Schlumberger Internet website:
   http://www.oilfield.slb.com/content/services/formation/analysis/chfr.asp

LIST OF ACRONYMS AND ABBREVIATIONS

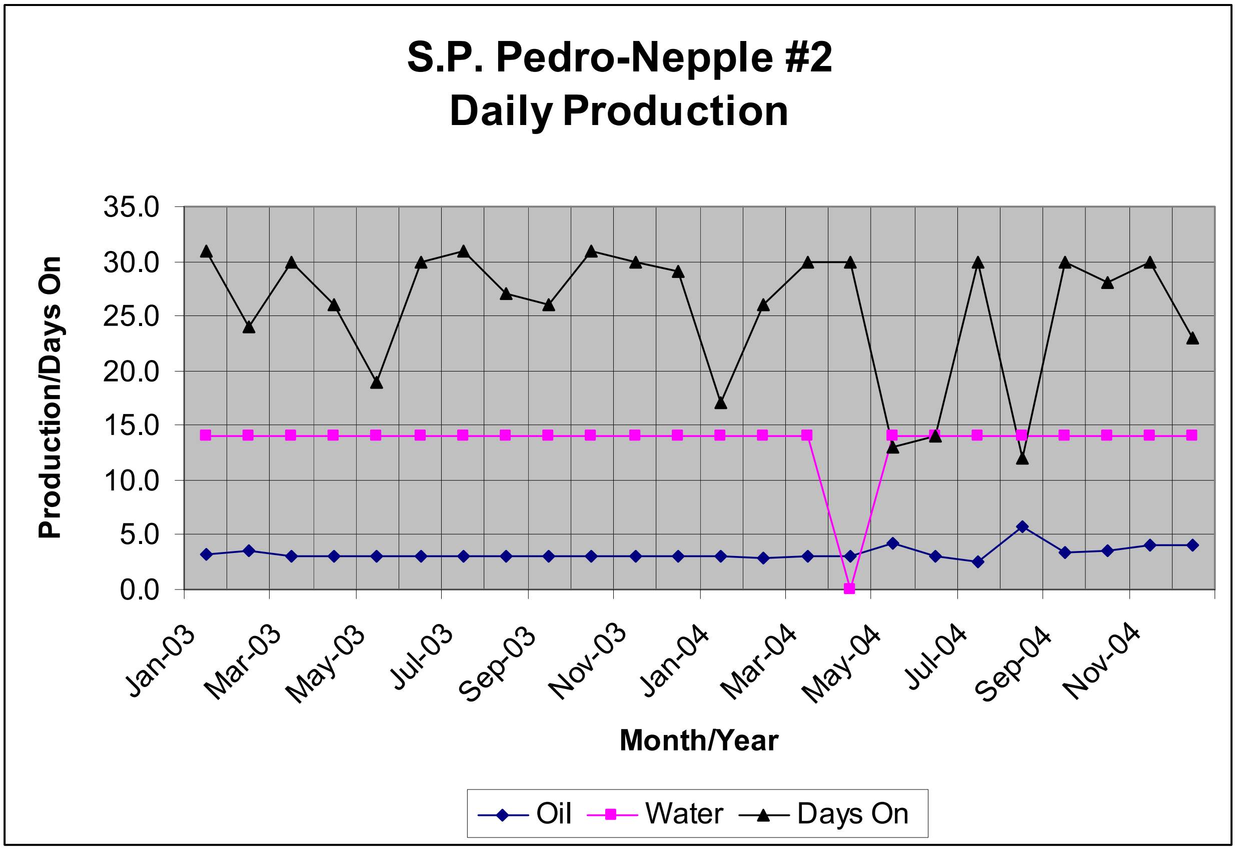
BOPD:	Barrels Oil Per Day
CBL:	Cement Bond Log
CCL:	Casing Collar Log
CHFR:	Cased Hole Formation Resistivity tool
DOGGR:	California Division of Oil, Gas and Geothermal Resources
FOP:	Fluid Over the Pump
GR:	Gamma Ray
OH:	Open Hole
TDT:	Thermal Decay Tool
USI:	Ultra-Sonic Imager

GRAPHICAL MATERIALS

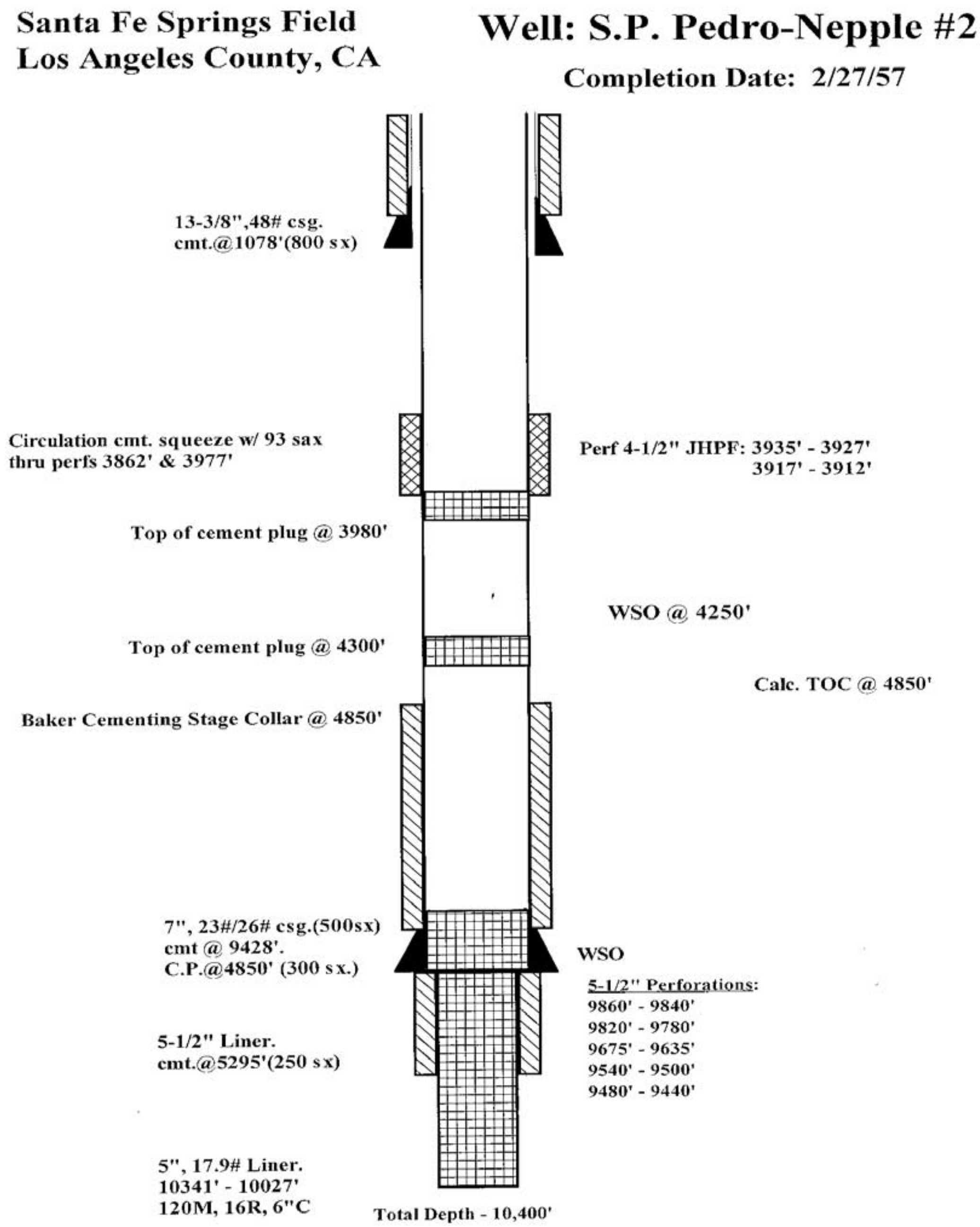
1. CHFR log example – Bell Zone (Logged date: January 11, 2004)



2. S.P. Pedro Nepple #2 Production Plot



Recompletion workover occurred in May 2004. Daily oil production has marginally increased to an average of 3.7 BOPD from the previous 3.0 BOPD.



S.P. Pedro-Nepple #2 – Well Mechanical Diagram

Diagram indicates uphole secondary cement squeeze and recompleted interval.