WELL CASING CATHODIC PROTECTION EVALUATION PROGRAM IN THE SPRABERRY (TREND AREA) FIELD

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ABSTRACT

Pioneer Natural Resources is currently undertaking a study of well casing failures in the Spraberry (Trend Area) Field located primarily in Midland County, Texas. Failure trend studies indicate a high incidence of external casing failures in the San Andres formation, a known saltwater-bearing and saltwater disposal formation that generally has substantial H2S content. Several well casings were selected as candidates for down-hole inspection logs to determine if cathodic protection could be a viable solution to the external corrosion problem. "Test" cathodic protection systems were installed and down-hole tools were utilized both prior to and after energizing the systems to assess the external condition of the well casing. Anodic/cathodic areas and axial current flow patterns identified on the logs were correlated to previously conducted cement bond logs, casing inspection logs and gamma ray/neutron logs as well as areas of externally coated casing. Based on logging results and economic evaluation, implementation of a cathodic protection pilot project commenced on November 27, 2001.

INTRODUCTION

Pioneer Natural Resources' Spraberry (Trend Area) Field operating area is comprised of over 3,500 wellbores, with completion dates varying from the 1950's to present. Production in the Spraberry ranges from single well leases to large unitized areas encompassing hundreds of wells. Since the 1950's, both independent and integrated oil companies have exploited the Spraberry resource, and several of the older wellbores have changed operators multiple times. Drilling was a primary focus through the 1980's and 1990's. Although activity has slowed, drilling continues even today. However, maintaining low cost operations, not drilling, will dictate continued survival in the Spraberry.

Casing failures have been a major expense over the last three years, and trending failure history indicates a swiftly rising failure rate. Thirty-two (32) repairable leaks were recorded in 1999, sixty-seven (67) in 2000, sixty-seven (67) in 2001 and seventy-five (75) are projected for 2002. A closer study of individual failures revealed that 75% have occurred between 3,500' and 6,000', 15% occurred deeper, and only 10% occurred shallower.

External corrosion caused by the San Andres, a saltwater bearing and saltwater disposal zone, is suspected to be the primary cause of failures occurring below 3,500'. Six Pioneer-operated Spraberry Units, covering 270 sections, dispose of 60,000 BWPD into the San Andres. Table 1 shows a breakdown of the Spraberry Units, disposal volumes and recorded failures.

Many wells have known cement tops below the San Andres disposal zone. Even if these tops are above the San Andres, channeling in the cement is often extensive enough to allow corrosive San Andres water access to the casing and begin the external corrosion process. Attempts have been made to raise the top-of-cement above the San Andres and improve protection; however, the low frac gradient of the Upper Spraberry and the highly porous San Andres, have rendered many attempts unsuccessful or uneconomical. On selected wells completed since October 1999, an interval of externally coated casing was positioned through the San Andres. To date, no failures have occurred within the coated interval; however, three recorded failures have occurred at depths below the externally coated interval.

CATHODIC PROTECTION EVALUATION PROGRAM PROCEDURE

The cathodic protection (CP) evaluation program was conducted per NACE recommended practice RPO186-2001 and was defined as follows:

- Select well casing for evaluation
- Install "test" deep type cathodic protection groundbed
- Conduct "native state" down-hole log
- Conduct "CP applied" down-hole log(s)
- Evaluate resultant data

A review of well casing failures with respect to age of the well, depth of the failure and cement completion methodology was undertaken in order to identify potential wells for inclusion in the evaluation process. Key factors identified in this review include depth of the failure, low (below San Andres formation) cement completion, high (above San Andres formation) cement completion, externally coated casings, and bare casings. Consideration was also given to wells in close proximity to saltwater disposal wells in addition to unprotected offset wells to cathodically protected wells. A total of nine (9) wells representing either a single characteristic or a combination of the “key factor” characteristics were selected for the evaluation program.

One (1) well experienced a failure prior to on-site testing and was deemed uneconomical to repair. A partial test was completed on a second well, but was halted due to paraffin contamination. The testing was deemed uneconomical to complete at this location and was subsequently aborted. Complete testing was conducted on the remaining seven (7) wells.

CATHODIC PROTECTION

The most common form of corrosion can be generically identified as an electrochemical cell. This cell must have four (4) components; anode, cathode, electrolyte, and external circuit. Corrosion, with resultant metal loss, will occur at the anode as an oxidation reaction while the corresponding reduction reaction will occur at the cathode surface. The electrolyte provides an ion path for the chemical reaction while the external circuit must provide the electron path to complete the reaction. Naturally occurring anodes and cathodes are present on the surface of the steel casing as **a** metallurgical property of the steel while the moisture content of the soil serves as the electrolyte. The steel casing fulfills the role of electrical conductor as the external circuit. See Figure 1.

Cathodic protection is a method of corrosion control involving the application of a separate carefully designed electrochemical cell. This method provides a suitable anode to be consumed in the corrosion process while the structure to be protected is forced to be the cathode (thus the term *cathodic* ***protection).*** The soil continues to function as the electrolyte while cabling is provided as the external circuit. See Figure 2.

INSTALLATION OF “TEST CATHODIC PROTECTION SYSTEMS

Design parameters for the “test” cathodic protection installations were quantified as follows:

Anticipated d.c. current requirement: **7-8** amps

Anticipated circuit resistance: ***3*** ohms

Each cathodic protection “test” groundbed was specified as follows:

1 ea.	9” x 250’ drilled hole
5 ea.	4” x 80” linseed oil treated graphite anodes equipped with centralizers and individual No. 8 AWG/ HMWPE lead wires; longest lead 260’, each subsequent lead 10’ shorter
260’	1 ¼” perforated polyethylene vent pipe
6100#	(– 240’) metallurgical grade coke breeze backfill
500#	(– 10’) bentonite plug material (per TNRCC 0051 requirements)
1 ea.	5 circuit galvanized junction box equipped with hinged cover, hasp latch and individual Holloway type RS 0.01 ohm shunts

Portable test equipment and temporary negative header cable was utilized to energize the “test” groundbeds.

Cathodic protection “test” groundbeds were installed at the selected locations in accordance with the design specifications. All groundbeds were located between 125’ and 250’ of the wellhead.

SCHLUMBERGER CORROSION AND PROTECTION EVALUATION TOOL (CPET)

The Schlumberger Corrosion Protection and Evaluation Tool (CPET) is designed to identify and quantify on-going corrosion on the external side of the well casing. The tool consists of three (3) primary sections:

- Tool electronics section
- Electrode section
- Hydraulic section

The electrode section consists of four (4) sets of three **(3)** each metallic contacts oriented 120 degrees apart. Each set of contacts is separated by a distance of two (2) feet resulting in an overall separation of six **(6)** feet between the top and bottom sets of contacts. These contacts are mounted on hydraulically controlled arms which are typically retracted for the tool trip down-hole and extended for the logging trip up-hole. The hydraulics together with tool mounted springs result in contact pressure of approximately 50 pounds per square inch. A series of voltage readings coinciding with known applied currents are taken at each tool station stop. On-board processing applies Ohm's Law calculations to determine the casing resistance for that span. ***Axial current*** (defined as that current flowing up or down the casing) is calculated from the potential measurements and the calculated casing resistance - again using Ohm's Law. Axial current direction as well as magnitude is noted with positive current defined as that current moving up-hole and negative current as that current traveling down-hole. Differentiating this axial current with respect to depth results in a ***radial current density*** measurement. A positive radial current density is defined as current leaving the casing (anodic area) while negative radial current density is defined as current collecting on the casing (cathodic area).

CPET LOG DATA INTERPRETATION

It is evident from an understanding of the theory of the CPET tool operation that all calculations, including those for radial current density and axial current, hinge on the initial voltage measurements. Thus, if errors are introduced in the initial voltage measurements, these errors are translated to all subsequent calculations. Accurate initial voltage measurements are ***essential*** to obtaining a ''clean'' log run. Proper preparation of the well casing proved to be an important step in the evaluation and recommendations include: running a bit and scraper for paraffin/scale removal, setting a bridge plug above the top perforations, and loading the casing with fluid to allow for increased logging speed. Tool electrode contact resistance, which can be monitored during logging but is not normally a part of the final log presentation, is a critical part of the initial voltage measurement. However, the initial voltage measurements (which include contact resistance) are displayed on the normal log presentation and can be used as a checkpoint for data quality. Ideally, both the 2' and ***6'*** average potential difference measurements should closely "track" each other representing good correlation between the 2' and 6' voltage measurements. Where the two curves do not track indicates little or no correlation between the voltage measurements and as such, all subsequent calculations and representations could be in error. Thus, any indications of anodic or cathodic areas corresponding to these areas are somewhat questionable.

A second data quality checkpoint would be the calculated average casing resistance which is displayed on the normal log presentation. Again, 2' and 6' average casing resistances are presented with good "tracking" indicative of good tool electrode /casing contact. Typically, the casing collars can be distinguished on this presentation as areas of high casing resistance since the applied current must pass through the casing thread/collar/casing thread. This is an area of higher resistance when compared to that of the casing alone. Areas where the collars are not clearly evident could indicate inaccurate initial voltage measurements and thus, inaccurate representations of radial current density (anodic and cathodic areas) and axial current flow patterns.

Again, axial current is defined as current moving up or down the casing. Positive axial current is considered to be UP casing and negative current is considered to be DOWN casing. Careful analysis of this curve data reveals the native state, i.e. natural, current flow patterns on the casing, but more importantly, the current flow patterns after the application of cathodic protection. It is not unusual to note native state axial current flow patterns both up and down the casing (with associated current discharge noted as anodic on the radial current density curve) while ideally all current will be noted to collect on and travel UP the casing (positive axial current) during application of cathodic protection.

CPET LOG DATA CORRELATION

CPET log analysis can be strengthened with correlation to other sources of down-hole information such as wellbore diagrams, cement bond logs (CBL), gamma ray/neutron logs and casing inspection logs. These alternate sources of information are "second opinions" which lend credibility to the initial CPET log interpretation.

Wellbore diagrams, for instance, give useful information regarding age of the well, hole size and depth together with surface casing details, production casing size and depth, perforation locations, externally coated casing intervals and cement tops. Cement bond logs can be used to identify cement tops and can also be used to identify voids in the cement to some degree. Gamma ray/neutron logs are useful to identify formation changes and those areas of formation porosity often associated with water formations, both salt (San Andres) and fresh.

Casing inspection logs can verify intervals of external casing corrosion which can be correlated to anodic areas.

CPET WELL LOGGING

CPET logging was conducted on seven (7) wells with five *(5)* of these selected for discussion. Each is individually presented below.

Preston Spraberry (PSU) ***3909A***

Well Data
Age: 9 years
Reported Top of San Andres: 4,100’
Reported Top of Cement: 3,300’ (Temperature Survey)
External Casing Coating: None

The native state log indicated axial current to be primarily down-hole, i.e. negative values, with corresponding anodic areas indicated from the radial current density calculation noted at the San Andres formation. The “CP applied” log revealed axial current to be up-hole, i.e. positive values, with corresponding cathodic areas indicated from the radial current density calculation. See Figure 3. A magnified view of the casing log data spanning from 3,900’ to 5,500’ includes information relative to the casing interval traversing the San Andres formation. This view offers a clear indication of the existence of anodic areas on the casing during the native state log with subsequent correction to cathodic areas with the application of cathodic protection current. See Figure 4.

This log would indicate external corrosion protection could conceivably be obtained with a combination of cement and CP; but, was not obtained with cement alone.

Midkiff 315A

Well Data
Age: 2 Months
Reported Top of San Andres: 4,100’
Reported Top of Cement: 3,150’ (Cement Bond Log)
External Casing Coating: 3,919’ to 5,429’

The native state log again indicated axial current to be primarily down-hole with some negative slope of the curve corresponding to the San Andres formation and significant negative slope of the axial current curve corresponding to the shallow fresh water formation. The “4 amp CP applied” log revealed axial current to be up-hole with an expected increase in magnitude with the “second pass” log at the increased CP current level of **8** amperes.

Good correlation was noted between the neutron log, cement bond log and the CPET axial current log data. See Figure 5. This log would indicate excellent external corrosion protection could be achieved with a combination of cement, external casing coating and cathodic protection. However, this was not obtained with cement and externally coated casing alone.

*Shackelford Spraberry (SSU) 251****7A***

Well Data
Age: 2 Years
Reported Top of San Andres: 4,050’
Reported Top of Cement: **6,8**12’ (Cement Bond Log)
External Casing Coating: 3,876’ to 5,405’

The native state log indicated axial current moving both up-hole and down-hole with mild negative slope associated with the interval of casing in the San Andres formation that was externally coated, and significant negative slope corresponding to that casing in the shallow fresh water formation. The “4 amp CP applied” log indicated a positive shift of the axial current with a significant amount traveling up-hole. The positive axial current magnitude as well as depth of penetration continued to increase with the “second pass” log of 8 amperes. The axial current was not observed to reach the total casing depth. See Figure **6.** This lack of total casing depth current penetration was attributed to reported 150’- 200’ thick salt/anhydrite stringers known to exist between 1300’ and 4100’. These high resistance salt/anhydrite stringers could slow the applied CP current penetration rate and subsequent polarization of the casing.

This log would indicate good external corrosion protection could be expected with the combination of cement, external casing coating, and cathodic protection from surface to below the San Andres formation. Better current depth penetration could be expected in time with permanent CP installations and constant current application.

Shackelford Spraberry (SSU) 3909A

Well Data	
Age:	5 Years
Reported Top of San Andres:	4,050’
Reported Top of Cement:	3,680’ (Temperature Survey)
External Casing Coating:	None

The native state log recorded negative axial current values indicating down-hole current flow and negative slopes with corresponding anodic areas indicated from the radial current density calculation. The application of 8 amperes of CP current resulted in a positive shift in the axial current with a significant amount recorded as moving up-hole. This correction had an associated radial current density calculation indicating the change from anodic to cathodic area on a large percentage of the casing including that casing in the San Andres formation. See Figure 7. A magnified view of that casing from 4,200’ to 5,200’ provides details of the referenced corrective action. See Figure **8.**

This log would indicate good external corrosion protection could be expected with the application of cement and cathodic protection from surface to below the San Andres formation. Protection to total depth could reasonably be expected with continuous application of the cathodic protection current. Cement alone would not offer external corrosion protection to the well casing.

Midkiff 313

A native state log was conducted on the referenced well casing to establish a “baseline” data pattern. Immediately upon completion of this log, the Midkiff 315A well, an offset to the 313, was energized utilizing a previously installed “test” cathodic protection system. The “energized” log was then conducted with particular attention given to the resultant axial current data curve. To test for an interference effect, the “baseline” and “energized” axial current curves were overlaid for a comparison. See Figure 9. The native state axial current was found to travel primarily down-hole. The “energized” axial current curve was noted to “track” the “baseline” axial current curve from hole bottom to ~ 4,400’. Above this depth, the “energized” axial current curve was noted to shift in the negative direction indicating more current traveling down-hole when the offset well CP system was energized. No significant radial current density shifts, i.e. anodic areas, were observed to correspond with this negative axial current shift and interference appeared minimal.

CONCLUSION

Analysis of the log data indicate the following trends:

- Anodic zones (areas of casing identified as losing current to the surrounding formation during the “native” state log) were found to occur in the San Andres formation generally described as 4,000’ to 5,200’. The San Andres formation is a known saltwater disposal formation experiencing injection rates of up to 22,000 barrels per day in some areas of the field. In addition, a shallow fresh water formation generally described as 1200’ to 1650’ also indicated anodic activity.

- Cathodic protection (CP) current was generally observed to reach total logged depth of all casings where applied. The amount of cathodic protection current noted to reach total logged depth of the casing was proportional to the magnitude of the applied current and the duration of the application, but subject to variables such as formation changes. A single instance of suspected high formation resistance slowing the penetration of CP current to total logged depth was noted at SSU 2517A; however, CP current was still noted to reach 5700’ with the short duration of the applied current. This instance of high formation resistance was theorized to consist of 150’ to 200’ thick anhydrite/salt stringer formations reported to occur between 1300’ and 4100’.

- Effective cathodic protection of the well casings was essentially achieved with the application of 8.0 to 9.0 d.c. amperes. Complete polarization of the casing could not be expected to occur during the relatively short duration of the “test” cathodic protection system, however, with a permanent installation it is expected that complete polarization will occur.

- Application of cement and/or external coating on the casing alone or in combination improved the corrosion protection but did not completely eliminate the anodic areas.

- Comparison of CPET data to wellbore diagrams and other log data, i.e. cement bond logs, and gamma ray/ neutron logs, revealed good correlation. This positive correlation lends credibility to the CPET log data and subsequent recommendations for effective cathodic protection of the subject well casings.

- Minimal cathodic protection interference effects were noted on the offset well log indicating cathodic protection could be applied in target areas with reasonable assurance of no adverse effects on unprotected offset wells.

- Recommendations for future well completions could include:

- Cement completion as high as practical.
- Externally coated casing extending from the top of cement to the top of the San Andres formation.
- Cathodic protection installation for effective external protection of the casing.

PILOT PROJECT AND ECONOMIC EVALUATION

After completing the evaluation program, a sixty (60) well pilot project was proposed, approved and implementation commenced on November 27.200 1.

To select the pilot area, a casing failure map was constructed consisting of casing failures inside six Pioneer-operated Spraberry Units. Definite high casing failure clusters were apparent and a 5% section area inside the Shackelford Spraberry Unit (SSU) was selected for a sixty (60) well pilot project. See Figure 10. Of these six Spraberry Units, the SSU accounts for the largest disposal volume (22,000 BWPD) and has also experienced the most recorded casing failures (81) over the last seven (7) years. The selected pilot area is located directly between two San Andres disposal wells, which have a combined disposal volume of 6,500 BWPD. The pilot area alone has experienced twenty-one (21) of the eighty-one (81) SSU failures.

On a semi-log scale, cumulative failures were plotted over time and a best-fit curve was applied to the data to “predict” future failures. Another accepted approach is to fit the data with a straight line, suggesting an exponential failure growth rate. However, this evaluation was based on the more conservative best-fit curve approach shown in Figure 11. From the cumulative failure curve, annual predicted failures were calculated and converted to casing repair expenses and BOE’s lost due to plugging wells deemed uneconomic to repair. Assuming CP effectiveness of **80%**, i.e. CP will prevent 80% of predicted failures, the project yielded a payout of 2.2 years, ROR of *56%* and a NPV of **$3.6** million.

After completing the installation process, the actual number of occurring failures will be compared to the predicted number of failures and any observed differences will be directly attributed to the effectiveness of cathodic protection.

ACKNOWLEDGEMENTS

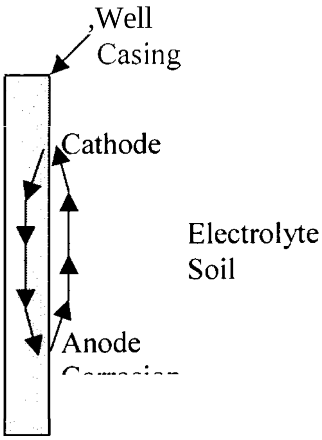
The authors would like to thank Paul McDonald and Randy Johnson for the opportunity and support to report the findings contained herein. We would also like to thank Schlumberger for their involvement throughout the logging process.

Table 1
Spraberry Unit Disposal Volumes And Recorded Casing Failures Since 1994

Spraberry Unit	San Andres Disposal Volume (BWPD)	Recorded Casing Failures
Shackelford	22,000	81
Driver	**18,000**	**39**
Midkiff	8,000	24
Preston	8,000	**12**
North Pembrook	*5,000*	**3**
Merchant	1,500	**4**

FOUR COMPONENTS:

Anode
Cathode
Electrolyte
External
Circuit



ELECTRO – Casing portion of drawing (Electrical part of the circuit)

CHEMICAL – Soil portion of the drawing (Chemical part of the circuit)

Figure 1 - The Electrochemical Cell

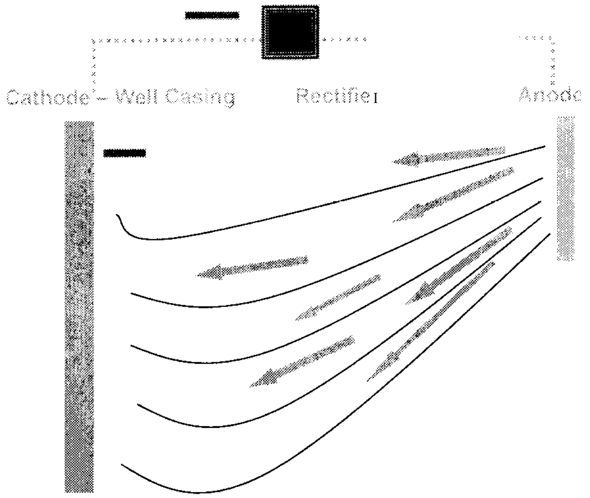


Figure 2 - Simplified Cathodic Protection Schematic

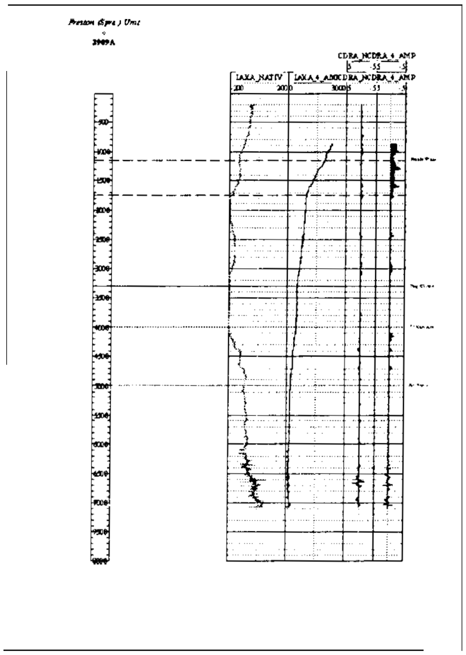


Figure 3 - PSU 3909A -Native and 4-amp Passes. Note the native axial current reversal through the San Andres.

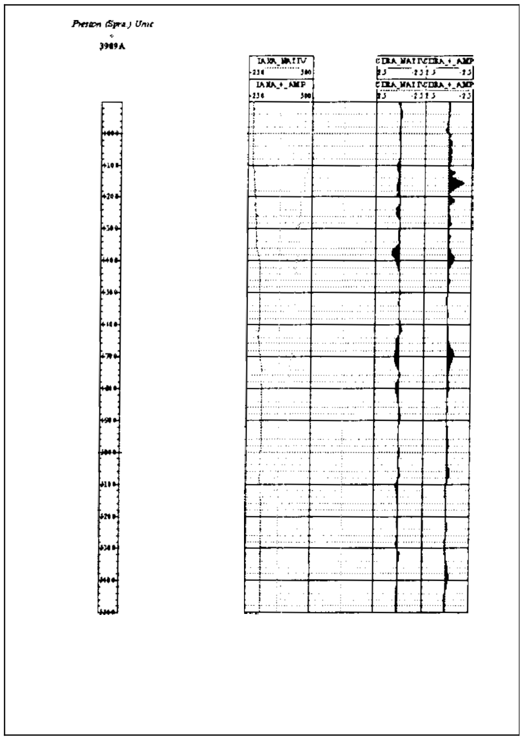


Figure 4 - PSU 3903 A - Maginified View of Native and 4-amp Passes through the San Andres

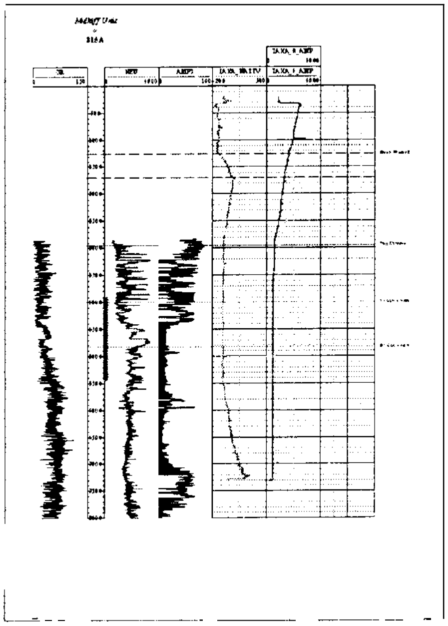


Figure 5 - Midkiff 315A - 4amp and 8 amp axial current curves are overlaid.

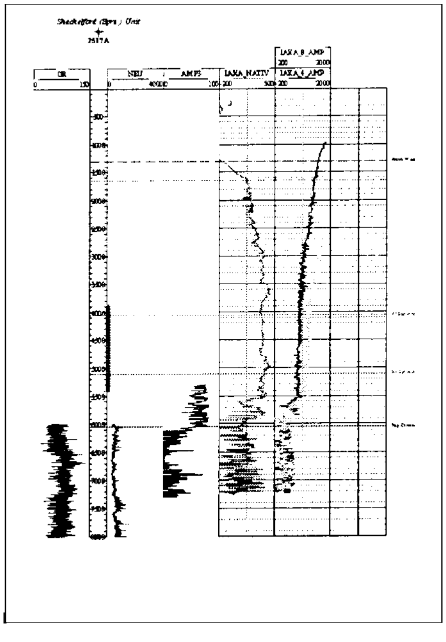


Figure 6 - SSU 2517A - Only case in which current was not observed at bottom of logged interval.

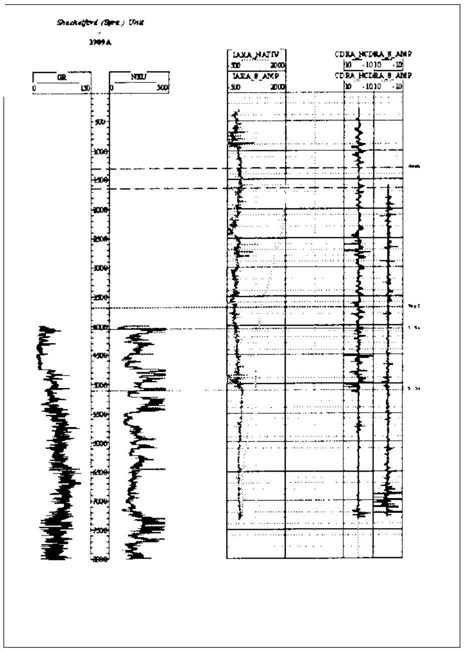


Figure 7 - SSU 3909A - Native state and 8-amp axial current curves are overlaid.

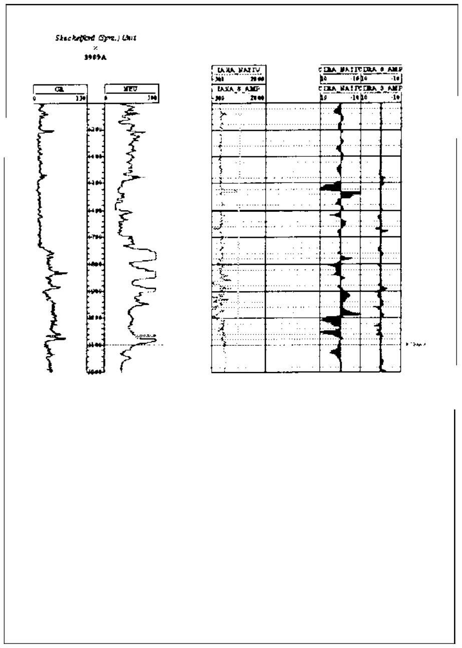


Figure 8 - SSU 3909A - Application of CP greatly reduced the anodic activity shown on the current density curve.

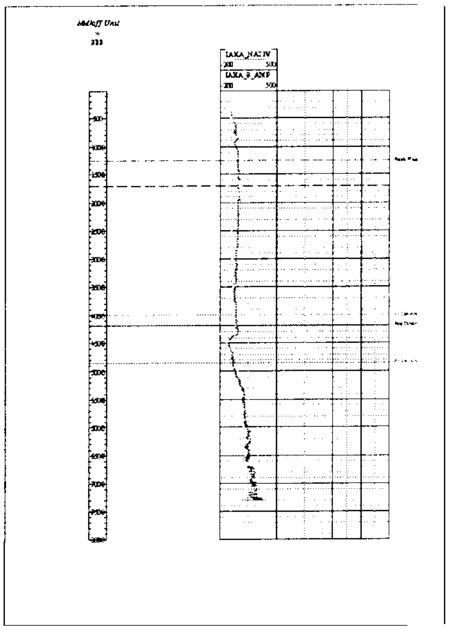


Figure 9 - Midkiff 313 - Minimal interference effect noted while applying 8-amps on an offset well.

Figure 10 - Casing Failure Map with Outlined Pilot Area

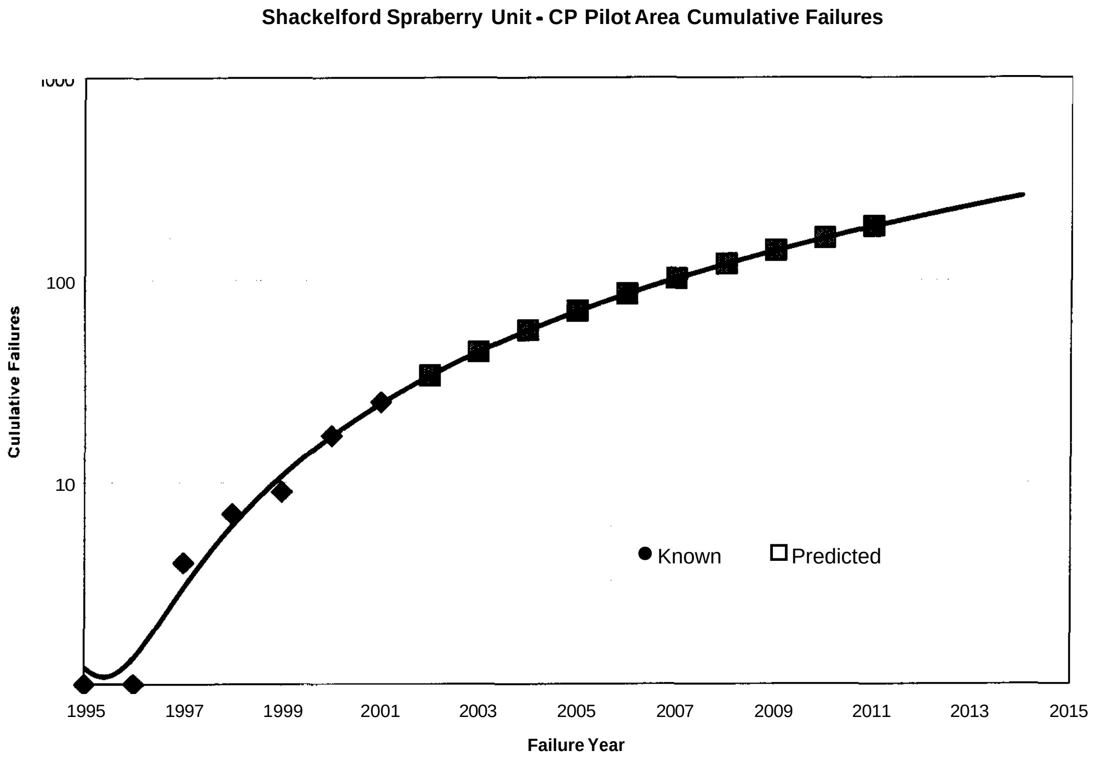


Figure 11 - Cumulative Failure History and Best-fit Curve Failure Prediction