ADVANCES IN DOWNHOLE CORROSION EVALUATION

Peter D. Graham
Schlumberger Well Services

ABSTRACT

Since the decline in oil prices, the trend in the industry has been toward the maintenance of producing, existing reserves and away from the cost of trying to find new ones. The concern over the longevity of producing fields and new environmental legislation has led to an increased interest in corrosion control of downhole tubulars.

If insitu complete and accurate measurements of downhole casing and tubing conditions can be made, the corrosion engineer can best determine the optimum cost-saving action to be taken. The consequences of not accurately evaluating the downhole condition relate to safety and environmental concerns, including blowouts and pollution, as well as loss of production.

Recent developments have led to the introduction of several new tools specifically designed for the evaluation of casing and tubing deterioration. These new developments coupled with improvements to existing measurement systems now provide accurate techniques for interpreting the integrity of casing and tubing.

The focus of this paper will be on the introduction and principles of measurement of this new technology. Resulting improved interpretation techniques will be demonstrated from actual field logs.

INTRODUCTION

In North America the oil and gas industry spends about $2.2 billion annually on corrosion control. In particular, some 3% of the overall operating costs of producing oil can be attributed to corrosion. Of this large expenditure only about 2% is spent on the measurement of corrosion, from which important decisions must be made that will determine how the remaining dollars are spent.

For instance, the cost of running a tieback liner on a new well due to drilling wear, or a replacement liner on an old well versus the cost of a workover repair are substantial to say the least. Therefore, the availability of complete and accurate information is essential in determining the most cost effective approach to repairing downhole casing problems.

Many times action is taken against a corrosion problem only after the damage has been done. Available techniques for monitoring downhole corrosion provide oil companies with the ability to monitor and detect corrosion before potentially devastating results occur.

Downhole wireline surveys can be used to monitor and predict corrosion rates, evaluate corrosion protection systems, identify the extent, location, and severity of defects, and in some cases provide valuable information as to their origin. Recent improvements to and introduction of new technology has vastly improved the interpretation and accuracy of these surveys.

These corrosion measurement systems can be grouped into three categories based upon measurement principles:

Mechanical Tools

(i) Multi-Armed Caliper Tools that provide internal radii measurements:

M.F.C. (Multi-Fingered Caliper Tool) which uses multiple survey arms to provide various internal casing radii.

T.G.S (Tubing Geometry Sonde) which provides similar measurements to the M.F.C. but is used to inspect tubing.

Electromagnetic Tools

(i) Flux Leakage and Eddy Current pad-type devices:

PAL (Pipe Analysis Log, also known known by tool acronym PAT-E) - used to evaluate the extent of internal and external corrosion and location of holes.

(ii) Electromagnetic Thickness type noncontact devices:

METT (Multifrequency Electromagnetic Thickness Tool, also known by tool acronym as ETT-D) - which measures a thickness product, electromagnetic caliper, casing magnetic properties, phase shift.

(iii) Cathodic Protection System Evaluation:

C.P.E.T. (Corrosion and Protection Evaluation Tool) used to identify electrochemical cells and evaluate C.P. systems.

Ultrasonic

(i) Resonant Frequency Casing Thickness Techniques:

A.C.E. (Acoustic Casing Evaluation Using the Ditigal Cement Evaluation tool C.E.T.) providing eight casing thicknesses, and radii as well as pipe roughness and ovality.

(ii) Borehole Televiewer techniques:

B.H.T.V. - high resolution internal acoustic imaging of the casing using ultrasonic amplitude and travel time mapping.

The principles of measurement, survey presentations, and basic interpretation of these systems will be presented individually. Application of the various devices will be discussed followed by case examples using multisurveys on a single well.

MECHANICAL CALIPER DEVICES

Mechanical type caliper tools are probably the oldest and most widely used system for measuring casing and tubing diameter. They are used primarily to locate internal obstructions, parted casing, pitting, holes, casing size and weight changes.

Principle of Measurement

The standard type caliper has a measurement section which consists of a series of fingers arranged around a central mandrel (Figure 1). As the tool is pulled up the hole the individual fingers contact the casing wall and these fingers act upon a maximum and minimum plate which in turn move a pair of potentiometers which send a signal to the surface indicating the maximum and minimum radii. Only the particular fingers positioned at the point of maximum or minimum radii will cause movement of the corresponding plate.

MFC

The MFC tool comes in configurations from 36 to 72 fingers, depending on the particular casing size to be inspected. The MFC operates similarly to that explained above (Figure 2) except that in its normal configuration the tool is divided into three independent sectors of 120° each having a maximum and minimum plate; therefore, the tool outputs three minimum and maximum radii. This allows for greater confidence in the measured radii, ability to detect tool eccentricity versus casing ovality as well as an estimation of the circumferential extent of the defect.

The tool offers excellent accuracy and radial resolution. The data can be sampled at differing rates depending on the vertical resolution required down to a vertical sampling rate of .2". A gamma ray (GR) or casing collar locator (CCL) can be run in combination for depth control. An alternate hardware configuration is available whereby the tool is divided into six independent sectors of 60° each. Each sector records a maximum radii only.

Figure 3 shows an example of an MFC log presented on an expanded depth scale. The six maximum radii (Rad 1 - Rad 6) are presented in tracks 2 and 3. In track 1 a radial cross section is presented showing the assumed casing outer radii, with measured absolute, maximum (MXRD) and minimum (MNRD) radii as well as the six radii average (AVRD) the log is indicating parted casing.

A radial plot presentation is available. The presentation shows three concentric circles, two of which are the nominal outer and inner radii for the particular casing size and weight. The other is the measured radii. The number of sectors corresponds to the number of maximum signals available, three or six. The individual radii indeed show the measured diameter to be about 6.6" which is the ID of the outer string of casing.

TGS

The tubing geometry sonde is a multi-fingered caliper device which uses six different feeler and centralizer assemblies to cover the range of tubings from 2-7/8" to 5-1/2". Sixteen radii measurements are made with each of the configurations by the 16-finger assemblies. Instead of potentiometers being used for the measurement system, linear voltage differential transformers (LVDT) are used to convert mechanical movement to electrical impulse. The smaller size of the LVDT'S allow all of the finger measurements to be recorded and sent uphole in digital form. This system has less mechanical drag than potentiometer type systems.

The excellent vertical resolution of the tool permits sampling at .3" intervals at an acceptable logging speed of 1800'/hour. Greater detail can be achieved at slower logging speeds.

The more common configuration of the tool allows the tool to be opened downhole but it must be brought back to surface to be closed and reset. Versions are currently available that can be repeatably opened and closed downhole.

The standard field presentation consists of eight diameters being displayed with a maximum/minimum radii (Figure 4). An enhanced presentation can be made at our data center which will correct the raw data for tool eccentering.

Figure 5 is the data center presentation. The left side of the log presents minimum and maximum diameter curves with a numerical listing of minimum and maximum diameter over each 20 feet. The right side of the display is the 16 radii side by side. A numerical listing of the same data is also presented.

ELECTROMAGNETIC DEVICES

Pipe Analysis Log (PAL)

The pipe analysis log uses nondestructive electromagnetic flux lines which pass through the casing. Defects in the casing, both internal and external, will cause a deflection on the log. An eddy current measurement is also provided to distinguish internal defects from external defects.

Principle of Measurement

An electromagnet in the tool generates a magnetic field whose flux lines permeate the casing in the direction parallel to the wellbore (Figure 6). The magnetic flux path is distorted in the vicinity of a defect, producing a small component normal to the casing wall above and below the defect and thus the flux lines are said to "leak" from the casing. The tool consists of an upper and lower array of sensing pads that ride along the casing wall providing for 100% casing coverage.

Two coils, an upper and lower in each sensing pad, detect this flux leakage as they pass over a defect. (Figure 7). As the flux leakage coils pass over the defect this normal component induces a current that grows from zero to a maximum and back to zero with a current being induced in both the upper and lower coils of each pad. The difference in the induced current between the upper and lower flux leakage coils is the measure of magnitude of the defect. A maximum response of flux leakage from the upper and lower pad arrays is sent uphole.

The eddy current measurement is made using the same two coils in each pad; however, a third coil in the pad is used to generate a high frequency magnetic field Bc (Figure 8) which induces a circulating current in the casing. This induced current generates a counter veiling field Bi and the resulting field is detected by the flux leakage coils and separated from the lower frequency flux leakage signal by a frequency filter.

In good pipe the induced field produces the same current in both coils. When a defect is encountered on the pipe's inner surface, the field is disturbed and a current imbalance between the coils results, producing a deflection on the log. As with flux leakage, the maximum eddy current from the upper and lower array is sent uphole.

The flux leakage and eddy current curves from each array are presented in Track 2 and 3 as a cross section with the lower array on the left. Deflections toward the middle of the page are eddy current response while those directed toward the outside are flux leakage. Enhanced curves which result from holding the responses of the upper and lower array 360 ms, presented in Track 1, assure that significant responses are not missed.

PAT-E

The PAT-E version of the PAL tool consists of an upper and lower array of six pads each. Instead of a maximum eddy current and flux leakage from each pad array being recorded, the eddy current and flux leakage responses from each pad are sent uphole, resulting in 24 measurements. Thus there is more information available as to the areal extent of the defect, permitting a single pit or hole to be distinguished from circumferentially extensive corrosion.

The PAT-E has a .2" vertical sample rate while logging down at a respectable rate of 3600'/hr. It also allows for evaluation of only the inner string in multiple-string configurations. With the use of digital data transmission, combination with other corrosion evaluation devices is possible.

The flux leakage measurement is dependent on the rate of change of the flux vector which is very dependent on the sharpness, shape and depth of the defect. Uniform thinning therefore cannot be detected and linear features such as splits will only be seen at the ends. Recorded deflections are also a function of tool speed, sonde current, pad design, magnet strength, and casing properties.

For these reasons quantitative results are poor at best. Defects are identified on the log as internal or external and classified as light, moderate, extreme corrosion, or possible hole. The PAT-E is particularly suited to hole finding capability in otherwise good casing, finding perforations and identification of localized external or internal pitting.

Figure 9 shows an example of a log run using the PAT-B. After the logging, the pipe was pulled and the actual corrosion was cataloged and photographed. Depth, PAT-B interpretation and actual defect are listed above.

Figure 10 is the same well logged with the PAT-E. All twelve pads are displayed with flux deflections increasing to the left and eddy current increasing to the right. With the increased information the severity of the defects can be better predicted.

ELECTROMAGNETIC THICKNESS DEVICES

Principle of Measurement

Electromagnetic thickness devices use nondestructive, noncontact, inductive measurements to detect general areas of corrosion. The primary measurement of the system is based on a phase shift between a transmitter current and receiver voltage. The transmitter coil induces a circumferential current in the casing which in turn induces a voltage in the receiver coil. In air this phase shift will be 90° and in casing will increase with increasing metal thickness in accordance with the following formula:

Delta Phase = t x (2x omega x mu x sigma) 1/2 Equation (1)
t = metal thickness (inches)
omega = operating frequency (radians/sec)
mu = operating frequency (Henries/meter)
sigma = casing electrical conductivity (Seimens)

The phase shift between a similar coil system operating at a higher frequency is used to make a caliper measurement.

Multifrequency Electromagnetic Thickness Tool (METT)

The METT tool makes three related electromagnetic measurements - caliper, casing properties, and phase shift. The higher the operating frequency of the transmitter coil the better the vertical resolution while the lower the frequency the better the depth of penetration. The tool has different transmitter/receiver coil systems that are optimized for a particular measurement.

The electromagnetic thickness system measures the phase shift between a transmitter and receiver. The thickness system can operate at 35 HZ, 17.5 HZ, or 8.75 HZ. The lower frequencies extend the measurement range and allow for evaluation in multiple strings. An auxiliary measurement named LRAT is displayed on the log to insure that the optimum frequency for the phase system is utilized.

The electromagnetic caliper measurement is made using a high frequency so that the fields created penetrate only the internal surface of the casing. The voltage measured at the receiver is a function of casing I.D. and casing properties at the pipe inner wall. A two-component caliper measurement allows for a unique solution and a casing properties corrected internal diameter measurement is obtained.

Short (CIDS) and long spaced (CIDL) caliper measurements are made so that an accuracy of +/- .05" can be maintained for varying size casings. Conductive well bore fluid will contribute to the measurements made by the caliper system. A computed caliper (ECID) uses the two differently spaced caliper measurements to correct for conductive fluid effects.

The properties measurement is based upon the same theory as the electromagnetic caliper. The voltage of the received signal is again a function of casing properties and ID, but since a correct ID is available from the caliper system the properties measurement can be made. Three different frequencies provide for three different properties measurements with increasing depth of investigation. Casing properties shallow (CPRS), medium (CPRM) and deep (CPRD) are recorded. None of these measurements will penetrate the casing.

Casing properties are related to casing conductivity (sigma) and magnetic permeability (mu) according to the formula.

$$CPR = (mu/sigma)\ 1/2 \times 10^{6} \qquad \text{Equation (2)}$$

Casing conductivity is generally a well-behaved process, being a function of the chemical composition of the steel and is therefore uniform over a casing joint. Magnetic permeability which relates to magnetism is an ill-behaved process dependent on chemical composition, magnetic history, mechanical stress and manufacturing process. Therefore, if we assign a conductivity to equation (2) and substitute it into equation (1) we can solve for thickness t. A conductivity thickness product is computed and output on the log.

Figure 11 is an example of an METT log in an old injection well. The old packer depth can be picked from the log at 2396'. The caliper is indicating holes and increased ID. The thickness curve confirms the significant metal loss.

Figure 12 shows areas of decreasing phase shift between 1910' and 2000' that would normally be interpreted as decreasing metal thickness. It can be seen that the decreasing phase shift is a result of changing magnetic properties and the thickness curve sees no significant change in metal thickness.

CATHODIC PROTECTION EVALUATION SURVEYS

Electrochemical corrosion is the result of naturally induced electrical currents that flow in the casing as the result of a potential difference existing between points on the casing. The metal with the higher potential becomes the anode (Figure 13) losing electrons to the cathode and positive iron ions to the electrolyte. The anode loses metal at a rate proportional to the current flow as can be determined by Faraday's Law.

Since metal loss occurs at the anode, the casing can be protected if all points on the casing are caused to be cathodic - thus Cathodic Protection. This can be accomplished by a sacrificial anode or an impressed current system that attempts to drive current from a buried anode through the earth returning to the source via the casing to be protected. (Figure 14)

Principle of Measurement

A casing potential survey determines the amount of current flowing in the casing by taking potential difference measurements along the casing inner wall (Figure 15). The survey is accomplished with a down hole tool that has casing contacts spaced a known distance apart on the tool. A differential voltage measurement is taken and using Ohms Law with an assumed casing resistance, the amount and direction of current flow can be determined. By taking the difference in currents at two depths, current can be determined to be entering (cathodic) or leaving (anodic) the casing. Because of the small voltages measured, the electrodes were typically spaced 15-25' apart and stationary measurements made at 50-100' intervals.

Limitations of the survey were that bit and scraper runs were needed for good tool to casing contact, the well bore fluid had to be nonconductive (gas or diesel) and a value for casing resistance had to be assumed to calculate current.

C.P.E.T. Corrosion and Protection Evaluation Tool

The C.P.E.T. was specifically designed to overcome the limitations and associated costs of conventional surveys. A schematic of the tool is shown in Figure 16. Four sets of three electrodes are spaced two feet apart along the sonde with each array consisting of three knife blade type contactors spaced 120° apart. Each electrode is electrically isolated from the others and the wellbore, which permits the tool to obtain valid readings in the presence of conductive wellbore fluid.

The arms are hydraulically activated and can usually maintain proper contact without a bit and scraper run. The differential voltages are measured downhole with a temperature compensated, precision voltmeter and the data transmitted digitally uphole. The accuracy of the equipment allows for a 2' vertical resolution.

Potential difference is measured between adjacent electrodes and outside electrodes on each axis (Figure 17). Casing resistance is measured by injecting a known current via the top and bottom electrodes on one axis with the potential drop measured by the inner two electrodes. Contact resistance is measured between 12 different electrode pairs by injecting a small known current between the electrode pairs and measuring resulting potential.

A fluid ohmic drop measurement is made between a set of downhole fluid electrodes and the wellhead as well as the potential between the wellhead and a copper-copper sulfate reference electrode. The fluid resistance drop measurement allows for identification of internal corrosion cells included in the axial current readings. This corrosion cannot be impeded by a C.P. System.

Casing resistance is combined with the potential measurement to obtain axial current. A calculation of radial current density can be made and converted via Faraday's law to metal loss. If a casing conductivity is assumed, casing thickness can also be presented. All these measurements are obtained in a sequential fashion by taking 6' stations to provide for a 2' resolution. The entire measurement sequence takes only about 6 seconds at each station and an equivalent logging speed of 1500'/hr. is obtained.

The most common use of profiling devices is to monitor the effectiveness of a cathodic protection system. The much higher resolution and accuracy afforded by the CPET allows for fine tuning of cathodic systems or interference testing. It can also be used to evaluate the necessity of installing a C.P. system on an unprotected well. This would be invaluable information when attempting to make this decision.

Figure 18 is an example of a CPET run on a protected well. The log confirms the well to be adequately protected.

ULTRASONIC DEVICES

Borehole Televiewer
Principle of Measurement

The borehole televiewer is an acoustic logging tool that uses an ultrasonic transducer to obtain detailed information about the inside of the casing. The tool acquires amplitude and transit time information and uses that information to image the internal surface of the casing. Liquid in the wellbore is required for all acoustic devices.

BHTV - Borehole Televiewer Tool

The BHTV uses an ultrasonic transducer attached to a vertical shaft (Fig 19) which is rotated at 3 rev/sec with 250 samples being taken per revolution. Thus 750 travel time and amplitude measurements are taken per second in a spiral path up the casing. A second stationary transducer in the tool is used to measure the fluid velocity by which the travel times can be converted into radii. The vertical resolution of the tool is variable from .2" to 6".

The travel time information can be displayed as a grey scale map with increasing travel time corresponding to darker shades according to a variable intensity scale. A full 360° is presented at each depth.

The transit time measurements converted to radii can be displayed in a radial plot showing concentric circles of assumed outer and inner diameters and actual points measured (Figure 20).

Amplitude data can be displayed in a map form similar to the transit time with darker shades corresponding to lower amplitude. Rough pipe associated with pitting or holes causes dispersion of the acoustic energy and this measurement is usually more sensitive to defects than travel time. If a defect is smaller than the impinging acoustic beam width, the first signal back to the transducer will be the travel time of the undamaged casing and the time from the damaged portion is not recorded. This is not the case with the amplitude as the returning pulse will be attenuated.

Transit time, amplitude and radial cross sections can be produced in the field. Alternately a more fine tuned display can be presented by our data centers using more sophisticated processing. A much better grey scale imaging can be presented and color imaging of the BHTV amplitude is also possible.

Figure 21 is an excellent example of the BHTV'S resolution. The well was shot at 3 shots per foot and the exact location of the perfs was desired. The amplitude map shows a number of rows of three shots per foot; yet the transit time does not see the defects as the perforations are smaller than the beam width.

Figure 22 is a color enhanced amplitude map. The dark blue represents undamaged pipe with increasing damage going through green and yellow to red. Some bands of severe corrosion are evident. The collar is visible just above 883' and is actually amplitude variations caused by exposed threads.

Acoustic Casing Inspection
Principal of Measurement

Ultrasonic methods are used to evaluate casing internal radii as well as wall thickness. In a similiar manner to the BHTV a transit time is converted to internal radii. Unlike the BHTV the entire wave form reflected from the casing is recorded and sent uphole instead of just a transit time measurement. The ultrasonic transducers causes the casing to resonate. An analysis of the resulting wave form in the frequency domain can determine the casing's resonant frequency which is directly related to thickness through the velocity of sound in steel.

A.C.E. Acoustic Casing Evaulation

The digital CET (Cement Evaluation Tool) is an ultrasonic device originally developed for cement evaluation. The tool has eight focused transducers in a helical spiral along the tool body spaced at 45 degrees around the tool (Figure 23). The ultrasonic transducers emit a pulse of energy which cause the casing to resonate. The returning signal (Figure 23) is then digitized and sent uphole for analysis.

As indicated in the figure the travel time (DT) is measured and converted to radii using the fluid velocity measured by a ninth transducer in the sonde. Eight radii can be presented along with ovality (maximum difference between opposing diameters) and tool eccentering.

Casing internal roughness can be evaluated by measuring the amplitude of W1, the direct reflection from the inner wall of the casing. If the inner wall of the casing is smooth most of the sonic energy is reflected back to the transducer providing a high amplitude. Rugosity, scale, etc. tends to scatter the energy and a low amplitude is received.

Casing thickness is computed from the recorded wave form after converting it to the frequency domain. The resonant frequency is identified and from this casing thickness can be computed. Since this measurement is a function only of the inner string of casing it is the only inspection device that can accurately measure inner string thickness in multiple strings.

Eight thickness, radii and rugosity measurements can be displayed in a variety of ways. Real time casing cross sections of measured radii and thickness can be computed and displayed in the field (Figure 24). A digital listing of the data is also available.

In the Acoustic Casing Evaluation display available from Data Services, the radii measurements are presented side by side in a color three-dimensional display with the color legend given above. The colors are scaled in a percentage metal loss from an input nominal radii and O.D. A similar presentation is used for thickness and rugosity. Wireline depths and average metal loss based upon thickness and radii are presented on the left-hand side. This is the standard colour A.C.E. presentation (Figure 25).

Figure 26 is an example of a new colour presentation available called PIL (Pipe Inspection Log). The PIL software supports all current casing inspection devices. The data from all devices can be analyzed together and displayed in an almost limitless number of variations. In the PIL color plot of the acoustic casing evaluation no nominal wall thickness or radii input is necessary to display the images. Instead the image is continuously corrected for weight changes and other affects so that only defects are highlighted. Histograms (Figure 27) of the data are available for indicating casing size and weight changes as well as quick identity of possible problem areas. A single joint cross section presention (Figure 28) is available to examine defects in greater detail.

CASING EVALUATION - OBJECTIVE VS. TECHNIQUE

The first step in any casing evaluation is to define the objective. Once the objective has been established the best evaluation methods can be determined. Typically all of the devices fall into two categories - overall inspection device or detail device.

Overall casing inspection devices give a good quantitative generalized evaluation. These devices typically have a vertical resolution of 2" or greater. The METT, CPET, and A.C.E. are excellent overall evaluation devices.

Detail inspection devices are required when looking for localized corrosion such as isolated pitting or holes. The PAL, MFC and BHTV devices are excellent detail devices. The PAL tool overlaps into the overall evaluation application except that it lacks any quantitative measurements.

When tool limitations are considered, such as ultrasonics requiring liquid in the wellbore, the optimum logging program can be chosen and typically will require several devices. Sometimes objectives can limit the technique required to one device such as would be the case in evaluating inner string thickness in multiple strings.

Multilog Casing Examples

Figure 29 is a combined log example of an MFC/METT. This combination provides for hole identification, pitting (external or internal), splits, scale identification, wall thickness, qualitative evaluation of surface casing.

The logs in Figure 30 were from a client that had corrosion problems usually at approximately the same depth in various wells which resulted in casing leaks. The cause of the leaks was unknown and many times problems of not being able to squeeze the leak were encountered even though this section of casing was well above the cement top. It was thought that possibly electrochemical corrosion could be occurring so that a CPET tool was recommended to examine for the presence of any anodic areas. An METT was used to evaluate remaining metal thickness and an MFC was run for hole finding capabilities. A CET was run to see if this interval actually contained "free pipe" and the wave forms were processed and an ACE presented (Figure 30).

The cement map from the CET showed good acoustic impedence across most of the problem area with free pipe above and below it. This cased interval was across a section of "red beds" and apparenty these shales had swelled out to surround the casing. The METT and ACE showed good remaining wall thickness and the internal diameter measured by ACE, METT, and MFC showed about nominal I.D. Isolated areas of casing deformation were also identified by these three logs with the METT indicating a possible problem in the indicated collar. The CPET did not show any signs of significant electrochemical corrosion. The combination of the logs indicated that the swelling shales were causing casing deformation that occasionally resulted in collar leaks that were then difficult to squeeze. The recommendation was made to run cement across this interval on any new wells. The casing collar leak indicated was successfully squeezed.

Conclusions

The technology now exists to permit accurate and complete evaluation of downhole casing conditions. This information can be used to correct problems before they become critical, identify possible corrosion causes, and monitor the effectiveness of corrosion protection systems such as cathodic protection. The correct application of the devices will allow the corrosion engineer to cost effectively evaluate and correct corrosion problems that will result in long-term cost savings.

References

Roberts, D. L., Richards, J. W., "A casing evaluation using ultrasonic techniques - a unique approach for West Texas wells", Schlumberger Wireline Symposium, March 1987

Dennis, B., "Casing Corrosion Evaluation using Wireline Techniques", NACE Corrosion 88, March 1988

Donahue, M., "Corrosion Document", Internal reference document Schlumberger, March 1988

Smolen, J. J. "Pat Provisory Interpresentation Guidelines," Internal reference document Schlumberger, July, 1976

Dawson, J. L., King, R. A., "Corrosion and Corrosion Control in the Oil Industry", In House Company Course Schlumberger, Paris, Sept. 1985.

Acknowledgements

The author wishes to thank Steve Neuman, Log Interpretation Engineer, for his time in preparing the several colour Acoustic Casing Evaluation examples.

All presentations in this paper are in black and white. Color-enhanced copies of certain figures are available from the author. (Editor's note).

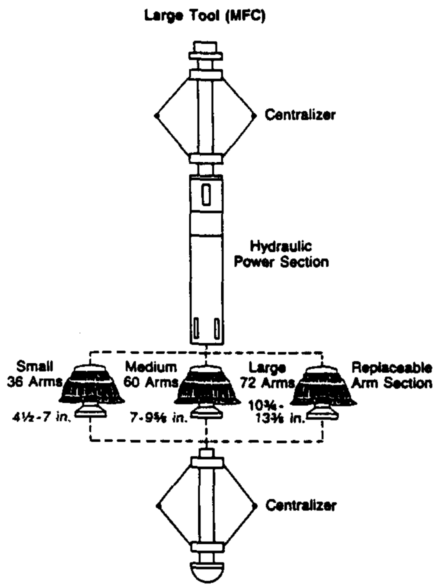


Figure 1 — MFC multifingered caliper tool

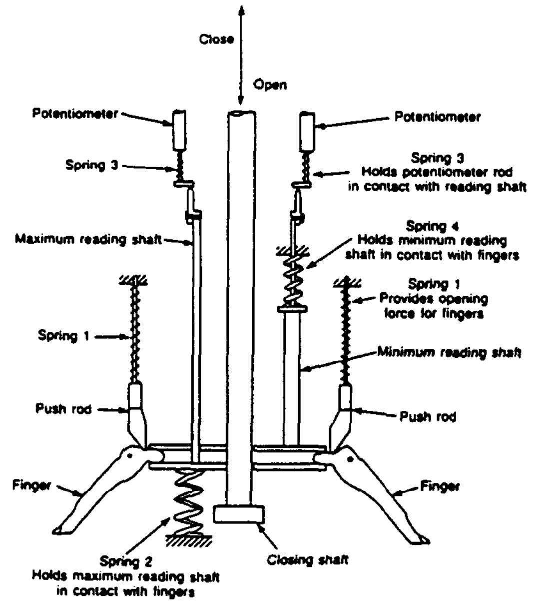


Figure 2 — MFC mechanical measurement section

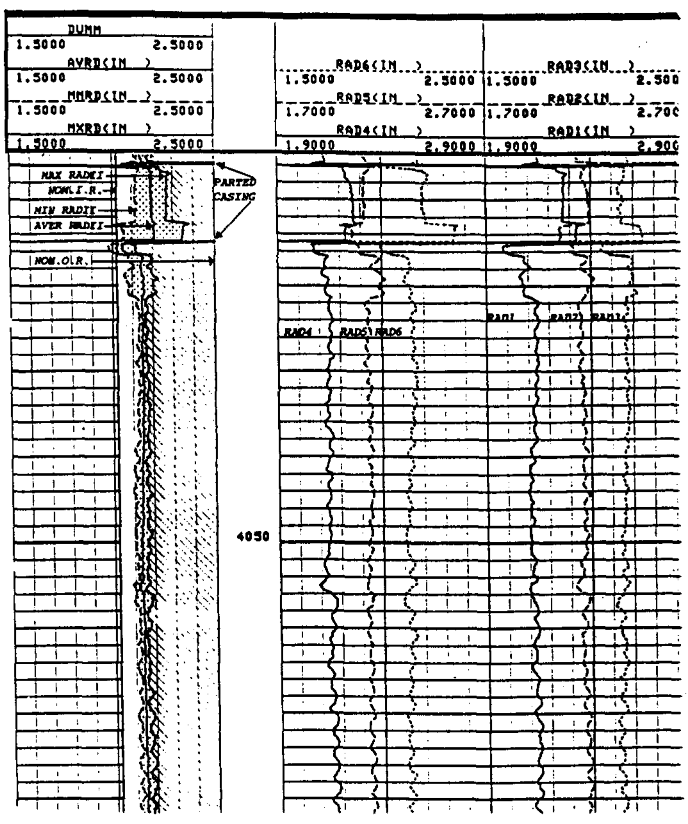


Figure 3a — Parted casing example using the MFC — 5-1/2 - in. casing parted inside 7-in.

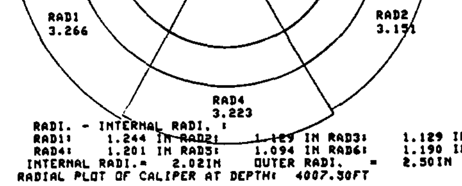


Figure 3b — Radial plot taken through parted casing — 5 1/2-in. casing inside 7-in.

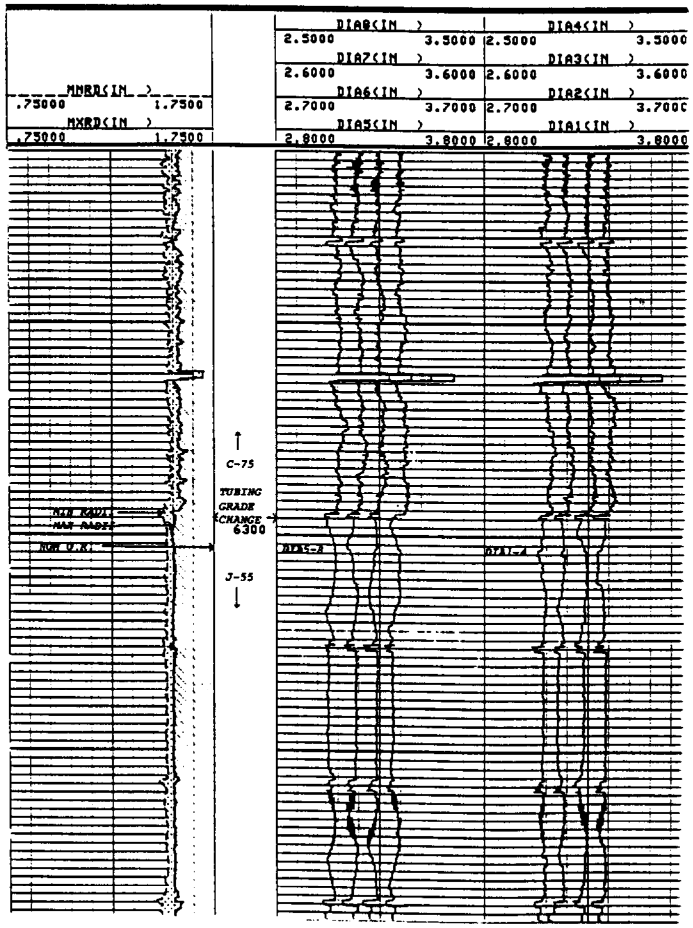
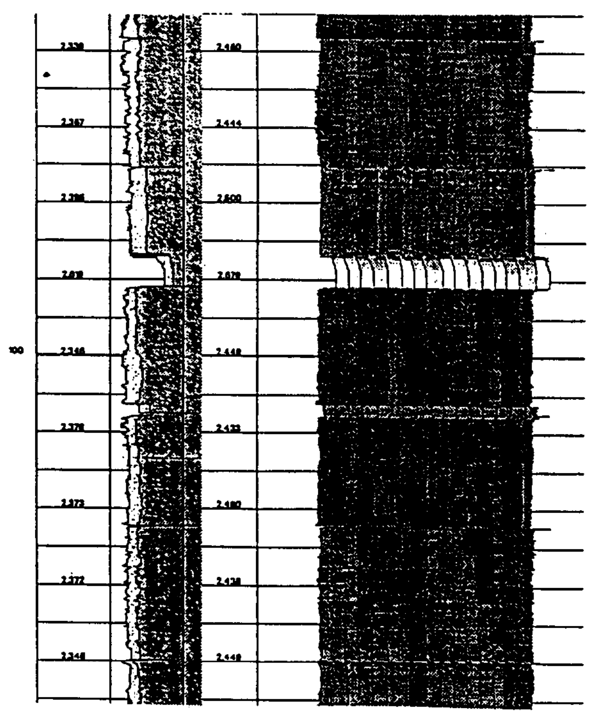


Figure 4 — TGS in 3-1/2" tubing showing significant change in corrosion after the tubing grade changes



LISTING

PIN DEPTH (FEET)	BOX DEPTH (FEET)	MEAN DIAM. (INCH)	MEDIAN DIAM. (INCH)	MAX. PIT (INCH)	AT DEPTH (FEET)	MAX. SCALE (INCH)	AT DEPTH (FEET)	JOINT NO.
10210.0	10179.0	2.419	2.420	0.153	10179.17	0.049	10209.58	325
10177.0	10151.0	2.395	2.396	0.166	10150.96	0.043	10150.67	324
10149.0	10117.0	2.390	2.390	0.077	10116.13	0.039	10148.50	323
10115.0	10087.0	2.409	2.414	0.089	10086.83	0.044	10086.63	322
10085.0	10053.0	2.394	2.394	0.209	10052.33	0.041	10062.71	321
10051.0	10024.0	2.421	2.422	0.165	10023.50	0.060	10023.29	320
10022.0	9989.0	2.393	2.396	0.063	9989.21	0.045	10022.96	319
9987.0	9956.0	2.405	2.408	0.053	9960.17	0.054	9972.46	318
9954.0	9927.0	2.395	2.394	0.251	9926.46	0.035	9931.54	317
9925.0	9896.0	2.431	2.420	0.082	9925.00	0.040	9895.17	316
9894.0	9862.0	2.407	2.410	0.167	9861.29	0.040	9891.08	315
9860.0	9833.0	2.425	2.426	0.231	9832.96	0.036	9854.21	314
9831.0	9797.0	2.416	2.420	0.161	9796.13	0.050	9796.38	313
9795.0	9768.0	2.401	2.402	0.226	9767.50	0.045	9767.21	312
9766.0	9734.0	2.387	2.390	0.159	9733.58	0.034	9733.17	311
9732.0	9706.0	2.393	2.394	0.149	9705.54	0.055	9729.54	310
9704.0	9671.0	2.400	2.402	0.055	9674.46	0.045	9672.83	309
9669.0	9642.0	2.405	2.404	0.249	9641.50	0.034	9643.17	308
9640.0	9613.0	2.423	2.424	0.041	9635.88	0.067	9612.29	307
9611.0	9580.0	2.395	2.396	0.216	9579.75	0.038	9594.42	306
9578.0	9551.0	2.420	2.422	0.039	9550.29	0.035	9565.71	305
9549.0	9517.0	2.393	2.394	0.053	9516.92	0.028	9549.92	304
9515.0	9486.0	2.418	2.422	0.169	9485.33	0.036	9485.50	303
9484.0	9454.0	2.430	2.432	0.046	9453.46	0.038	9464.46	302
9452.0	9425.0	2.395	2.400	0.053	9424.71	0.049	9432.83	301
9423.0	9394.0	2.405	2.408	0.185	9393.50	0.035	9418.83	300
9392.0	9366.0	2.415	2.418	0.241	9365.42	0.048	9369.58	299
9364.0	9330.0	2.412	2.412	0.212	9329.58	0.045	9355.75	298
9328.0	9299.0	2.418	2.422	0.207	9303.96	0.036	9306.75	297
9297.0	9271.0	2.416	2.420	0.077	9270.38	0.039	9271.42	296
9269.0	9243.0	2.442	2.444	0.046	9253.38	0.037	9248.50	295
9241.0	9209.0	2.412	2.414	0.236	9208.83	0.051	9226.50	294
9207.0	9181.0	2.421	2.424	0.025	9187.54	0.049	9180.17	293
9179.0	9145.0	2.410	2.408	0.214	9144.71	0.037	9144.21	292
9143.0	9116.0	2.409	2.406	0.218	9115.21	0.041	9118.96	291
9114.0	9082.0	2.410	2.400	0.226	9082.00	0.037	9102.88	290
9080.0	9051.0	2.480	2.440	0.149	9050.92	0.052	9050.63	289
9049.0	9017.0	2.408	2.412	0.086	9016.79	0.049	9016.50	288
9015.0	8989.0	2.399	2.402	0.065	8988.04	0.039	9013.13	287
8987.0	8954.0	2.406	2.408	0.141	8953.33	0.059	8953.92	286
8952.0	8936.0	2.419	2.422	0.036	8949.58	0.034	8939.25	285
8934.0	8894.0	2.408	2.410	0.169	8894.00	0.054	8893.38	284
8892.0	8865.0	2.390	2.390	0.177	8864.50	0.054	8890.67	283
8863.0	8844.0	2.415	2.410	0.070	8861.71	0.042	8857.88	282
8842.0	8800.0	2.393	2.392	0.143	8799.46	0.043	8799.92	281
8798.0	8771.0	2.378	2.384	0.024	8772.46	0.042	8796.50	280
8769.0	8736.0	2.380	2.384	0.057	8769.58	0.032	8736.54	279

Figure 5 — Data Services presentation of TGS log

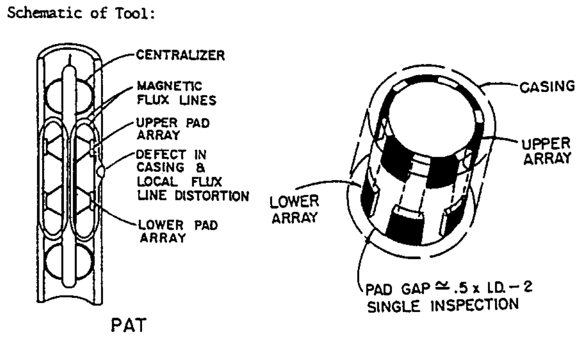


Figure 6 — Pipe analysis tool (PAT)

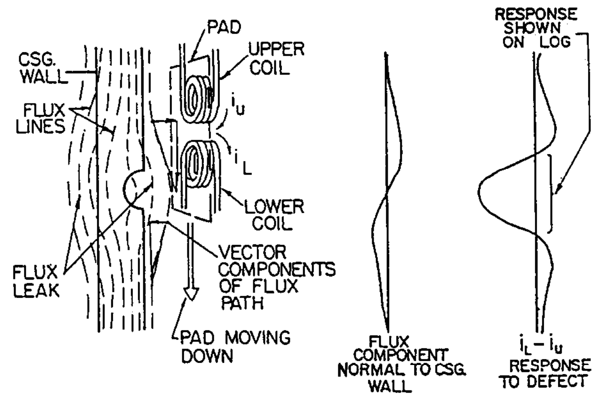


Figure 7 — Flux leakage test

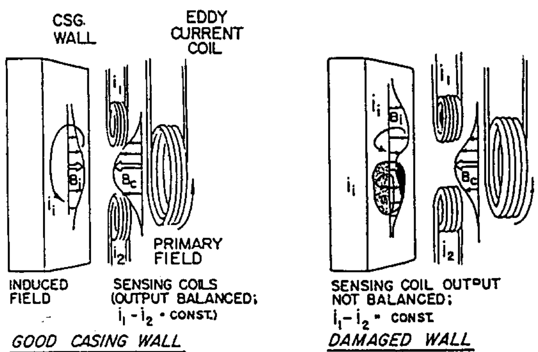


Figure 8 — Eddy current test

DEPTH	PAT-B INTERPRETATION	ACTUAL DEFECT
1863	SEVERE - OUTSIDE	61% PENETRATION - OUTSIDE
1868	MODERATE - OUTSIDE	53% PENETRATION - OUTSIDE
1870	SEVERE - OUTSIDE	RING WITH 85% PENETRATION 1/4" THROUGH HOLE
1872	THROUGH HOLE	3/4" THROUGH HOLE
1873	SEVERE - OUTSIDE	RING WITH 78% PENETRATION
1876	MODERATE - OUTSIDE	20% PENETRATION - OUTSIDE
1878	SEVERE - OUTSIDE	RING WITH 80% PENETRATION PIN HOLE
1879	SEVERE - OUTSIDE	3/8" HOLE

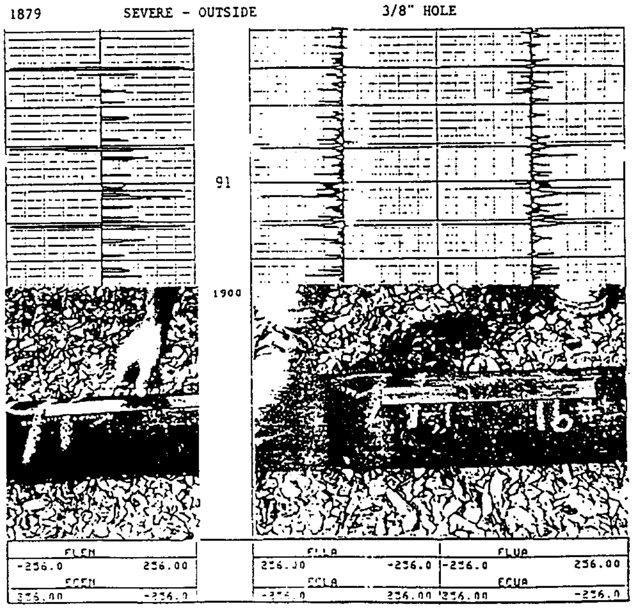


Figure 9 — PAT-B log in damaged casing that was pulled for visual examination and comparison to log

DEPTH	PAT-E INTERPRETATION	ACTUAL DEFECT
1863	63%,OUT.,4 PADS	61% PENETRATION - OUTSIDE
1868	80%,OUT.,8 PADS	53% PENETRATION - OUTSIDE
1870	100%,ALL PADS	RING WITH 85% PENETRATION 1/4" THROUGH HOLE
1872	100%,2 PADS	3/4" THROUGH HOLE
1873	100%,OUT.,ALL PADS	RING WITH 78% PENETRATION
1876	$40%,OUT.,ALL PADS	20% PENETRATION - OUTSIDE
1878	85%,OUT.,4 PADS	RING WITH 80% PENETRATION PIN HOLE
1879	100%,2PADS	3/8" HOLE

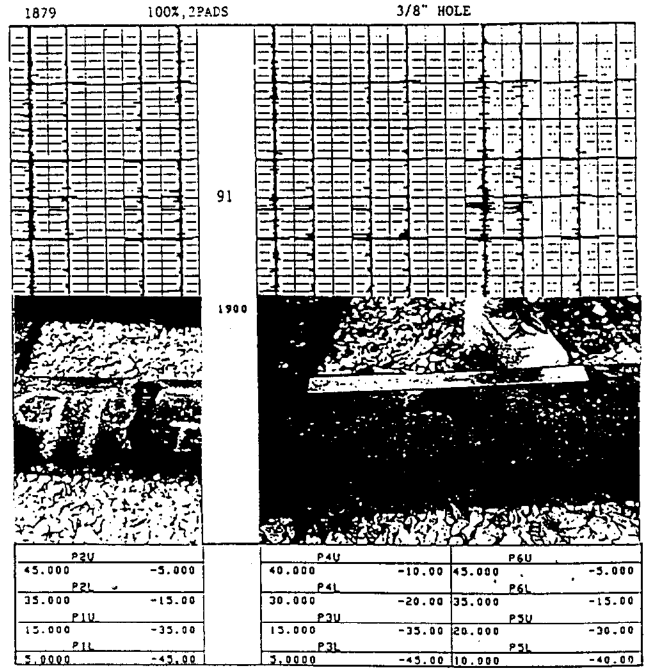


Figure 10 — PAT-E log in same well as Fig. 9 — interpretation is improved over PAT-B by sending information from each pad uphole

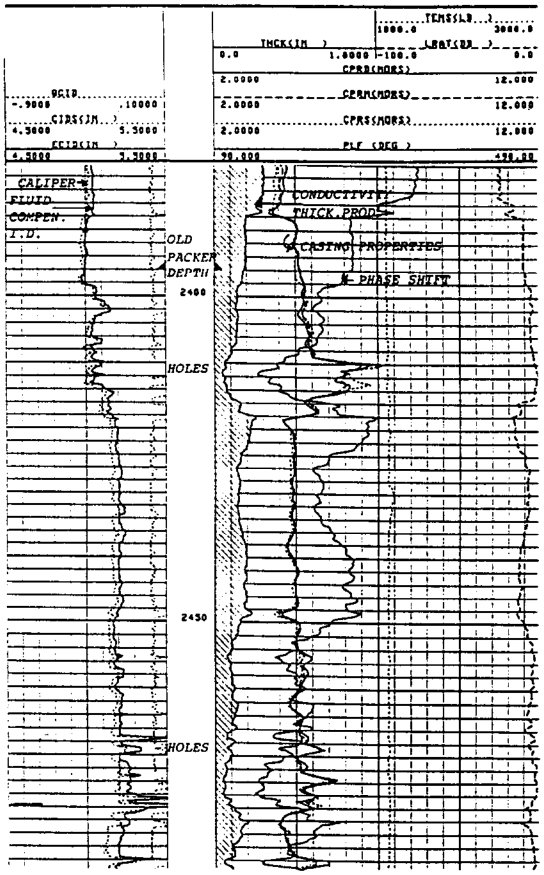


Figure 11 — METT log showing old packer depth and damaged casing

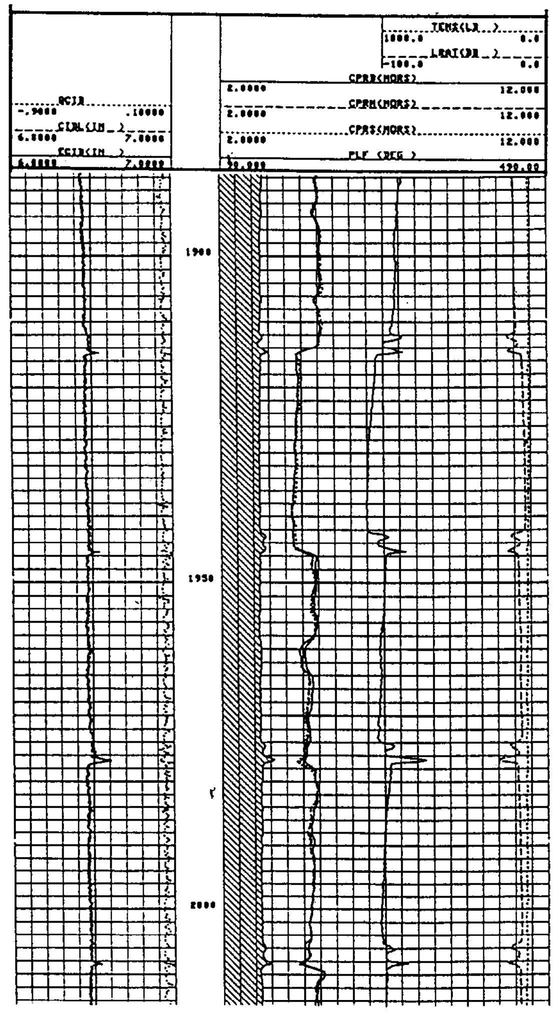
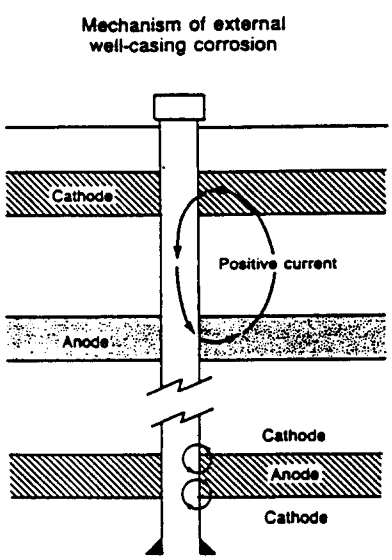


Figure 12—METT log showing varying magnetic properties and phase shift with no net change in thickness



Electrochemical current flow resulting in external metal loss

Figure 13 — Electrochemical corrosion

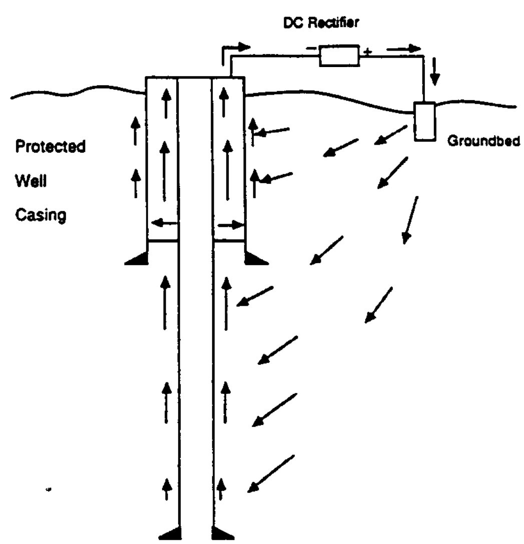


Figure 14 — Cathodic protection

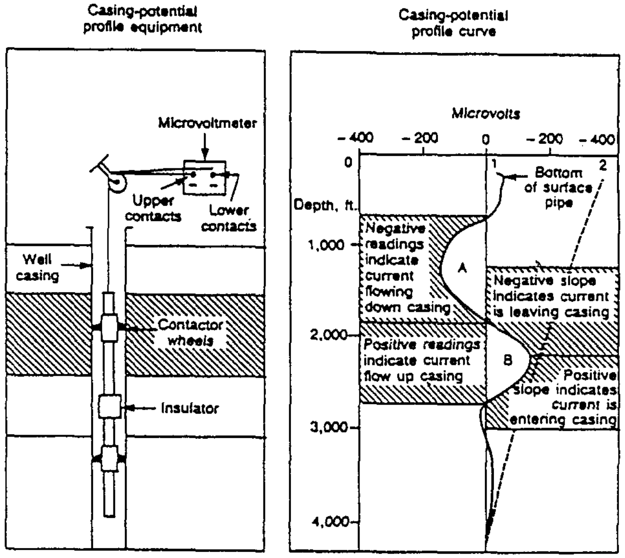


Figure 15 — Casing potential profiling measurement system and log

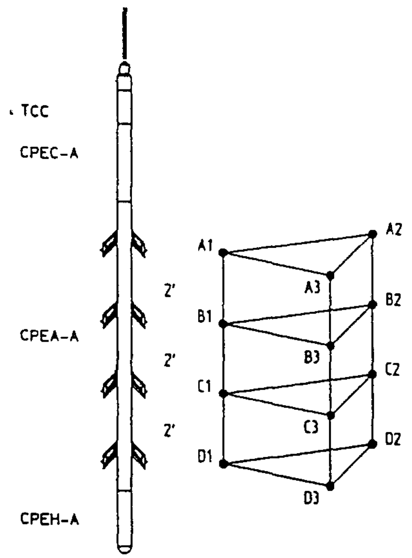


Figure 16 — Corrosion and protection evaluation tool (CPET)

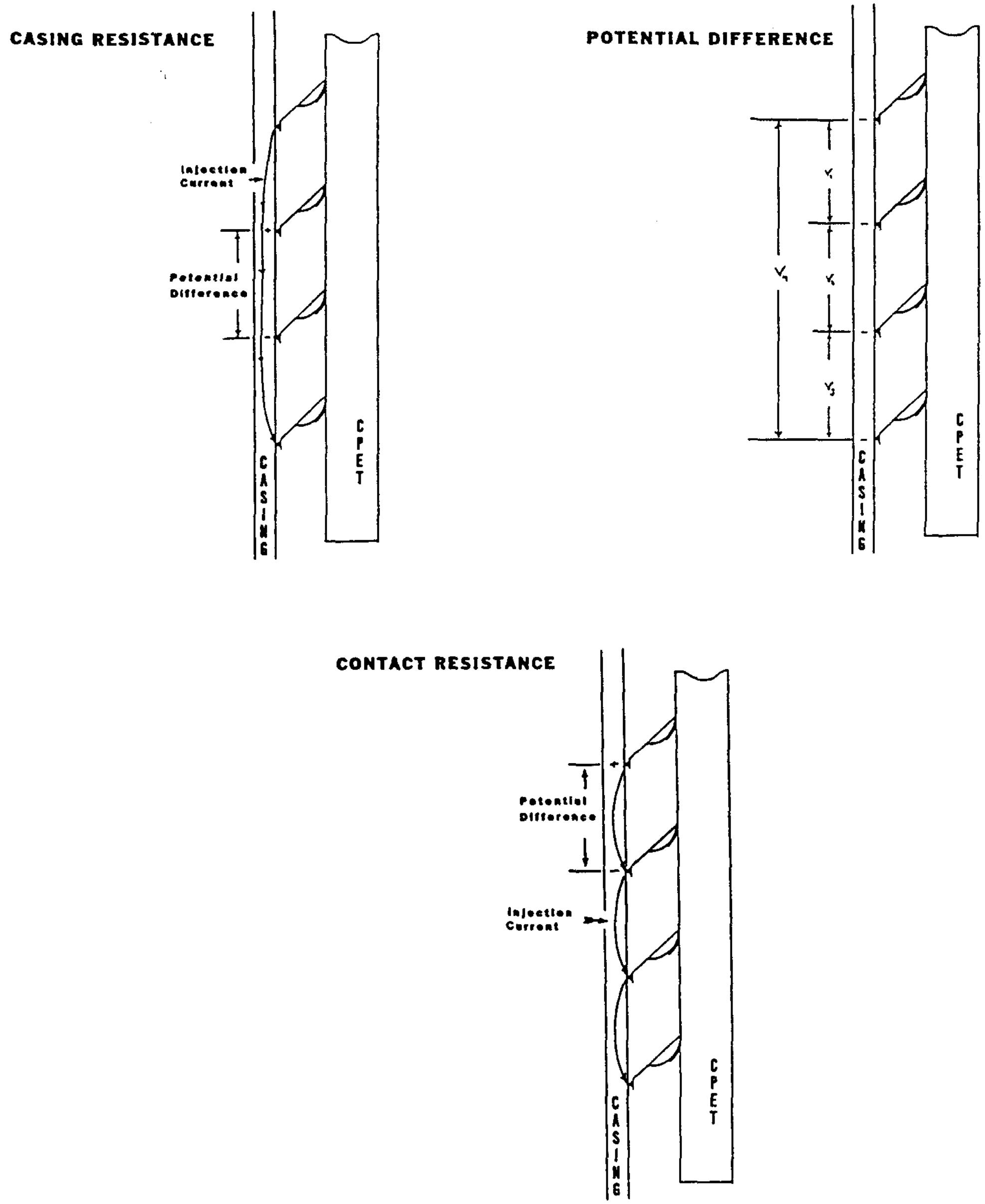


Figure 17 — CPET measurement principles

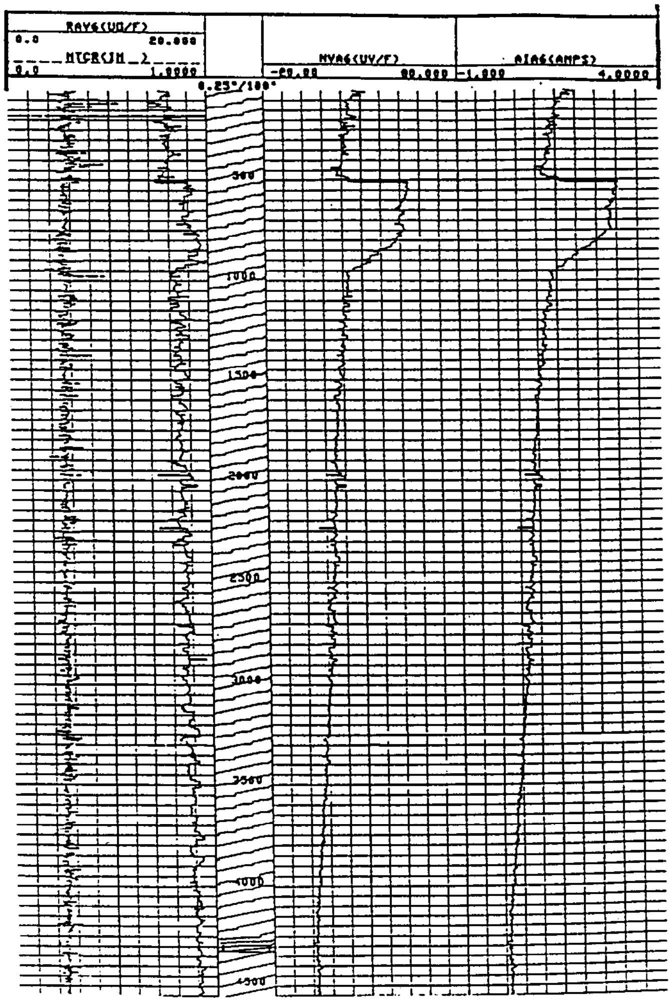


Figure 18 — CPET log on a protected well

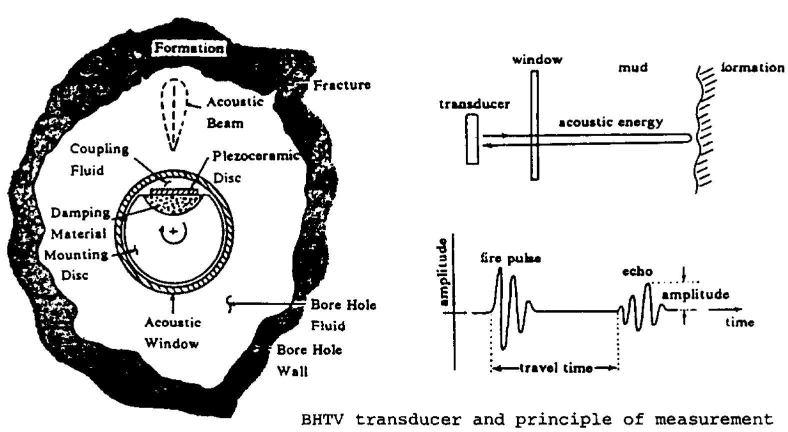


Figure 19 — Borehole televiewer tool (BHTV)

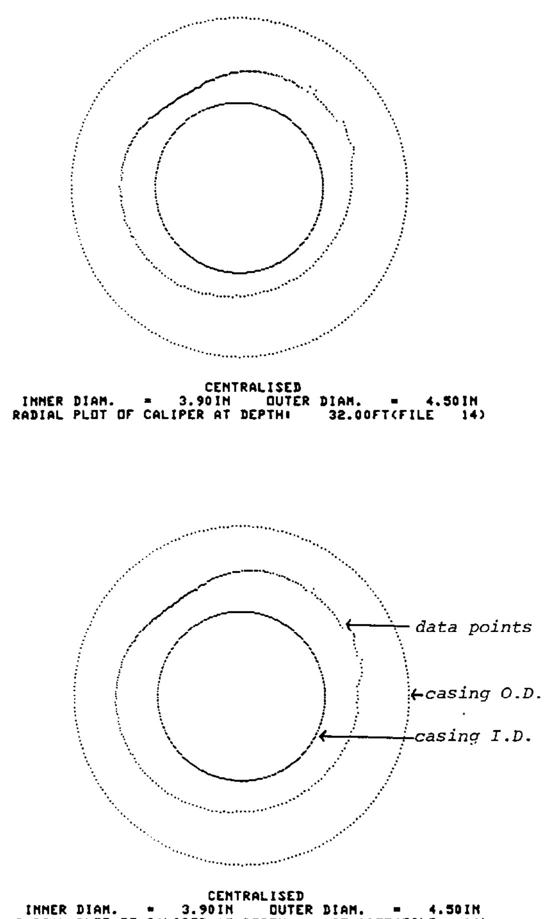


Figure 20 — BHTV — 250-point radial plot

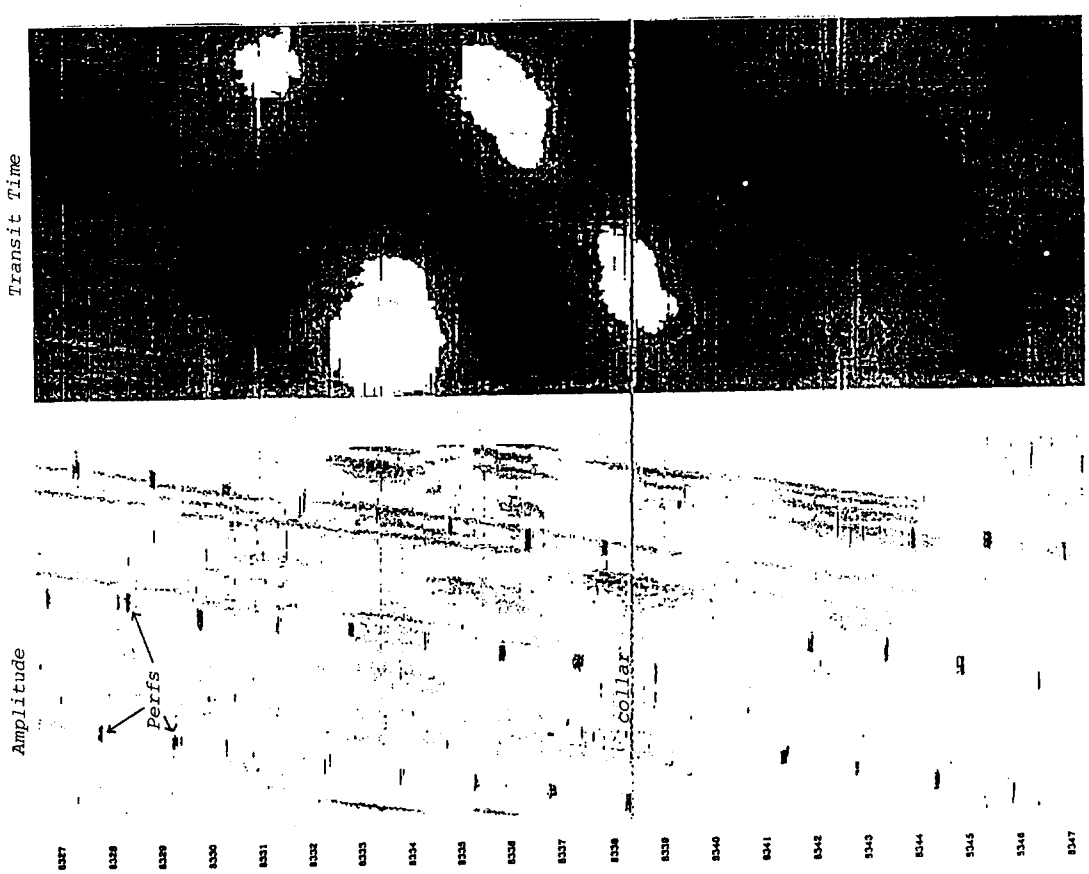


Figure 21 — BHTV example showing perforations

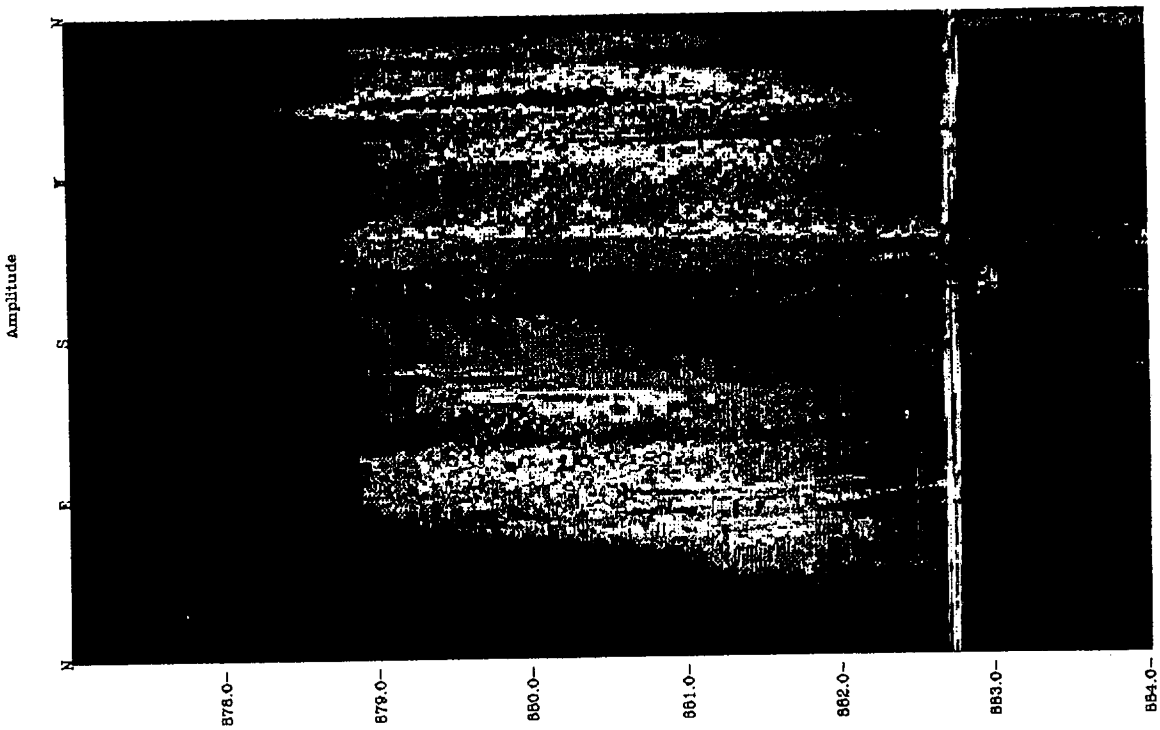
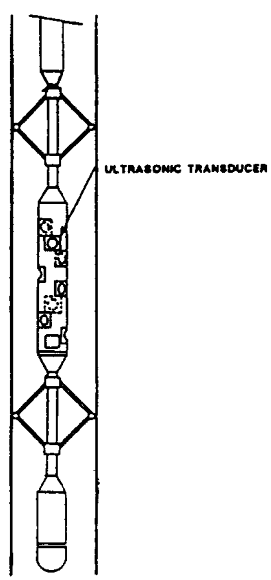
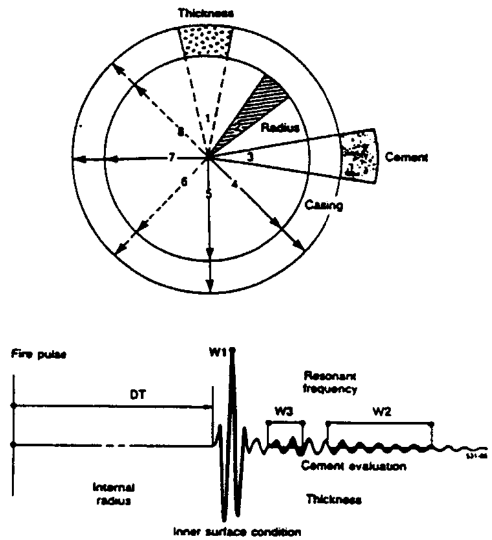


Figure 22 — Data Services BHTV amplitude imaging of internal corrosion



ACE - Acoustic Corrosion Evaluation tool.



ACE ultrasonic waveform

Figure 23 — Acoustic casing evaluation tool (ACE) and principle of measurement

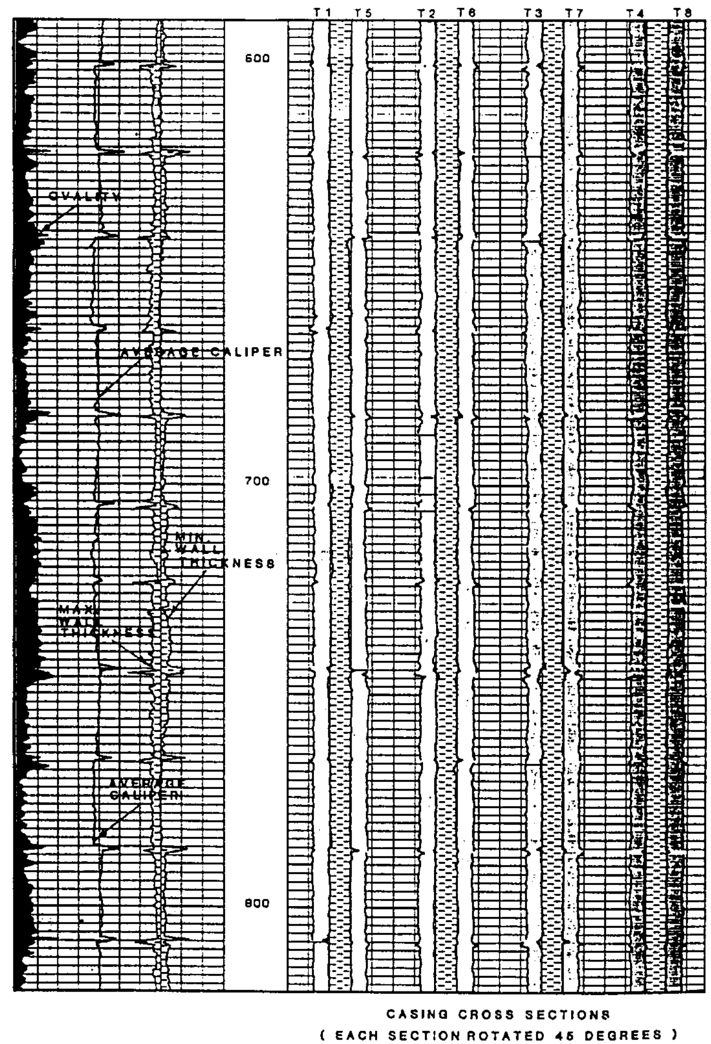


Figure 24 — ACE cross section presentation available at wellsite

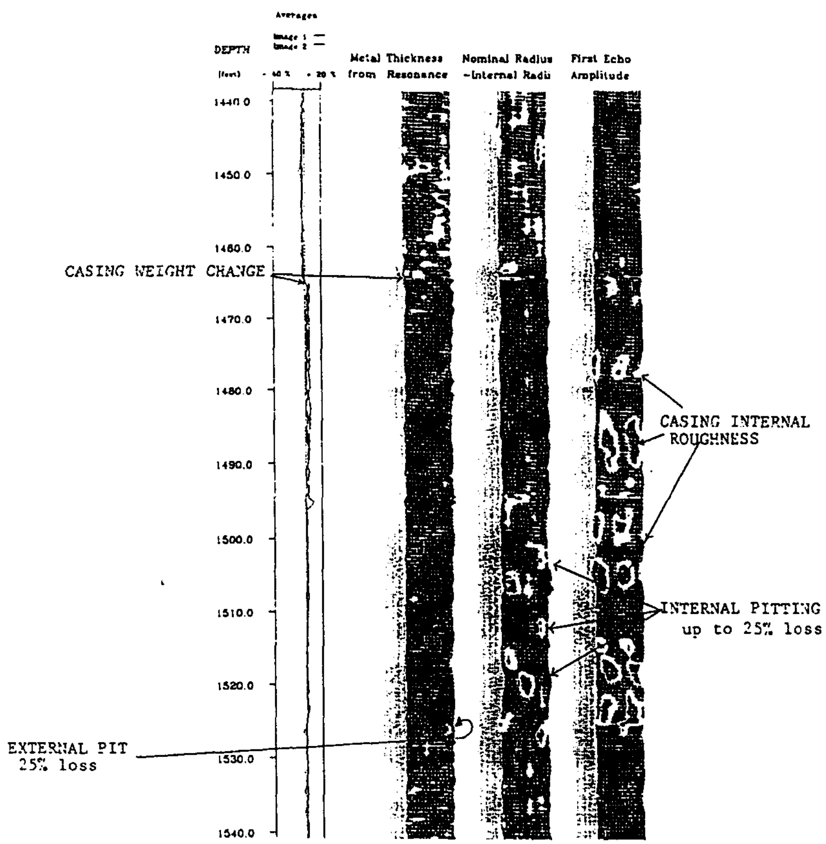


Figure 25 — Acoustic casing evaluation (ACE) color presentation from Data Services

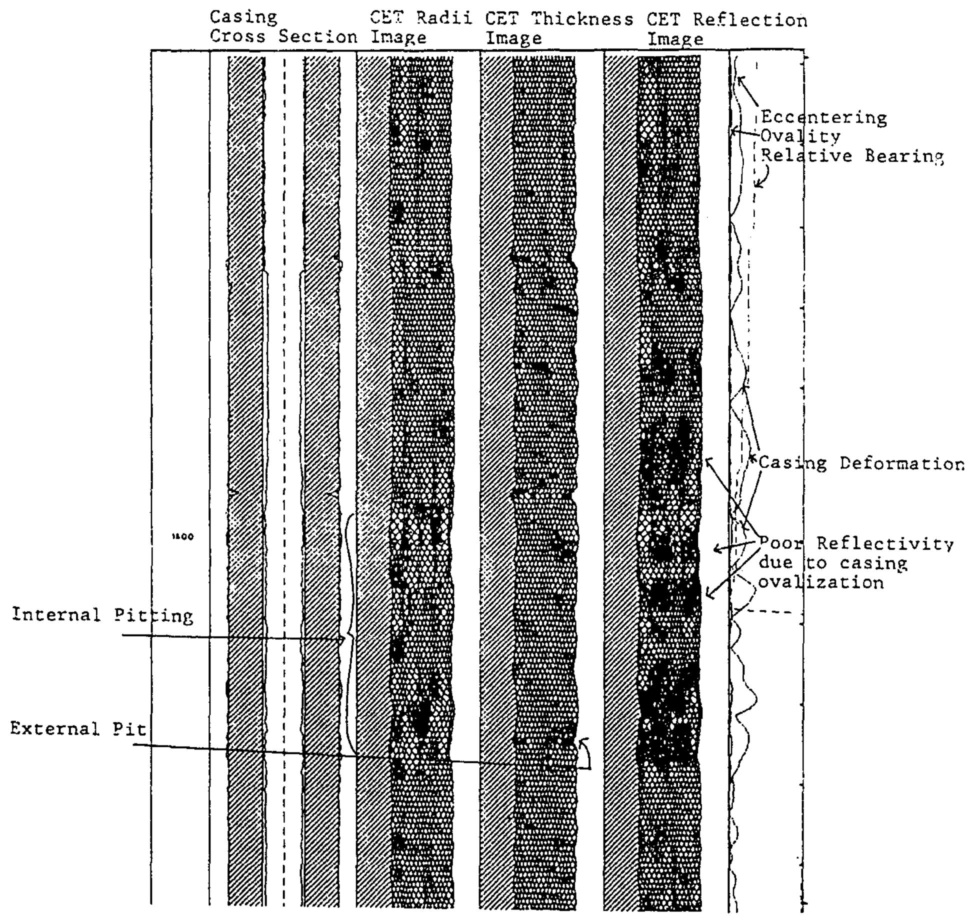
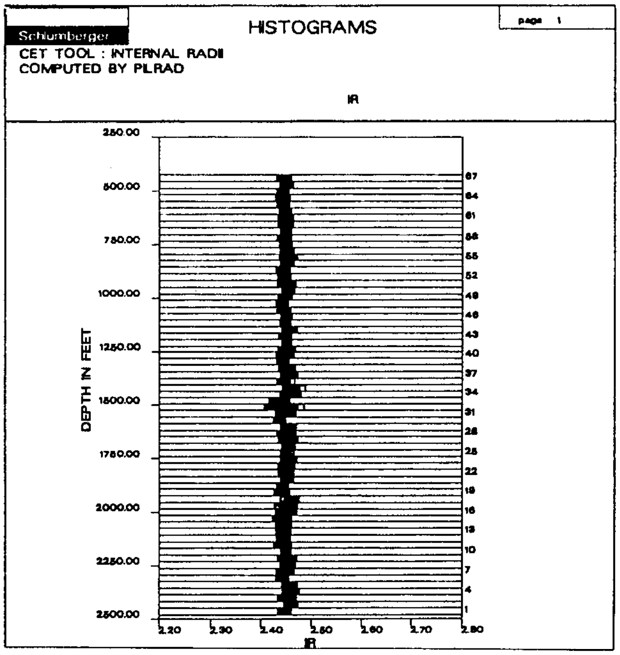
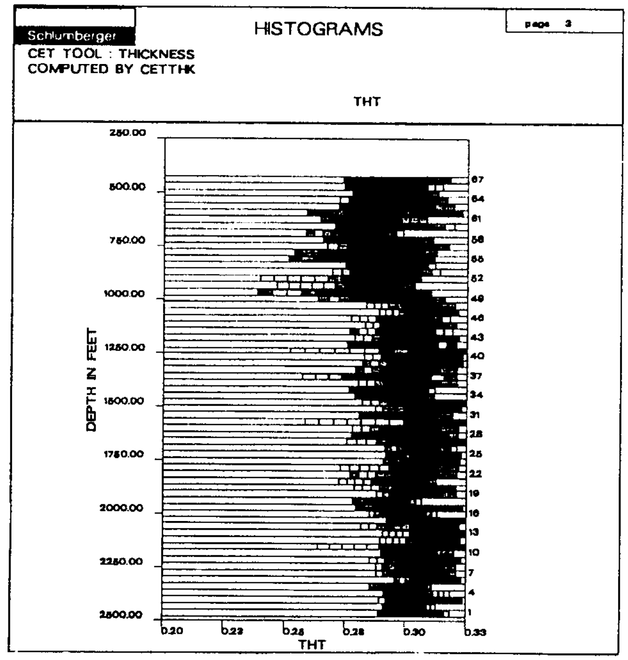


Figure 26 — Pipe inspection log (PIL) presentation from Data Services

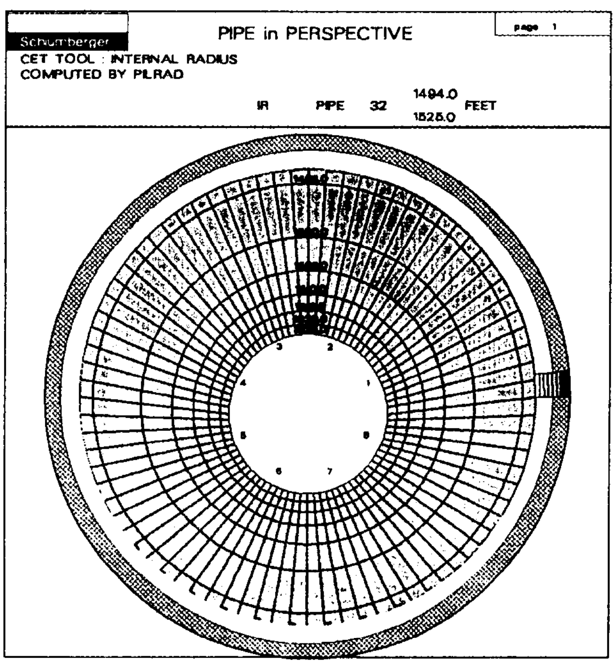


Uniform internal radii indicates consistent casing size & weight with minor internal problems



Casing thickness shows greater variance due to manufacturing tolerance and deformation

Figure 27 — PIL histograms of internal radii (IR) and thickness (THT)



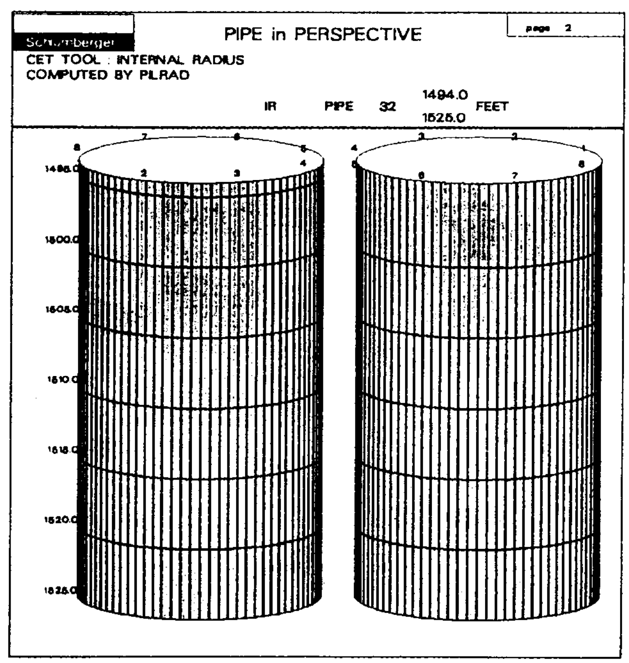
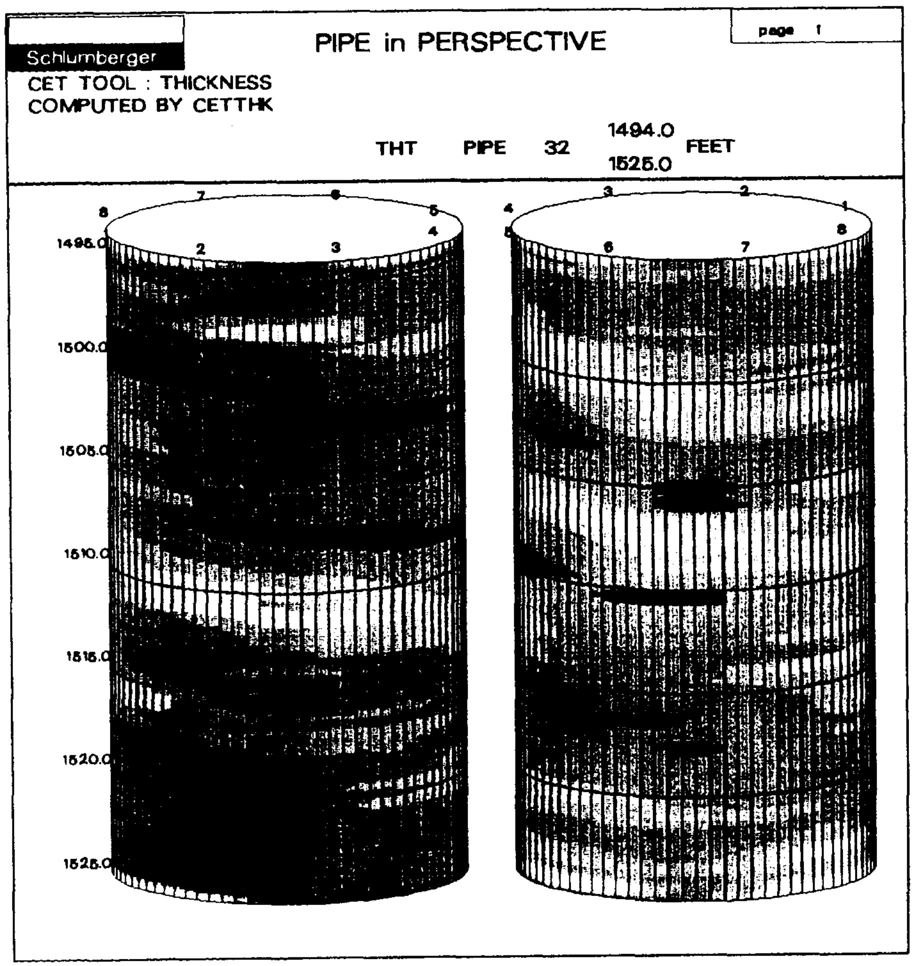


Figure 28a — Pipe in perspective — internal radii



"Banded" type variance in thickness due to pipe manufacturing technique

Figure 28b — Pipe in perspective (thickness)

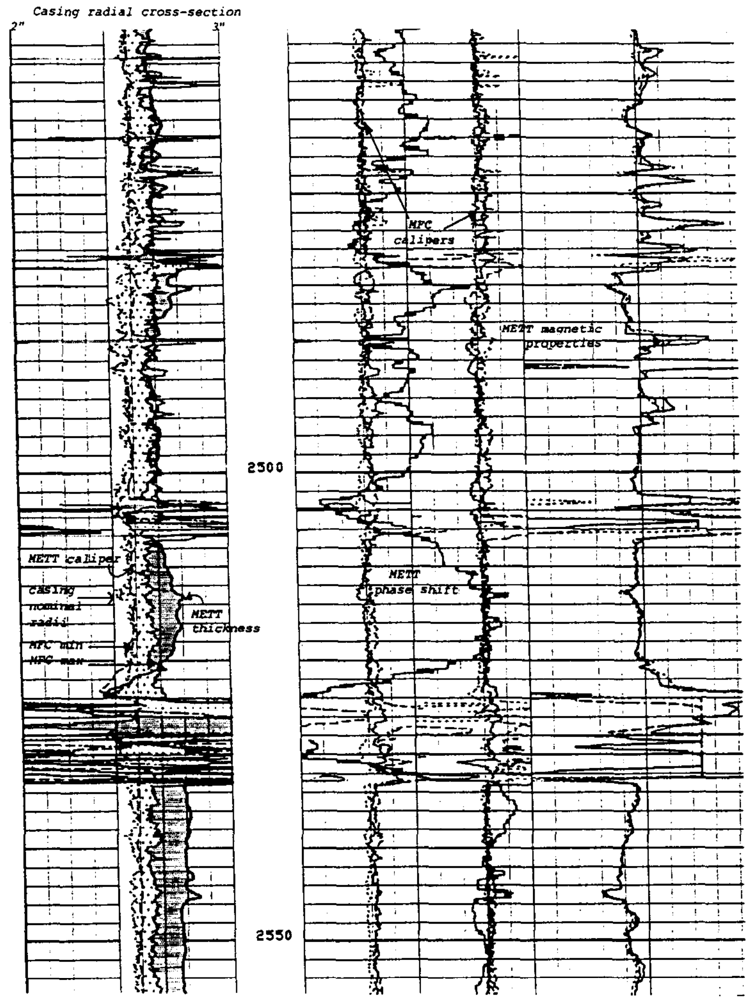


Figure 29 — Combined MFC-METT presentation with radial cross-section.

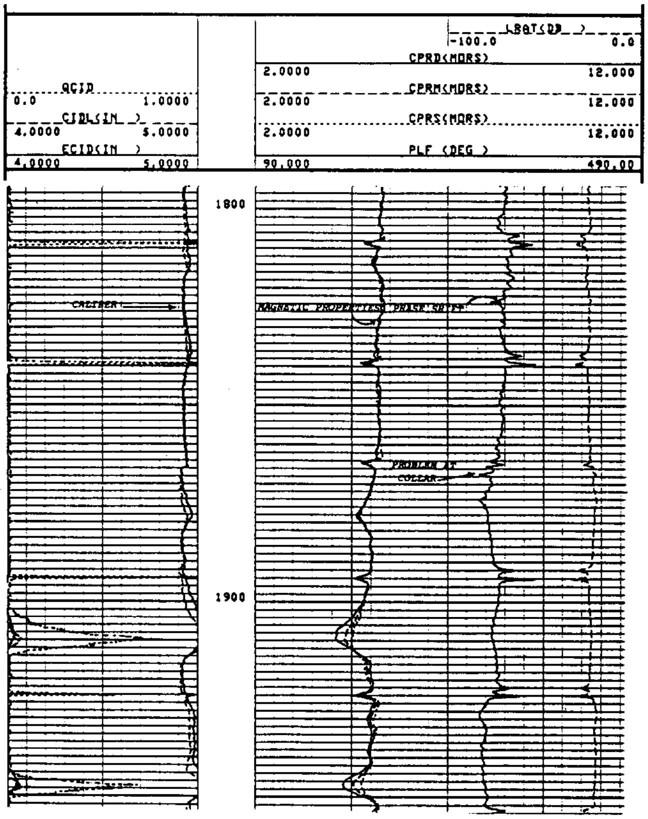


Figure 30a — METT log indicating problem collar and ovalized casing at 1910 ft.

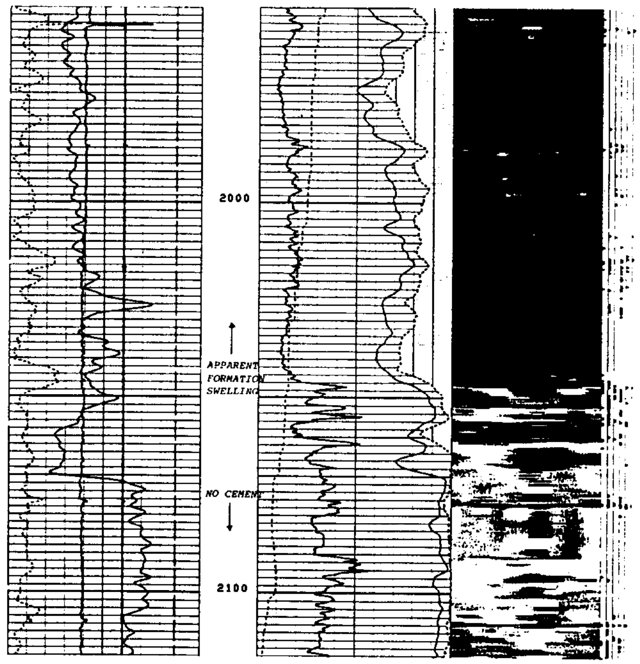


Figure 30b — Swelling of red bed shales against casing as indicated by CET

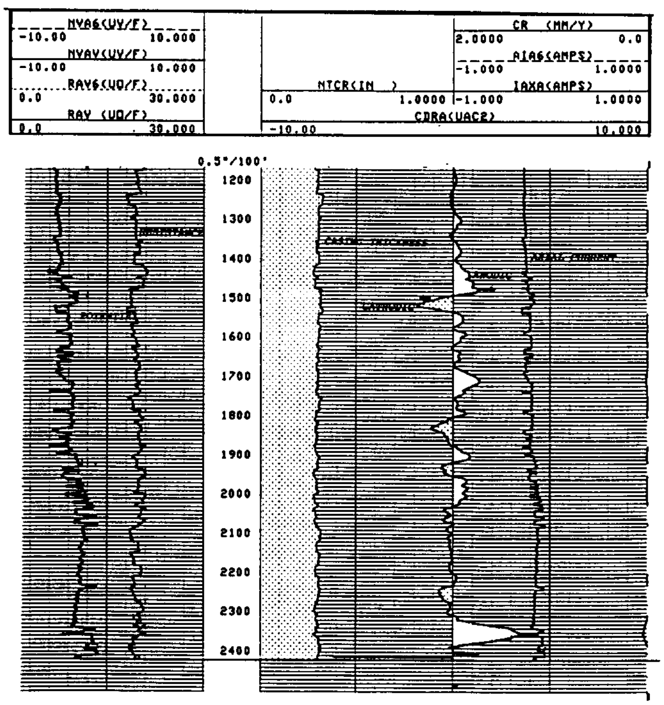


Figure 30c — CPET field log indicating no significant electro-chemical corrosion