LLNL Environmental Restoration Division (ERD)
Standard Operating Procedure

ERD SOP 1.6: Borehole Geophysical Logging—Revision 4

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1.0 PURPOSE

1.1 Borehole geophysics is a subsurface characterization method that involves *in situ* measurement of the physical properties of geologic materials penetrated by boreholes. Properly calibrated borehole geophysical (wireline) measurements can be used to define lithologic units, make correlations between wells, and estimate detailed quantitative geohydrologic property profiles of the lithologic units.

1.2 This SOP specifies procedures for conducting standard borehole geophysical logging operations at the Livermore Site and Site 300. The standard suite of geophysical logs used (summarized in Attachment A) at the two sites include:

A. Natural Gamma Radiation Log (NGL).

B. Electromagnetic Induction Log (IL).

C. Spontaneous Potential Log (SP).

D. Electrical Resistivity Log (E-Log).

E. Guarded Electrode Resistivity Log (GL).

F. Borehole Video Log (BVL).

G. Three-Arm Caliper Log (CL).

H. Acoustic Borehole Televiewer (BHTV).

I. Neutron Log (NL).

2.0 APPLICABILITY

2.1 The main application of borehole geophysics at LLNL is subsurface characterization. Geophysical logs are semi-continuous calibrated physical property measurements of the materials penetrated by the borehole. Because of this, the logs are internally consistent, and can be used to correlate lithologic indicators between boreholes. A wide variety of borehole geophysical logging tools that measure several different physical properties are available. Not all available logging tools are needed for a given logging operation. In order to select an appropriate suite of geophysical tools for a given site, it is important to consider the conditions in the borehole which are influenced primarily by the hydrogeology encountered and the drilling method used.

2.2 Livermore Site boreholes are commonly fluid filled due to mud rotary drilling operations and because saturated formation conditions are encountered between 30 and 120 ft below ground surface (bgs). Given these borehole conditions, the recommended logging suite for the Livermore Site boreholes consists of the following logs: Caliper, NGL, SP, E-Log, Guard Log and IL. The order the logs are run is determined by borehole conditions.

2.3 Saturated formation conditions at Site 300 are encountered at a wide range of depths between 15 and 500+ ft bgs, depending mainly on surface elevation. Site 300 boreholes are commonly air filled above the water table because minimal quantities of fluid are introduced into the borehole during air-mist rotary drilling operations. Therefore, the recommended logging suite for Site 300 boreholes consists of the following logs: Caliper, NGL, and IL. The order the logs are run is determined by borehole conditions. If the Site 300 are mud-rotary driven or waterfilled air/mist rotary drilled, the Guard Log is also recommended.

2.4 NGL and IL logs can be run in air-filled or fluid-filled, uncased boreholes or polyvinyl chloride (PVC)-cased wells. Whenever possible, geophysical logging costs can be minimized by logging several wells per mobilization. This approach minimizes mobilization costs and eliminates rig standby costs.

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4.0 DEFINITIONS

See SOP Glossary.

5.0 RESPONSIBILITIES

5.1 Division Leader

The Division Leader's responsibility is to ensure that all activities performed by ERD at the Livermore Site and Site 300 are performed safely and comply with all pertinent regulations and procedures, and provide the necessary equipment and resources to accomplish the tasks described in this procedure.

5.2 Hydrogeology Group Leader (HGL)

The HGL's responsibility is to ensure that proper procedures are followed for activities (i.e., drilling, borehole logging and sampling, monitor well installations and development).

5.3 Subproject Leader (SL)

The SL is responsible for the overall investigation, plannning, assessment, and remediation within a study area.

5.4 Drilling Supervisor (DS) or Designee

The DS or designee is responsible for designing the overall drilling and Petrophysical program, notifying the geophysical logging contractor when logging operations are required, and communicating any requests or changes in the logging program that will result in changes in geophysical logging charges.

5.5 Drilling Coordinator (DC) or Designee

The DC or designee interface between the DS and the field activities and is responsible for providing the Drilling Work Plan to the Drilling Geologist, coordinating any necessary surveys prior to drilling, monitoring the progress of drilling activities daily, and to oversee the disposal of all investigation-derived wastes.

5.6 Drilling Geologist (DG)

The DG's responsibility is to provide the logging engineer with a logging program and documenting all logging operations on the *Wireline Logging Summary* (Attachment B), ensuring that the correct logs are run in the specified order, and all calibration and QA/QC procedures specified in the current versions of *Proposed Borehole Geophysical (Wireline) Log Measurement Protocols for Environmental Monitor, Injection, and Extraction Wells* (*Reference material) and *Proposed Wireline Measurement Witness Check Lists for Environmental, Monitoring, Injection, and/or Extraction Wells* (*Reference material) are carried out.

*The above reference material can be obtained from ERD Library.

5.7 Geophysical Logging Contractor

The geophysical logging contractor's responsibility is to provide a qualified logging engineer (person qualified and familiar with logging equipment, operations**,** LLNL procedures) and the following:

- Properly calibrated logging tools.
- Sufficient back-up tools to ensure that all requested services will be successfully performed.
- Ensure that all measurements have a common depth basis (i.e., depth-matched data).
- Mud/mud filtrate resistivities (R_m, R_{mf}).
- Borehole corrected data.
- Paper copy field prints of all logs at the proper depth and horizontal scales.
- Paper and reproducible copy final prints of all logs at the proper depth and horizontal scales.
- Mud density and viscosity.

- Log ASCII standard (LAS)-formatted diskettes containing all digital measured and processed log data.

5.8 Petrophysicist (Log Analyst)

The Petrophysicist is responsible for the following:

- Designing the overall borehole geophysical logging program.
- Overall borehole geophysical log QA/QC program.
- Development of quantitative petrophysical volumetric and fluid flow models.
- Quantitative well log analysis.
- Synthesis of the borehole geophysical log data.
- Laboratory core and well pump test measurement data.

5.9 Engineering Group

The Engineering Group is responsible for removing pumps from monitor wells prior to logging.

5.10 Geologist

The Geologist is responsible for correlating logs between boreholes and developing subsurface geology models.

5.11 Modeling Team

The Modeling Team is responsible for converting subsurface geology and petrophysical models into quantitative, flow and volumetric models of the subsurface.

6.0 PROCEDURES

6.1 Discussion

6.1.1 Borehole geophysical measurements are obtained from geophysical logging tools suspended in uncased boreholes or cased wells. These tools measure a variety of physical properties of geologic materials penetrated by the borehole, including:

A. Formation electrical resistivity or conductivity.

B. Formation electrochemical contrasts between the borehole and *in situ* fluids.

C. Formation natural gamma ray emissions.

D. Borehole diameter.

E. Formation acoustic velocity.

F. Formation hydrogen ion concentrations.

G. Acoustic reflectance of the borehole wall.

H. Formation electron density.

6.1.2 Measurements are made as the tool is pulled up the borehole at a constant rate on a multi-conductor armored cable (or wireline) using a power supply at the surface (Attachment C). Measurement depth is controlled by passing the cable over a calibrated sheave. Downhole data are transmitted via the cable to a computer at the surface where the data are stored and processed. Geophysical logs are paper copy records of borehole measurements plotted with amplitude on the horizontal axis and depth on the vertical axis.

6.2 Office Preparation

6.2.1 Develop a logging program that is consistent with the expected borehole conditions and characterization objectives. The logging program should specify all pertinent borehole information, such as:

A. Borehole identification number.

B. Borehole location.

C. Bit size.

D. Surface elevation (if available).

E. Services requested (logs) and order for running logs.

F. Drilling fluid type.

G. Casing details.

H. Amplitude and depth scales for each log.

6.2.2 Coordinate drilling operations with desired logging conditions.

A E-Log, BHC, and GL cannot be run in air-filled or cased boreholes.

B. BHTV should not be run in air rotary or hollow stemmed auger drilled borehole.

C. Borehole vidio should not be run in mud filled boreholes.

6.2.3 Notify the logging contractor 24 to 48 hr ahead of time of the required logging tools and appropriate contractual information (i.e., release numbers, etc.) before logging operations begin.

6.2.4 When logging operations are planned for existing wells, notify the Engineering Group two to three weeks prior to logging to schedule pump removal(s), if necessary.

6.3 Field Preparation

6.3.1 Provide the logging engineer with a logging program, and discuss any unusual conditions or departures from standard protocol prior to logging operations.

6.3.2 Provide logging engineer with the following information for the log header:

A. Borehole location.

B. Borehole ground level elevation.

C. Borehole depth.

D. Fluid level.

E Depth of any potentially problematic zones.

6.3.3 Prepare sufrace electrode loctions for those wells to be logged by E-log and/or Guard log by wetting the site daily to lower electrode contact resistances.

6.3.4 When logging mud-rotary boreholes, a 2- to 5-gal sample of the drilling mud will be collected during borehole conditioning and set aside for the logging contractor to determine mud resistivity (R_m), mud cake resistivity (R_{mc}), mud filtrate resistivity (R_{mf}), mud density, and mud viscosity.

6.3.5 Remove pumps from any wells prior to cased-hole logging operations.

6.4 Logging Order

6.4.1 Livermore Site

In uncased boreholes, run the E-Log, followed by natural gamma ray, guarded electrode resistivity log, and induction log. Because the caliper log could disturb the mud cake that protects the borehole, causing the borehole to collapse, the caliper log should be run last. If unusual borehole conditions develop, which could significantly increase the risk of losing a logging tool, the DG and DS should be notified before continuing logging operations.

6.4.2 Site 300

In uncased boreholes, the caliper log is usually run first to evaluate any unusual hole conditions (i.e., large diameter “wash outs” or small diameter “tight” zones). If unusual borehole conditions develop, which could significantly increase the risk of losing a logging tool, the DG and DS should be notified before continuing with logging operations.

6.4.3 Both Sites

E-Logs, guard logs, BHC, and BHTV must be run in uncased, fluid-filled boreholes. Electromagnetic induction logs cannot be run in metallic cased wells, but yield excellent results in PVC-cased boreholes. Natural gamma ray logs can be run in cased wells or uncased boreholes.

6.5 Calibration

6.5.1 Basically, there are three types of tool calibration standards:

1. Primary calibration standards involve permanent test pits, which are primarily used to calibrate logging tool prototypes, and shop standards.

2. Secondary or shop calibration standards are transportable calibration standards that are referenced to the primary standards. Shop standards are often too bulky to be easily transported to field sites. Logging sondes should be checked against these standards on a monthly basis.
3. Tertiary or field standards are compact enough that they can be easily taken to the field to verify that the sonde calibration has not drifted from the shop calibration at each logging job.

6.5.2 Conduct all tool calibration and QA/QC procedures as specified in the *Wireline Protocols and Witness Checklist*. See Section 5.5 of this SOP, for instructions to locate current versions of these documents.

6.6 General

6.6.1 Document all logging operations on a *Wireline Logging Summary* (Attachment B).

6.6.2 Always repeat geophysical logs over intervals of at least 50 ft., including completion interval(s), intervals of log response extremes, and any zones of questionable data on the main log. Display repeat sections on all field and final prints.

6.6.3 Clearly display all log scales at the top and bottom of all field and final prints.

6.6.4 Clearly display all shop and field calibration records on all field and final prints.

6.7 Natural Gamma Log (NGL) Operation

NGL tools detect gamma radiation emitted by radionuclides in the formation. The most common natural gamma ray emitting radionuclides are Potassium (^{40}K) and Uranium- and Thorium-series daughter products (^{214}Pb and ^{214}Bi). NGL are commonly used to characterize stratigraphy and make correlations between wells. They can also be used to infer quantitative estimates of effective porosity and hydraulic conductivity of the materials penetrated by the borehole. This log is widely used because it can be run in air- or fluid-filled conditions, drill pipe, and cased or uncased holes.

6.7.1 NGLs record gamma radiation emitted from the formation in counts per second (cps) or American Petroleum Institute (API) units. The recommended scale for field prints is 0–100 or 0–200 API units or counts increasing from left to right (LTR).

6.7.2 NGLs should be run at a logging speed of 10 ft/min, or slower.

6.7.3 NGL field and final prints should include standard source (e.g., API calibrator) calibration and a three-min. stability check documentation.

6.7.4 Use only 1.25 by 6 in. (or 1 by 8 in.) sodium iodide (NaI) crystal or other high efficiency detectors.

6.7.5 Use a 5-sec time constant for 1 by 6 in. detectors and a 4-sec time constant for 1 by 8 in. detectors.

6.7.6 In final prints, display NGL profiles in the left track (API Track 1) with API or CPS units increasing LTR.

6.8 Electromagnetic Induction Log (IL) Operation

Induction tools operate on the principle of electromagnetic induction. An electrical current is induced in the formation by generating a radio frequency (20–40 kHz), alternating current in the transmitting coil of the IL tool. The induced current is proportional to the formation electrical conductivity and is measured by a receiver coil spaced 1.5 to 2.0 ft from the transmitter. IL tools can be run in air-filled or fluid-filled conditions, and uncased boreholes or wells that are cased with non-electrically conductive material. IL logs are ideal for characterizing stratigraphy and making correlations between wells. They are also useful for inferring formation porosity.

6.8.1 The IL log is recorded in electrical conductivity units of millisiemens/meter (mS/m). Field and final prints should display both electrical conductivity in mS/m on the right of the depth track (display RTL, in API Track 3) and electrical resistivity in ohm-m (LTR 2-3 cycle logrhythmic display, in API track 2). Horizontal scales should be selected to maximize the amount of log that remains "on scale."

6.8.2 Run the IL log at 20 ft/min.

6.8.3 IL final prints should include tool shop and field calibration documentation.

6.8.4 In final prints, display IL profiles on the tracks to the right of the depth track in electrical resistivity (ohm-m) 2-3 cycle logrhythmic units increasing to the right in API Track 2, and conductivity mS/m units decreasing to the left in API Track 3.

6.9 Galvanic Resistivity (E-log or Guard) Operation

Both Electric Log (E-Log) and Guard Log tools measure apparent formation resistivity directly. An electrical current is passed between a current source electrode on the logging tool and a current return electrode at the surface. Electrical potential differences are measured between electrodes on the surface and at depth. The resulting V/I ratios are converted to apparent resistivities, using algorithms based upon the electrode array geometries and potential theory. Because these electrical tools are galvanically coupled directly to the earth with their electrodes, the techniques are called galvanic resistivity methods. Galvanic resistivity logs are ideal for characterizing stratigraphy and making correlations between wells. They are also useful for inferring formation porosity.

6.9.1 Galvanic resistivity log 16-in. normal (R_{SN}), 64-in. normal (R_{LN}), and guard (R_G) resistivities are recorded in units of ohm-meter (ohm-m). Field and final prints should display electrical resistivity in 2-3 cycle logarithmic ohm-m (LTR display in API Tracks 2 or 3). Horizontal scales should be selected to maximize the amount of log that remains "on scale."

6.9.2 Run the galvanic resistivity logs at 20 ft/min.

6.9.3 Galvanic resistivity final prints should include tool field calibration documentation.

6.9.4 In final prints, display galvanic resistivity profiles on the track to the right of the depth track (API Tracks 2 or 3) in 2-3 cycle logrhythmic electrical resistivity (ohm-m) units increasing to the right.

6.10 Spontaneous Potential Log (SP) Operation

SP is an electrochemical phenomena resulting from salinity differences between the mud filtrate and *in situ* waters and the passage of saline waters through clays. High clay mineral content zones act as cation selective membranes, allowing cations to pass but repelling anions. This selectivity will result in a cation deficiency on the more saline side of the membrane and a cation surplus on the low salinity side. If the *in situ* waters are more saline than the mud filtrate, the electrical potential (with respect to some distant reference point) opposite clay zones will be positive with respect to that opposite sands and gravels. If the mud filtrate is more saline than the *in situ* waters, the opposite will occur.

6.10.1 The SP curve is a relative measurement and is presented in units of millivolts (mv).

6.10.2 Run SP logs at 20 ft/min.

6.10.3 SP final prints should include tool field calibration documentation and three-minute electrode stability checks.

6.10.4 In final prints, display SP profiles in API Track 1 (left hand track) in mv units increasing LTR.

6.11 Borehole Video Log (BVL) Operation

BVL cameras are used to view uncased boreholes and cased wells. Best results are obtained in air-filled or clear fluid-filled conditions. Both black and white and color cameras are used to evaluate fractured bedrock, inspect borehole “washouts,” and inspect casing conditions.

6.11.1 Display the depth and well identification on video log and videotape.

6.11.2 Centralize the borehole video camera in the hole.

6.11.3 Make repeat runs over intervals specified by the DG.

6.11.4 Allow sufficient time for the BVL camera to equilibrate with downhole temperature and humidity conditions to ensure that the camera lens does not fog up. Distilled water can be poured in the borehole to clear fogged camera lenses.

6.11.5 Adjust brightness, contrast, and other image controls to optimize image clarity.

6.12 Three-Arm Caliper Log Operation

Three-arm calipers are used to measure borehole diameter as a function of depth. Caliper Logs consist of three to four arm sensors. Caliper logs are usually run first when conducting uncased borehole logging operations at Site 300, and last at the Livermore Site.

6.12.1 Scale the Three-Arm Caliper Log at 1 division per inch. The log should range from 3 in. to 18 in. for most boreholes.

6.12.2 Run a repeat section over any part of the hole designated by the DG.

6.12.3 Indicate the drill bit diameter on the log.

6.13 Borehole Compensated (BHC) Acoustic Logs

BHC logs measure the acoustic inverse volocity (interval transit time) of the material penetrated by the borehole. This is accomplished by conducting multiple miniature seismic refraction shots as the sonde containing one (or two) acoustic transmitter(s) and two receivers is retrieved from the bottom of a fluid-filled uncased borehole.

6.13.1 The BHC interval transit time (ITT) is displayed at µsec/ft RTL in API Tracks 2 and 3.

6.13.2 BHC tools should be run with centralizers.

6.13.3 Magnetostrictive (BHC) sources should be polarized prior to the logging job (piezometric sources need not be).

6.13.4 Run BHC at 10 to 15 ft/min.

6.13.5 Monitor BHC signals at both receivers to ensure that the automated picking algorithm does not skip cycles.

6.13.6 If possible, record full acoustic wave forms for both receiver and enhance with post processing before running the picking algorithm.

6.14 Neutron Log (NL)

Neutron logs measure the concentration of hydrogen ions in the material (formation and fluid) penetrated by the borehole. This accomplished by bombarding the borehole wall with high energy neutrons and noting the energy decay at one or more distances from the neutron source.

6.14.1 NL use chemical radioactive sources or neutron generators. Because of this, they can only be run in cased environmental wells and special protocols must be developed.

6.14.2 NL are statistical tools like the NGL and should be run at slow logging speeds (e.g., 10–15 ft/min or slower) to improve statistics.

6.14.3 NL data should be presented as logarithmic count rates (cps or API units) LTR or neutron porosity (hydrogen index units linear RTL in API Tracks 2 and 3).

6.15 Acoustic Borehole Televiewer (BHTV)

BHTV logs are run to provide acoustic images of the borehole wall. This is accomplished by reflecting high frequency acoustic energy (at direct incidence) from the borehole wall. BHTV products are borehole wall acoustic reflectance and acoustic caliper images of the entire 360° degree borehole wall. These images can then be enhanced and interpreted on an interactive workstation to provide detailed structural and stratigraphic information about the material penetrated by the borehole.

6.15.1 BHTV should only be run in mud rotary drilled, uncased boreholes.

6.15.2 Run BHTV at 10 ft/min or slower.

6.15.3 Run BHTV tool with centralizers.

6.15.4 Run BHTV up into surface casing as a check.

6.15.5 Use interactive workstation enhancement and interpretation for BHTV images.

6.16 Field Post Operation

6.16.1 Compare geophysical log measurements to lithologic information determined from drive samples and cores, and information from nearby wells during and after logging operations.

6.16.2 Discuss all geophysical log anomalies with logging engineer. Contact the DS and Petrophysicist immediately if any QA/QC issues arise that cannot be resolved at the drill site.

6.16.3 When multiple logs are run in the same hole, ensure that log profiles are keyed to the same depth reference. This can be done by comparing the depths of characteristic log responses from thin (1-ft to 3-ft-thick) claystone intervals on each log.

6.16.4 Compare main log with repeat section to check log repeatability. The logging engineer can provide field overplots to accomplish this.

6.16.5 The logging engineer will provide five field print copies of all logs at the proper depth and horizontal scales before leaving the site.

6.16.6 Resistivities (E-Log, GL, and IL) should all agree in clay zones.

6.16.7 Depth scale: Site 300 is 5"/100 ft; Main Site is 10"/100 ft.

6.17 Office Post Operation

6.17.1 Communicate any changes in final log specifications or corrections to the logging contractor within 1 to 2 days after logging operations.

6.17.2 Log ASCII standard (LAS)-formatted diskettes of all digital logging data should be received within 1 to 2 weeks of the completion of logging operations.

6.17.3 Inspect logging tool calibration documentation for each log product.

6.17.4 Wireline vendor should perform depth matching and borehole corrections before delivering final displays.

6.17.5 LAS diskettes should contain all measured data (include repeat sections and calibration) and processed results (depth matched and borehole converted data).

6.17.6 Final log prints of both measured and final processed displays will be delivered within 1 to 2 weeks of completion of logging operations.

6.18 Documentation of Failures

6.18.1 Calibration Failures

All borehole geophysical tool fabricators supply tool calibration protocol with their sondes. The logging vendor should attach records of the appropriate dated and signed shop and field calibration records to all final log prints. Departures from published calibration protocol and/or standards are noted on the *Wireline Logging Summary* (Attachment B).

6.18.2 Depth Control Failures

Borehole geophysical log depth control is established by passing the logging cable over a calibrated sheave. Depth control failures are noted by comparing driller's depths to logger's depths and logger's depths on multiple trip logging jobs. Depth control problems are noted on the *Wireline Logging Summary* (Attachment B).

6.18.3 Repeat Failures

Borehole geophysical measurements are repeatable physical property measurements. Borehole geophysical vendors run short (50 to 200 ft) Repeat Sections (Section 4.12) of logs to demonstrate that their results are repeatable. Direct measurement tools, such as resistivity logs have very narrow repeat measurement tolerance. Statistical measurement tools such as the radioactive logs have broader repeat measurement tolerances. Departures from published repeat standards are noted on the page 1 of the *Wireline Logging Summary* (Attachment B). Failure to repeat a logging measurement may be due to borehole conditions beyond the control of the logging vendor. If this is the case, it should be noted on the *Wireline Logging Summary* (Attachment B).

6.18.4 Inconsistency with Offset Borehole or Well Log Results

Borehole geophysical results should be easily correlated between nearby boreholes and/or wells. Abrupt changes in the character of borehole geophysical logs between offset boreholes/wells can occur due to changes in subsurface geology, borehole conditions, and/or logging equipment failure. Inconsistencies of borehole geophysical logs that occur between boreholes/wells should be noted on page 1 of the *Wire logging Summary* (Attachment B). If these inconsistencies are due to subsurface geology or borehole conditions, note that as well.

6.18.5 Tool Specific Check Failures

Some borehole geophysical data quality checks are tool specific, such as caliper measurements of casing inside diameter and gamma ray stability checks. Failures of these tool specific quality checks should be noted on page 1 of the *Wireline Logging Summary* (Attachment B). It should also be noted if these failures are due to borehole conditions or not.

6.18.6 Presentation Failures

Borehole geophysical data quality may be good, but appears to be bad because of poor presentation by the logging vendor. Borehole geophysical log presentation failures should be noted on the *Wireline Logging Summary* (Attachment B).

7.0 QUALITY ASSURANCE RECORDS

7.1 Quality Assurance reports that the borehole geophysical logging tools are: (1) working properly, (2) used according to their design, and (3) properly calibrated should be compiled for each logging job. The borehole geophysical logging contractor must document that the log products meet these conditions, and the DG must verify these conditions. The front of the *Wireline Logging Summary* (Attachment B) provides a convenient summary matrix to document any log product quality problems.

7.2 Specific borehole geophysical data quality assurance records are:

A. Wireline Logging Summary, compiled by the DG and augmented by the Petrophysicist.

B. One set of QA/QC annotated well log prints prepared by the Petrophysicist.

C. Any QA/QC electronic mail and/or memoranda generated by the DG and/or Petrophysicist for a specific log suite.

8.0 ATTACHMENTS

Attachment A—Geophysical Logs

Attachment B—Wireline Logging Summary

Attachment C—Schematic Diagram of Borehole Geophysical (Wireline) Logging Operation

Attachment A

Geophysical Logs

Attachment A. Geophysical logs.

Geophysical log	Description	Primary purpose
Natural Gamma Log (NGL)	Used in air- or fluid-filled, cased or uncased borehole, <14 in. diam. Measures natural gamma radiation emitted by the formation.	Characterize lithology; determine stratigraphic correlations.
Electromagnetic Induction (IL) Log	Used in air- or fluid-filled, uncased or PVC-cased boreholes, 2-10 in. diam. Measures formation electrical conductivity between 2 coils, 20 in. apart by using electromagnetic induction.	Characterize lithology; determine stratigraphic correlations. Estimate formation porosity.
Spontaneous Potential (SP)	Used in fluid-filled, uncased borehole only.	Characterize lithology; evaluate formation water salinity.
Electrical Resistivity (E-Log)	Used in fluid-filled, uncased borehole only.	Characterize lithology; determine stratigraphic correlations. Estimate formation porosity.
Borehole Video Log (BVL)	Used in air- or fluid-filled; cased or uncased borehole. Produces a video tape of the borehole (or casing) using a downhole camera.	Characterize lithology and evaluate fractures in open hole; evaluate casing and screen in cased hole.
Three-Arm Caliper Log (CL)	Used in air- or fluid-filled, cased or uncased borehole. Measures borehole diameter using 3 or 4 radially spaced arms.	Determine borehole rugosity in open hole or damaged casing in cased hole.
Acoustic Borehole Televiewer (BHTV)	Used in fluid-filled, uncased boreholes. Produces an acoustical image of the borehole well and acoustical measurement of borehole diameter.	Characterize lithology; determine stratigraphic correlations.
Borehole Compensated Acoustic Log	Used in fluid-filled, uncased boreholes. Measures formation acoustical in velocity (interval transit time).	Characterize lithology; provide velocity information for seismic interpretation; estimate formation porosity.
Guarded Electrode Resistivity Log	Used in fluid-filled uncased boreholes. Measures formation electrical resistivity.	Characterize lithology; determine stratigraphic correlations. Estimate formation porosity.
Neutron Log (NL)	Used in air or fluid PVC- or steel-cased boreholes only.	Characterize lithology; determine relative volumetric moisture content of the formation.

Attachment B

Wireline Logging Summary

GENERAL INFORMATION:

WIRELINE LOGGING SUMMARY

Operating Company	Well Name		Division	State / Province	County / Parish	Country
Section	Township / Survey	Range / Block	Surface Location			API Number
Log Job No.	Prospect / Field		Well Type ☐ Exploration ☐ Production ☐ Proj. Inj. ☐ Proj. Prod. ☐ EOR ☐ Other ______			Accession Number
Logging Service Order #	Service Company		Logging Engineer	Service Co. District	Logging Unit	Lexis Number / SSD Number
Start Date	Bit Size	Last Casing Size / Depth	Chevron Witness	F.E. Specialist	Date	I.D. Number

LOG QUALITY

This section applies only to the logs delivered at the well site.

(✓) Check only those boxes where problems exist

SEPARATE COMBINATION TOOLS INTO INDIVIDUAL SERVICES

LOG / SERVICE	1	2	3	4	5	6	7	8	9	10
SUITE #										
RUN #										
CALIBRATION FAILURES?										
DEPTH CONTROL FAILURES?										
REPEAT FAILURES?										
Check if the failure is caused by borehole conditions										
ARE THE LOGS CONSISTENT WITH OFFSETS?										
Check if the failure is caused by borehole conditions										
TOOL SPECIFIC CHECKS FAILURES?										
Check if the failure is caused by borehole conditions										
PRESENTATION FAILURES?										
LOG QUALITY RATING 1 (Poor) to 4 (Excellent) Scale (4 can be given if the failure is caused by borehole conditions)										

LOG QUALITY COMMENTS:

Explain all problems in the LOG QUALITY section

DATA SUMMARY

LOG INTERVALS

	BOTTOM	TOP
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

SIDEWALL CORES

	TOTAL
Total SWS Attempted	
Recovered	
Misfired	
Lost Bullets	
No Recovery	

FORMATION TESTER

	TOTAL
Pressure Attempts	
Good Pressure Sets	
Fluid Attempts	
Good Fluid Samples	

WELL CONDITIONS

Maximum Temperature ______

Maximum Deviation ______

Pump Down or Drillpipe Assist Required

Yes ______ No

Was pressure control equipment used?

Yes No

TIME SUMMARY

(Use quarter hour increments)

TOTAL JOB LOGGING TIME (1st rig up to final rig down) ______ hrs

OPERATIONS LOST TIME (Hole conditioning, etc.) ______ hrs

TOTAL LOGGER DOWNTIME ______ hrs

NUMBER OF FAILURES > 30 MIN ______

OPERATIONAL EFFICIENCY RATING 1 (Poor) to 4 (Excellent) Scale ______

ERD/CBz

OPERATIONS SUMMARY: (Include times of bit reaching TD, Circulation; Wiper trips; Logger's arrival & release from location; All wireline runs into hole including rig up, time in, on bottom, off bottom, time out, Incomplete log run due to tool failure or hole problems; Well site computed logs; Provide as detailed a chronology as possible)

OPERATING COMPANY	WELL NAME	IDENTIFICATION NO.

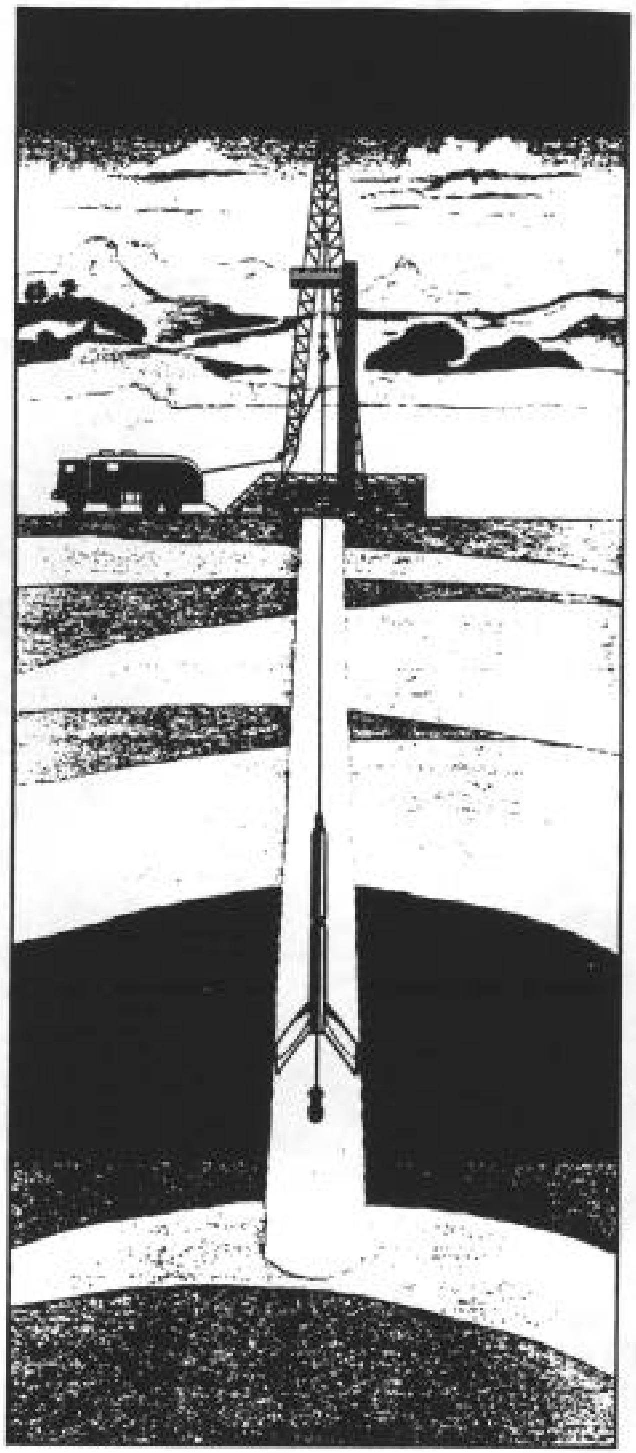
Date	Operations (Chronologically)	Time Summary Start	End	TD Driller / Logger	BHT	Hrs. of Circ.	Down Time Hrs.	Remarks (Calibration, repeatability, tool problem, etc.)

REMARKS & EXPLANATIONS: (Include any special circumstances that might have affected the logging operation, i.e. Were backup tools available? Was lost time due to equipment or operator error? Are there any questions concerning charges on the service order? Do any topics need to be discussed with salesmen? Were any tools logged out of tolerance? etc.)

[illegible]

Attachment C

Schematic Diagram of Borehole Geophysical (Wireline) Logging Operation



Attachment C. Schematic diagram of boreholegeophysical (Wireline) Logging Operation.