CONF-860304--7

SAND--85-2712C

DE86 009623

USE OF AN ACOUSTIC BOREHOLE TELEVIEWER TO INVESTIGATE CASING CORROSION IN GEOTHERMAL WELLS

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RECEIVED BY OSTI APR 29 1986

ABSTRACT

Corrosion of well and surface equipment due to the presence of hot, corrosive brines is one of the major problems facing geothermal operators. For wellbore casing, this problem is complicated by the fact that in-place inspection is difficult at best. In an attempt to improve this situation, a prototype acoustic borehole televiewer designed to operate in geothermal wells was used to study the corrosion damage to casing in three commercial wells. The results of this experiment were promising. The televiewer returns helped to define areas of major corrosion damage and to indicate the extent of the damage.

This paper briefly discusses the corrosion problem, describes the acoustic borehole televiewer, and then summarizes the results of the field test of the televiewer's capabilty for investigating corrosion.

INTRODUCTION

Geothermal energy is one of the most widely used of the so-called alternative energy resources. Throughout the world, geothermal resources are used to drive electrical generators or to supply process heat for industrial, agricultural and domestic applications. In the United States, geothermal steam is used to generate roughly 1.5 gigawatts of electricity, and this number is growing steadily.[1] The potential contribution from the various geothermal resources to U.S. energy supplies is quite large, and many of the resources could be utilized, if needed, in the near future.

Geothermal resources occur in several different forms.[2] Currently, a major contribution from geothermal resources is from the dry steam fields that concentrate large quantities of energy at a few places such as the Geysers Area in Northern California and the steam fields near

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Lardarello, Italy. The resources in the Geysers area generate more electricity than any other geothermal field in the world -- nearly all of the 1.5 gigawatts generated in the U.S. A more common form of geothermal energy, but one that is much more difficult to use, is hot water -- often superheated or mixed with steam. Though hot water resources are being utilized more widely abroad than in this country, especially in the Phillipines, Italy, Iceland, Japan and New Zealand, their application in the U.S. is growing. For example, by the end of 1985, there should be six plants producing more than 150 megawatts of electricity from the hot water resources of the Imperial Valley in California.[3]

The different geothermal resources present different problems and challenges to extraction systems -- problems that arise from the unique nature of geothermal resources. The causes of these problems include the hard rocks that usually make up geothermal reservoirs, the fractured and underpressured nature of the reservoirs, the content of the geothermal fluids, the quantities of fluids that must be produced, and, of course, the reservoir temperatures.[4] All commercial geothermal resources are produced through wells; and the unique geothermal reservoir characteristics generally cause problems during the drilling of these wells, while the characteristics of the produced fluids contribute to well problems during both drilling and production. These production problems can involve very severe scaling of wellbores and surface equipment; mechanical problems due to thermal cycling; and problems of corrosion in well casing, surface piping and power plant components. This last problem, which for certain reservoirs has been severe enough to preclude development, is the focus of this paper.

CASING CORROSION IN GEOTHERMAL WELLS

Corrosion occurs during several phases of drilling, completing and producing energy from geothermal wells. In many resource areas, it is standard to use corrosion inhibitors in the drilling fluids to control corrosion of drilling tubulars. This corrosion is especially severe during air or mist drilling, which introduce oxygen to hot steel exposed to highly corrosive fluids. Corrosion inhibitors for protecting drill pipe in such environments can cost more than $10,000 per day -- roughly the same as the drilling rig itself.[5]

After a geothermal well is drilled, it is lined with steel casing in order to maintain an open conduit between the reservoir and the surface. Like the drill pipe, this casing can be subjected to severe corrosion. However, once the well is drilled, no more oxygen is introduced downhole, and so the corrosion rate after completion is generally much lower than it is during the drilling phase. Nonetheless, the casing corrosion problem may be more serious than drill pipe corrosion because of the required lifetime for casing and because, after it has been cemented in place, replacement of casing may be difficult or impossible.

The likelihood of casing corrosion varies greatly among geothermal sites. For example, at the Geysers area, with its clean, dry steam, there has historically been very little problem with casing corrosion. On the other hand, in parts of the Imperial Valley in California, casing corrosion can be very severe, and the costs of combatting it can grow so large that commercial exploitation of the energy becomes unattractive. Even within the Imperial Valley, the characteristics of the geothermal fluids and, thus, the corrosion caused by the fluids can be quite different. At areas in the southern end of the valley, the fluid contains very few solids -- roughly 10,000 ppm or less -- and carries very little dissolved sulfur or other corrosive components; while at sites near the Salton Sea the solids content can be as great at 300,000 ppm and the fluids are quite corrosive. For this reason, the severity of corrosion at a geothermal site and how it will be combatted will be quite site specific. In fact, even at a single site corrosion severity varies with depth in the well and may vary with time as the temperature and constituents of the produced fluid change through the life of the well.

Corrosion of steel casing in a geothermal environment can take many forms,[6] and discussing them is not the intent of this paper. The interested reader is directed to the references and to the companion papers for this technical session. It has been suggested that the primary means of corrosion of geothermal casing is electrochemical in which metal is removed as ions in a galvanic cell.[6] Corrosion at the Salton Sea Field in Imperial Valley has been studied both by using coupons and by observing small diameter tubing, and corrosion rates of more than 1000 mils per year were measured.[7] Crevice corrosion in the tubing joints was especially severe.

In summary, corrosion of the wellbore casing is a serious problem facing geothermal development in many areas, and reliable methods for inspecting casing and gauging the damage caused by corrosion must be developed. One wellbore logging tool that could be useful in this application is the acoustic borehole televiewer. The next sections discuss this tool and a field test in which it was used to investigate casing corrosion.

THE ACOUSTIC BOREHOLE TELEVIEWER

The acoustic borehole televiewer (as it is commonly considered in wellbore applications) is an ultrasonic logging tool that was patented roughly 20 years ago by Mobil Oil.[8] This tool utilizes a rotating piezoelectric crystal that functions as a transceiver, sending an acoustic pulse into the borehole and receiving the reflected signal back. Its log is an ultrasonic scan of the borehole wall, and not a television or video picture. A schematic representation of the tool is shown in Figure 1, and Figure 2 is a photograph of Sandia's televiewer. Typically, only the first return is considered in analyzing the televiewer signal. This is true even though the entire waveform possibly contains useful information. (An active area of current research involves how to analyze and interpret subsequent arrivals.) At the current time, two features of the first return are utilized: its amplitude, which measures the reflectivity of the borehole wall (and transmissivity of the fluid), and the travel time, which indicates the distance between the transceiver and the borehole wall.

Acoustic borehole televiewers have proven especially useful in characterizing fractures intersected by the well. Figure 3 shows an example of a televiewer log of a fracture plane that intersects the borehole. The figure shows the wellbore wall as if it were vertically cut along the north edge of the well, opened, and laid flat. Well circumference is thus plotted horizontally, and well depth is plotted vertically. A planar feature that crosses the wellbore will appear as a sine curve on the televiewer log. The fracture shown is relatively closed. In the upper and lower portions of the sine wave, it shows clearly due to rock spalling into the well during drilling, while 90° away from these points, it almost disappears. Two different representations of the televiewer return are shown here. On the left, it appears in a trace that represents amplitude of the first return, and on the right it shows up in a caliper log that plots arrival time of the first return. (The amplitude log uses the amplitude of the return pulse to generate an intensity modulation, or gray scale, in which large returns are white and weaker returns are darker. The caliper log is formed by generating a voltage that is proportional to travel time and summing this voltage into the vertical sweep signal. This means that the traces for longer paths are displaced upward, and the result is a quasi-three-dimensional plot.) Another feature that can be studied using televiewer logs is casing damage, such as a deep scratch or gouge caused during drilling through casing -- when the lower portion of the well is being drilled after the upper portion has been cased. Figure 4 shows this type of feature using the same two formats as used in Figure 3.

Because a primary effect of casing corrosion is loss of metal which changes the internal surface of the pipe, televiewers should be useful in studying and characterizing it. Even minor corrosion changes the nature of the pipe surface, while major corrosion will change the internal diameter, or caliper, of the pipe as well. These two parameters correspond to the two measurements that are most commonly and most easily made by the borehole televiewer -- the amplitude of and time until the first arrival.

In order to test the usefulness of a televiewer in inspecting casing for corrosion, a field test was conducted in geothermal wells in the north end of the Imperial Valley. The tool that was used was a prototype televiewer developed by Sandia for general logging purposes.[9] The modifications that were made in order for the televiewer to survive geothermal environments are discussed in the Appendix below. It should be noted that several current hardware development and software research projects are centered around the televiewer. In particular, Sandia is participating, along with industry partners through the Geothermal Drilling Organization, in an attempt to commercialize a geothermal-capable televiewer. A third party, (Squire-Whitehouse Corporation) has been funded to develop and field a televiewer that will be available for geothermal applications.

THE FIELD TEST

At two different times during 1983 and 1984, the prototype televiewer was run in three wells at the north end of the Imperial Valley in order to study the wellbore walls. In particular, we at Sandia were interested in understanding the nature of the lost circulation zones encountered during drilling (intervals in the wells where drilling fluids were lost into the formation rather than returning, or circulating, to the surface); while the resource owner was curious about the integrity of the casings that were in the wells. (As indicated above, after a well is drilled, steel pipe is often inserted in a well to stabilize or "case" the hole. Usually, this pipe is cemented in place in order to support it and seal off fluids from the different formation levels; but the pipe in lower portions of the hole or inside other strings of casing can be inserted without cementing.) In addition, we both were interested in whether the televiewer could be used to assess corrosion damage.

That the runs had to be repeated is indicative of the difficulty of running sophisticated logs in harsh geothermal environments. For the first attempt at logging the wells, a commercial logging company was contracted to run the wireline and the tool, but their "high temperature" cable and cablehead (the apparatus used to connect the tool to the cable) could not be made to work in the hotter portions of the wells. Nonetheless, the televiewer returns from the cooler sections were encouraging enough to justify a second attempt.

In March of 1984, the second test was run in the three wells in which severe corrosion was suspected. Most casing in each of the wells was cemented in place (though at least one of the wells had an uncemented liner in part of its length), and so some method of downhole assessment of corrosion damage was desired in order to avoid the large expense of removing the casing to allow inspection at the surface. Optical cameras were tried in the cooler portions of the wells; but very little information was obtained when they worked, and their temperature capabilities limited their operation to the very shallow regions of the wells.

In the successful logging runs, the Los Alamos National Laboratory geothermal logging truck with state-of-the-art high-temperature cable (7 conductor, TFE teflon insulated) was used. The normal types of difficulties (such as tool, cablehead, and interface failures, which are often encountered when developmental tools are run) had to be overcome; but the three wells were logged in a four-day period. Figure 5 shows the televiewer being inserted into the wellhead lubricator above one of the test wells. In addition to studying corrosion, it was intended that the televiewer be used to investigate fractures and lost circulation zones in the open hole below the casing. This was done for a small portion of one well, but in each of the three wells the tool encountered a bridge or wash zone (a region where materials had come into the wellbore and reduced its diameter) that prevented passage to the bottom. As a result, the casing inspection provided the major results from the field test.

RESULTS OF THE FIELD TEST

The acoustic images provided by the televiewer displayed clearly the apparent effects of corrosion; and these are shown below for three stages of corrosion: surface roughness and deterioration, extensive surface pitting, and holes corroded completely through the casing. The baseline for comparison for these three cases is illustrated in Figure 6, which shows the standard televiewer display for depths between 700 and 710 feet in one of the wells. At this depth, the casing seems to be in good shape, as it shows no apparent damage. Both the amplitude and the caliper logs indicate a smooth casing wall.

Figure 7 shows a section of one of the wells where there appears to be minor corrosion and surface roughness. In the amplitude chart, several spots of decreased reflectivity can be seen as dim regions within the bright vertical stripe. (The stripe itself shows strong reflections from one side of the borehole and indicates that the tool was not centered in the hole. The azimuth of the stripe corresponds to either the near side or the far side of the casing -- depending on how far off center the tool was located.) The decreased reflectivity, or scattering of the acoustic wave, indicated by these dark spots is attributed to surface roughness caused by corrosion. The spots are not as obvious on the caliper chart, but several can be identified.

Figure 8 shows a section from 1510 to 1520 feet in one of the wells. This section displays pitting and serious corrosion. In this figure, the corrosion shows up as well defined low-reflectivity spots on the amplitude chart. The corrosion appears more severe than that shown in Figure 7 -- judging from the blackness of the spots in the amplitude signal. The corrosion also appears as delayed-return spots in caliper presentation. (Recall that the return from an area that is recessed into the casing will be displaced vertically "upward" in the caliper plot, giving the impression of a three-dimensional feature.) Analysis of the caliper log indicates that some of the spots penetrate roughly half the thickness of the casing. Figure 8 also shows the location of a casing collar (at 1516 feet), identified by the horizontal black stripe on the amplitude log and the black area under a white stripe on the caliper trace. This presents an interesting comparison to some of the results related to Figure 9. (A casing collar is a large pipe union that joins two pieces of casing.)

The final downhole result is shown in Figure 9. Only the amplitude presentation is available, but it clearly shows badly corroded regions. Analysis indicates that the signals returning from the most corroded areas are reflections from the cement that holds the casing in place. In other words, corrosion has penetrated entirely through the casing. This is especially worrisome in the area just below 1820 feet where it appears that a complete casing collar has been corroded away and there is a gap of about a foot in the casing string. Without the cement to support it, it is unlikely that this casing would remain in place. Furthermore, once corrosion has proceeded this far, it is unlikely that the casing could be removed from the well to be replaced, and this emphasizes the need for a tool that allows in situ measurement of casing corrosion.

Figure 10, which shows the state of some of the casing that had previously been removed from wells in the area, provides an interesting comparison to the corrosion indicated downhole by the televiewer.

SUMMARY

In several of the geothermal areas in the world, corrosion of wellbore casing due to the nature of the brines and the extreme exposure temperatures is a serious problem. The acoustic borehole televiewer seems to be an especially appropriate tool for identifying corrosion damage, and it is possible to upgrade a televiewer to enable it to function in most geothermal environments. The prototype geothermal televiewer developed at Sandia was used to study the effects of corrosion in three wells in the Imperial Valley, and the results of the field test were promising, with the televiewer displays giving detailed pictures of casing corrosion. This appears to be a potentially valuable application for the borehole televiewer.

APPENDIX: DEVELOPMENT OF A GEOTHERMAL TELEVIEWER

The major changes required to make the acoustic borehole televiewer capable of functioning in geothermal environments included: modification of the absorber and acoustic window, replacement of the slip ring assembly, modification of the downhole circuitry, and changes to the cablehead.[9] All of these changes were required to meet the desired operating temperature of 275°C.

The original transducer on the commercial televiewer was a lead metaniobate ceramic with a two-way beam width of about 3°. During tests at high temperature, large changes in capacitance and dielectric leakage were found, and this made design of electronic circuitry to drive the crystal impossible. The correction that was made in the high temperature televiewer was to a use a 36° Y cut of single-crystalline lithium niobate. The electrical properties of this material remain virtually unchanged over the temperature range from 25°C to 275°C.

The planar piezoelectric crystal of the televiewer radiates energy primarily in the two directions normal to its large faces. In order to reduce the amount of energy that radiates "backwards" into the tool, it is necessary to mount the crystal on an acoustic absorber that dissipates the acoustic energy that enters it. The original tool used a rubber absorber behind a perforated brass plate; but when exposed at high temperatures to the coupling fluid, which carries the signals between the transducer and the wellbore fluid, the rubber swelled and disintegrated. The absorption material was replaced with tungsten-loaded alumina cement, which is a rigid material with high acoustic impedence. The rigidity of this material allows the transducer to be mounted without the brass plate, and so it solves the temperature problem of the rubber and reduces the ring-down time for the transducer (the time required between the end of the transmitted pulse and the earliest subsequent time that the transceiver can receive a reflection) as well.

The purpose of the acoustic window is to allow good acoustic coupling between the interior (coupling fluid) and the exterior (borehole fluid) of the tool, while providing a barrier to keep corrosive borehole fluid out of the tool. The original tool used a Vespel window with o-ring seals. The Vespel proved unable to survive geothermal conditions and was replaced with Teflon. However, the teflon has a tendency to flow at high temperatures, and o-ring sealing would not work. Instead, the teflon is kept in compression and a pressure equalization bellows assures that no differential pressure exists across the window.

Operation of the tool requires that stationary electronics be linked to the transducer and other rotating parts. In the original tool, this was accomplished with slip rings. The high geothermal temperatures caused problems of brush wear and reduced spring forces, which in turn caused noise, contact bounce and generally unreliable operation in the slip rings; and so they were replaced by rotating transformers. This was possible since only a.c. signals are required to move between the fixed and rotating components. The rotating transformer assembly was built to occupy the same space that had been occupied by the slip rings.

Though the transducer and magnetometer (which is used to indicate orientation of the transducer) and the motor that rotates them can all function in temperatures to 275°C, many of the electronics components that remain stationary are not able to survive at the temperatures commonly found in geothermal wells. As a result, it was necessary to house them in a dewar to allow prolonged operation. In addition to the passive protection of the dewar, a heat sink material with a melting point of 138°C was packaged inside the dewar. These precautions allow extended use at geothermal temperatures.

The final major change to the televiewer to accommodate geothermal use was the modification of the cablehead. The conventional televiewer uses a standard seven conductor cablehead for mechanical and electrical connection with the surface. In order to overcome electrical shorting problems caused by borehole fluid getting into the cablehead, it was necessary to use Viton and Kalrez o-rings for sealing and to lengthen the cablehead so that Krytox oil could be used instead of grease.

Once these changes were made, the prototype televiewer was able to function in geothermal wells. It has been used several times to "view" both cased and open holes -- including the 1984 field test of its capability for investigating casing corrosion.

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This work was supported by the U.S. Department of Energy at Sandia National Laboratories under Contract DE-AC04-76DP00789.

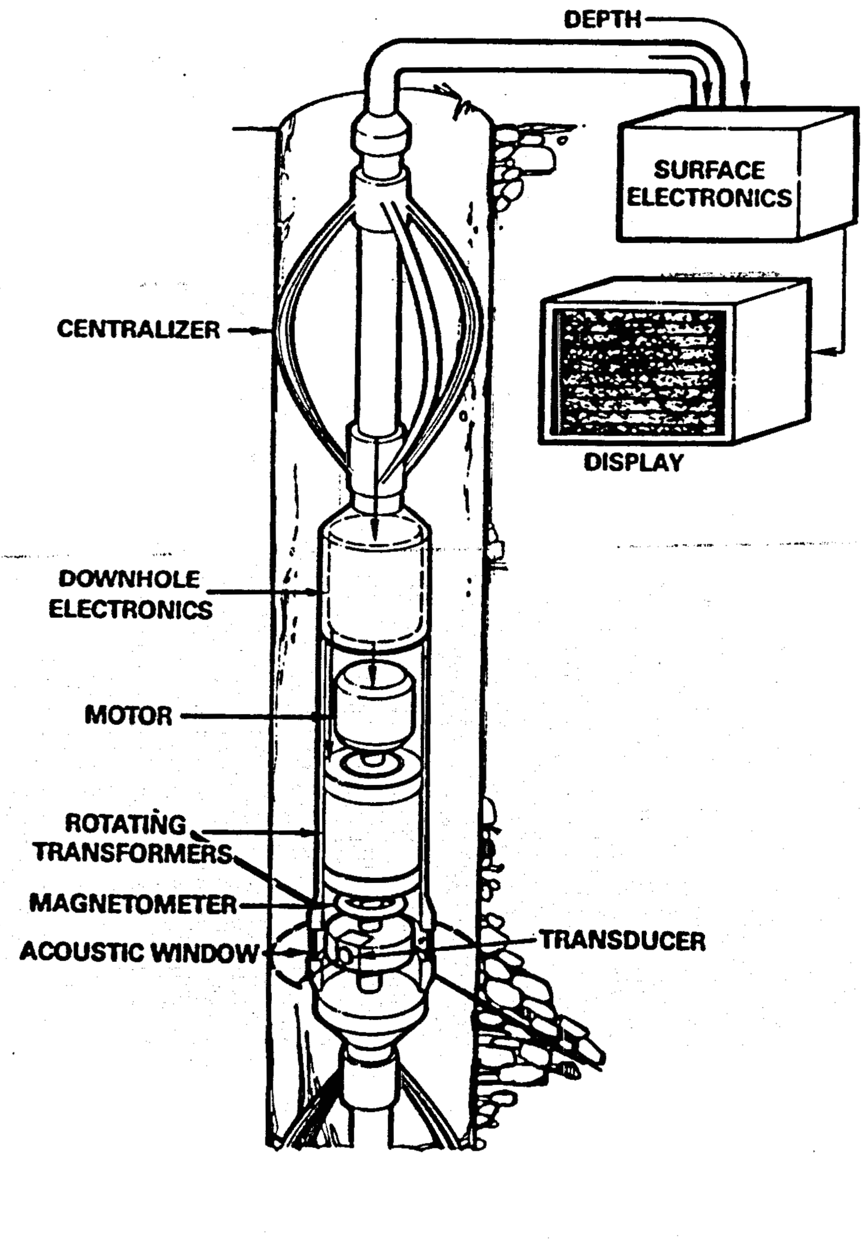

FIGURE 1 - Representation of Acoustic Borehole Televiewer.

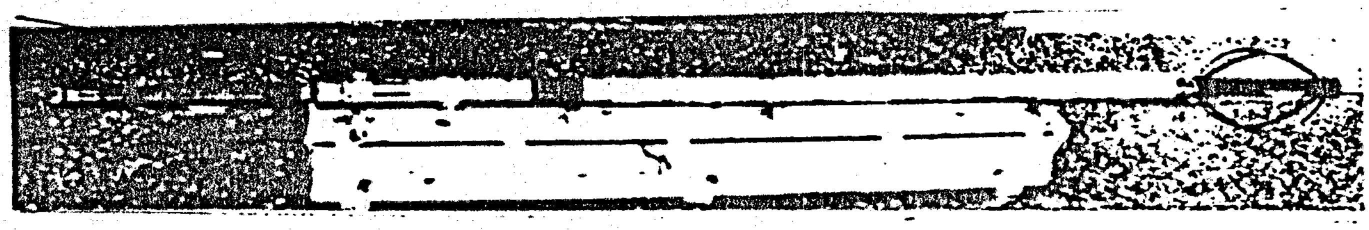

FIGURE 2 - Sandia National Laboratories' Borehole Televiewer.

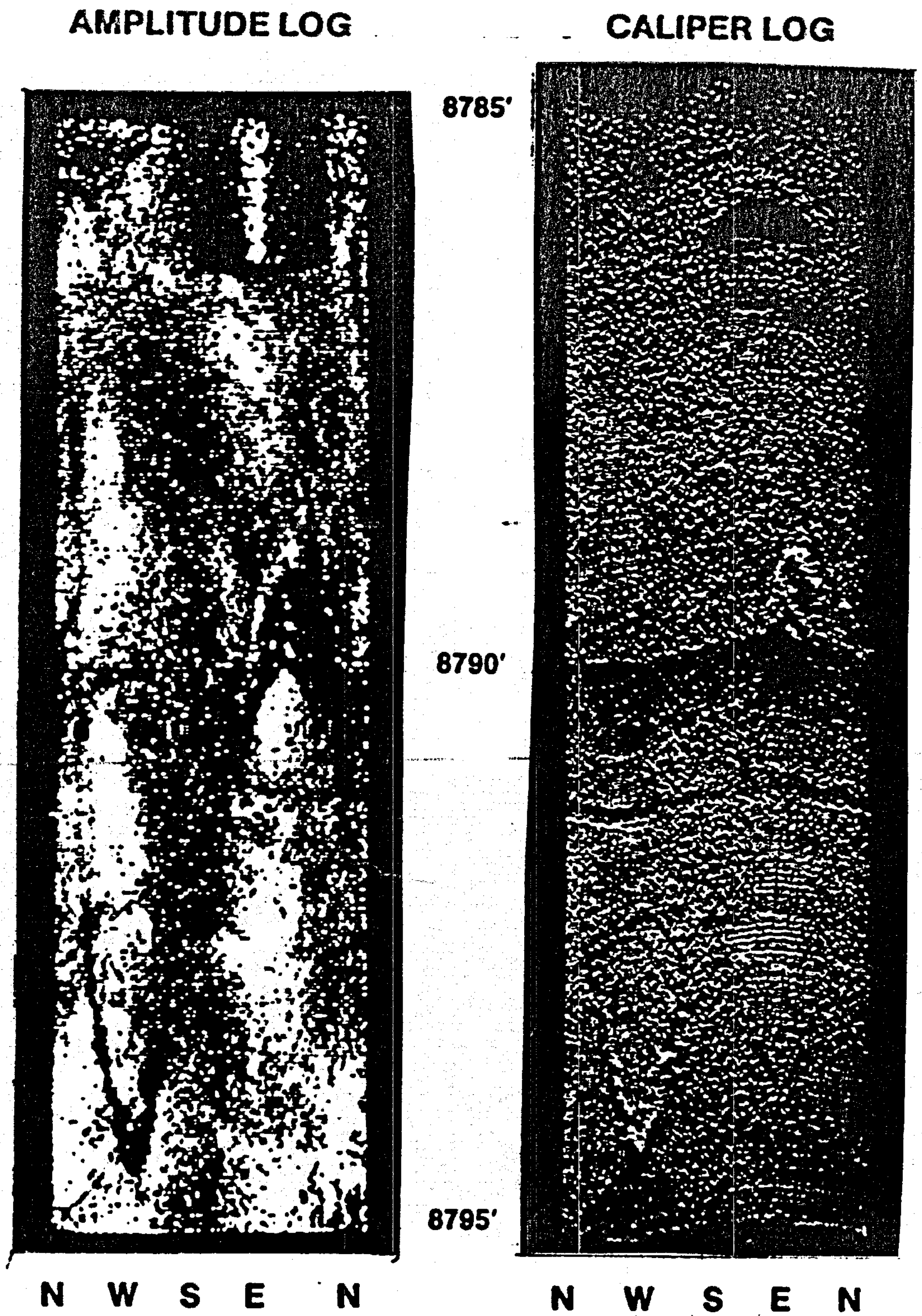

FIGURE 3 - Televiewer Log Showing a Fracture Intersecting the Wellbore.

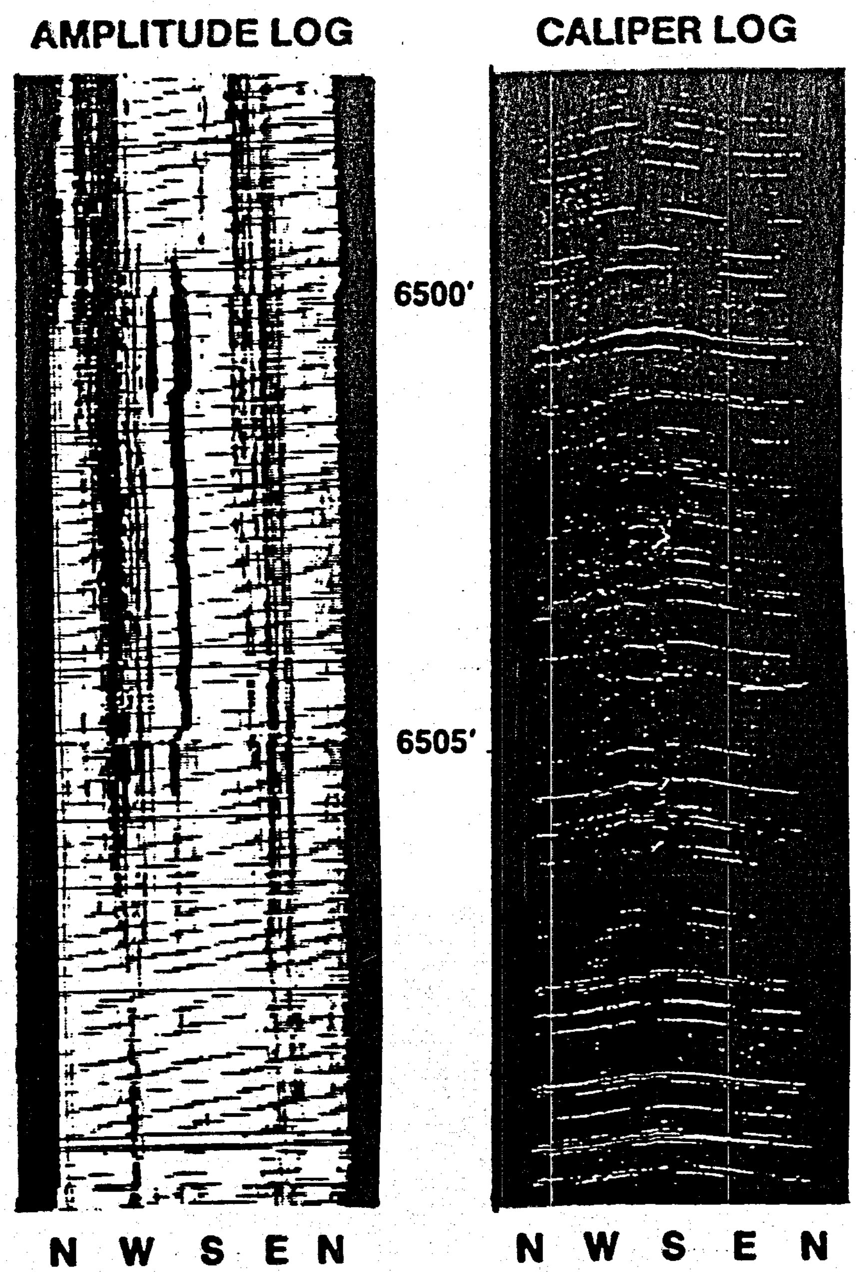

FIGURE 4 - Televiewer Log Showing Casing Damage.

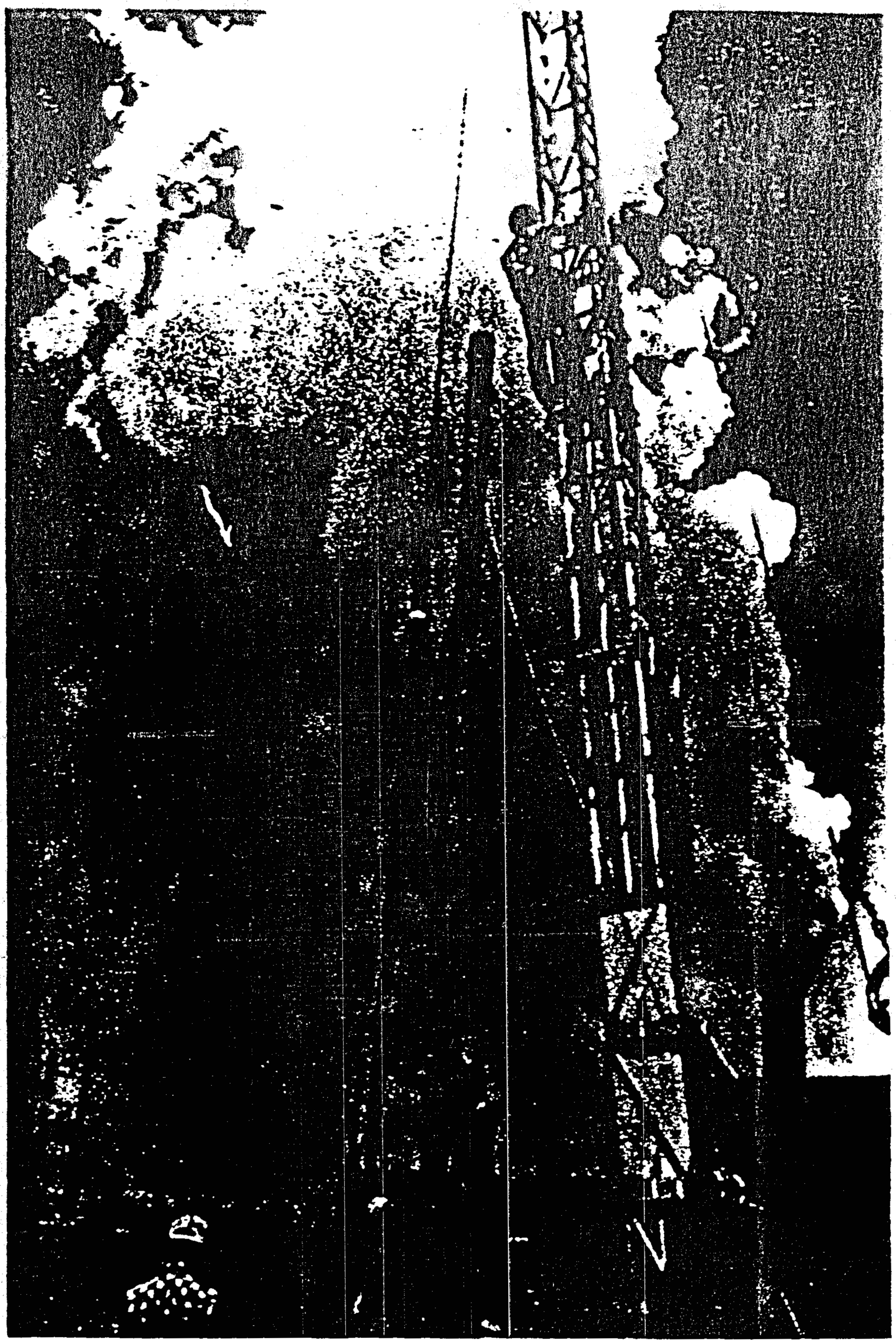

FIGURE 5 - Running the Televiewer During the Field Test.

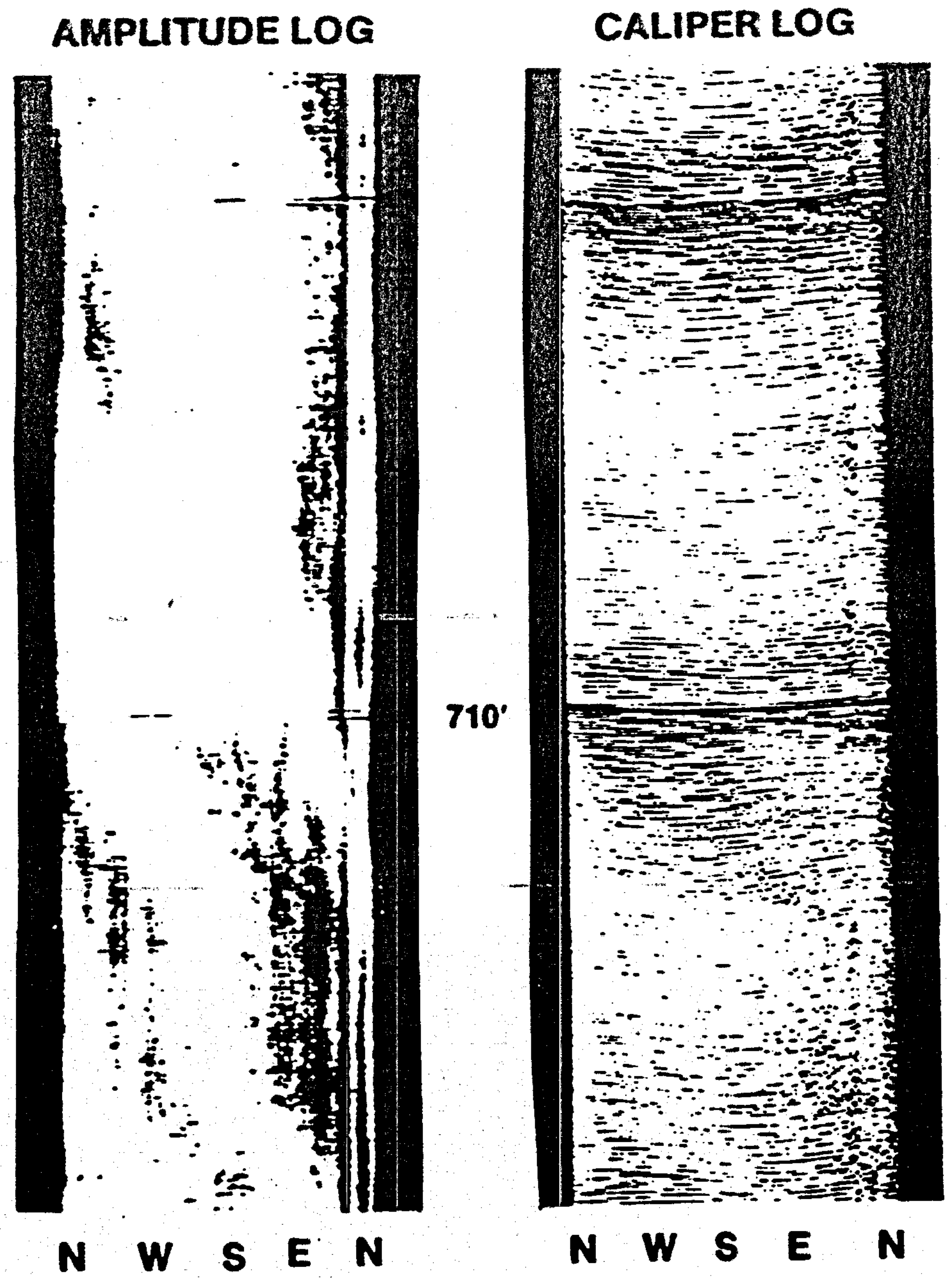

FIGURE 6 - Televiewer Log of Undamaged Casing.

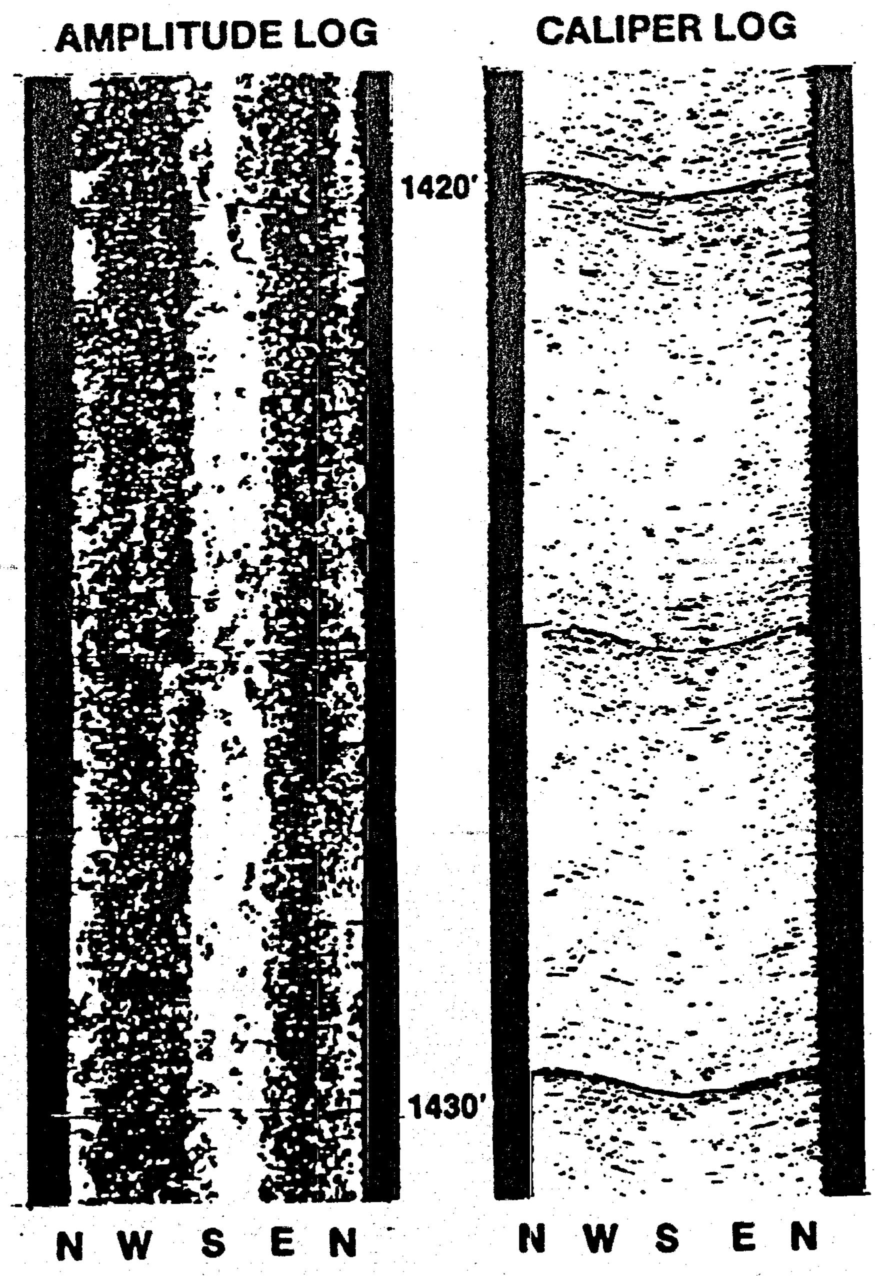

FIGURE 7 - Televiewer Log Showing Minor Corrosion.

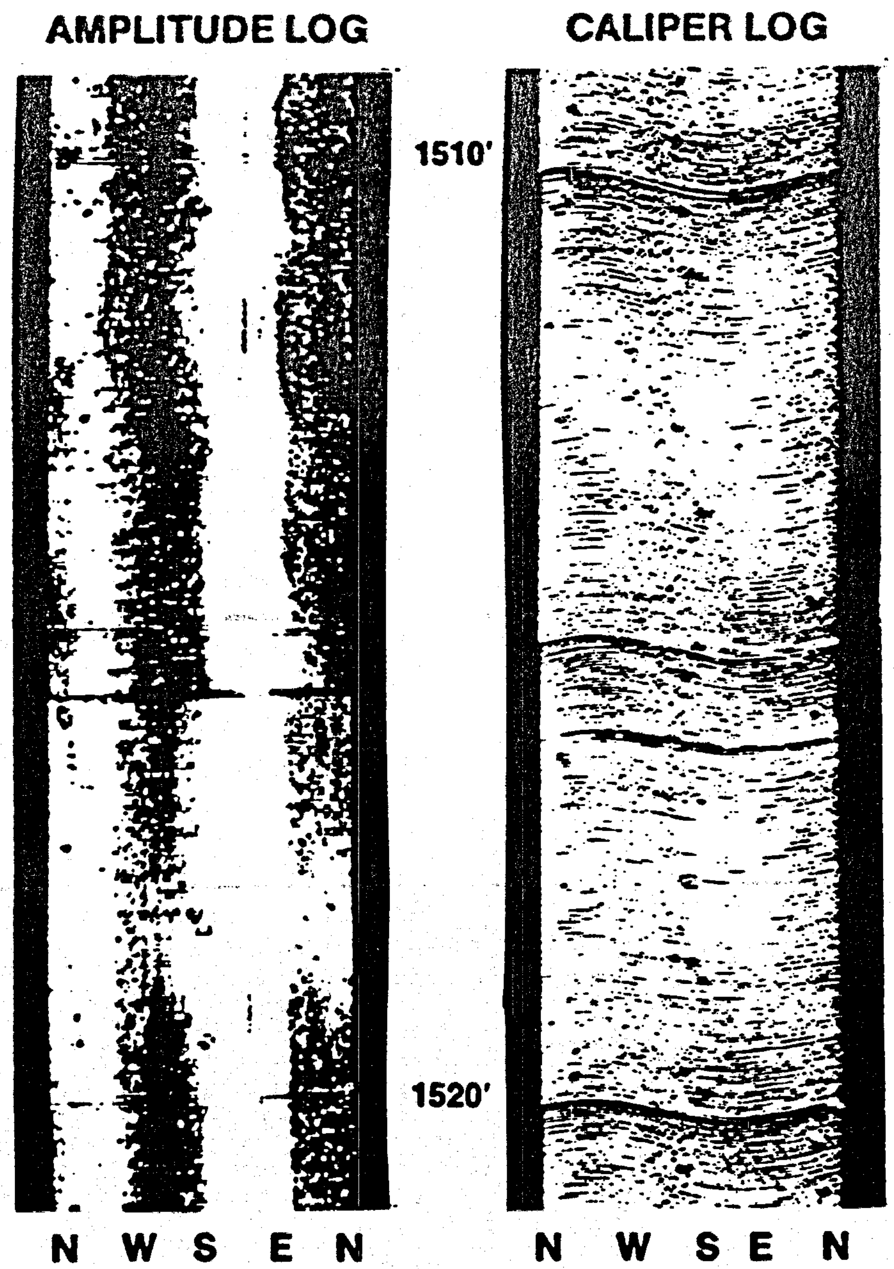

FIGURE 8 - Televiewer Log Showing Pitting Corrosion.

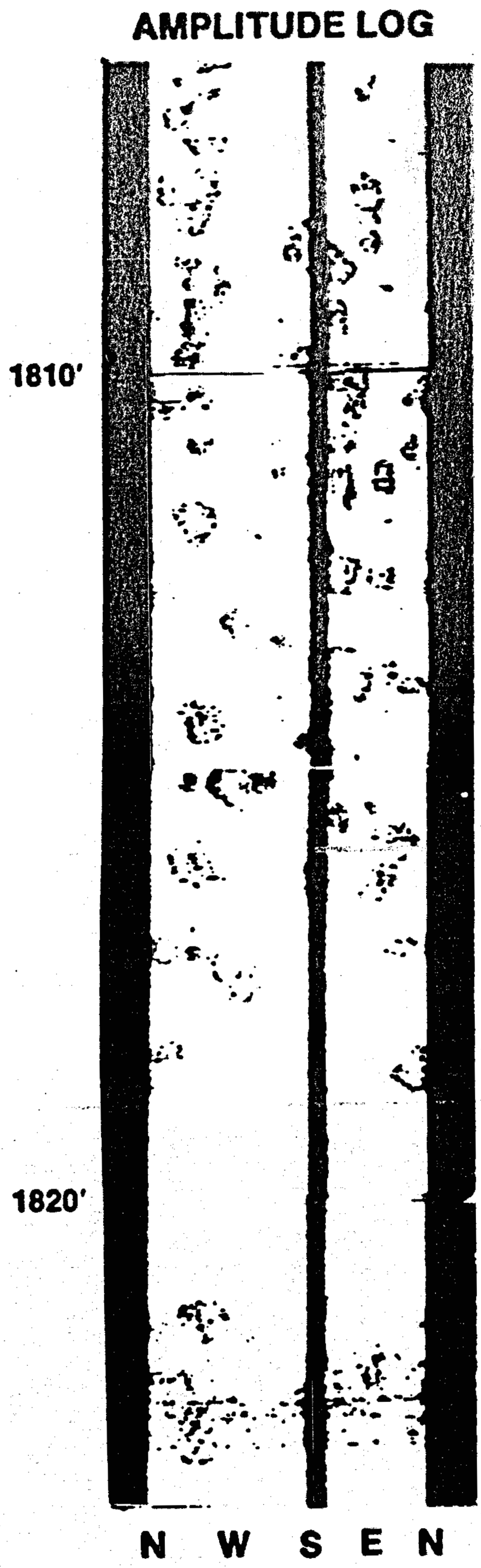

FIGURE 9 - Televiewer Log Showing Catastrophic Corrosion.

FIGURE 10 - Photograph of Corrosion Damaged Casing at the Surface.