MACTEC

# ATTACHMENT E

# GEOPHYSICAL TEST RESULTS

## CONSISTS OF:

**Final Report Boring Geophysical Logging**
**Dated January 3, 2007**

**Volume 1 Text and Figures**
**vol 2 (DVD with pdf of Vol 1 plus electronic files)**

**followed by**

**Final Report of Four Electrode Wenner Resistivity Tests**
**Dated December 4, 2006**
**CD with pdf of text plus electronic files**

**Volume 1 of 1**

GEOVision
geophysical services

# FINAL REPORT

# BORING GEOPHYSICAL LOGGING
# BORINGS B-201, B-206, B-207, B-211
# B-301, B-306, B-307 AND B-311

# SCE&G COL PROJECT
# V.C. SUMMER NUCLEAR STATION

**Report 6285-01 vol 1 of 2 rev B**

**January 3, 2007**

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**Report 6285-01 vol 1 of 2 rev B**

**January 3, 2007**

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# APPENDICES

# INTRODUCTION

Boring geophysical measurements were collected in eight uncased borings located at the VC Summer Nuclear Power Station, located in Fairfield County, South Carolina. Geophysical data acquisition was performed between June 20 and July 9, 2006 by Rob Steller and Chuck Carter of **GEO***Vision*. Data analysis and report preparation was performed by Rob Steller and reviewed by John Diehl of GEOVision. The work was performed under subcontract with MACTEC Engineering and Consulting, Inc., (MACTEC) with Matt Cooke serving as the point of contact for MACTEC.

This report describes the field measurements, data analysis, and results of this work.

## SCOPE OF WORK

This report presents the results of boring geophysical measurements collected between June 20 and July 9, 2006, in eight uncased borings, as detailed below. The purpose of these studies was to supplement stratigraphic information obtained during MACTEC's soil and rock sampling program and to acquire shear wave velocities and compressional wave velocities as a function of depth, as a component of the VC Summer Nuclear Power Station (VCSNS) Combined Operating License Application (COLA) Project.

| BORING DESIGNATION | DATES LOGGED | ELEVATION | COORDINATES - FEET | |
|---|---|---|---|---|
| | | | NORTH | EAST |
| B-201 | 6/22-23/06 | 423.7 | 892740.9 | 1903285.1 |
| B-206 | 6/24-25/06 | 424.3 | 892683.5 | 1903416.2 |
| B-207 | 7/7/06 | 423.9 | 892824.8 | 1902949.7 |
| B-211 | 7/7/06 | 422.2 | 892570.0 | 1903213.8 |
| B-211A | 7/8/06 | 421.8 | 892568.4 | 1903205.5 |
| B-301 | 7/8-9/06 | 417.1 | 891906.9 | 1902949.2 |
| B-306 | 6/20/06 | 413.4 | 891854.8 | 1903077.2 |
| B-307 | 6/22/06 | 402.6 | 891989.1 | 1902613.3 |
| B-307A | 7/8/06 | 402.4 | 891982.7 | 1902610.6 |
| B-311 | 6/20-21/06 | 419.5 | 891747.1 | 1902871.4 |

Table 1 Boring locations and logging dates

The OYO Model 170 Suspension Logging Recorder and Suspension Logging Probe was used to obtain in-situ horizontal shear and compressional wave velocity measurements at 1.6 foot intervals. The acquired data was analyzed and a profile of velocity versus depth was produced for both compressional and horizontally polarized shear waves.

A detailed reference for the velocity measurement techniques used in this study is:

Guidelines for Determining Design Basis Ground Motions, Report TR-102293, Electric Power Research Institute, Palo Alto, California, November 1993, Sections 7 and 8.

# INSTRUMENTATION

## Suspension Instrumentation

Suspension soil velocity measurements were performed in all borings using the Model 170 suspension logging system, serial number 19029, manufactured by OYO Corporation. This system directly determines the average velocity of a 3.3 foot high segment of the soil column surrounding the boring of interest by measuring the elapsed time between arrivals of a wave propagating upward through the soil column. The receivers that detect the wave, and the source that generates the wave, are moved as a unit in the boring producing relatively constant amplitude signals at all depths.

| |
|---|
| Winch Geovision 4-conductor |
| Sheave - Measuring wheel Geovision S/N 102 |
| |
| OYO PS170 Recorder and case Model 3331A S/N 19029 |
| |
| OYO PS Logger Borehole Probe, includes: |
| Reducer Model 3348A S/N 28063 |
| Isolation tube, 1m Model 3387B S/N 28068 |
| Weight Model 3302W S/N 12007 |
| OYO PS 170 Source Model 3304 S/N 19043 |
| Receiver/Sensor S/N 20040, S/N 30086 |
| Driver Model 3386A S/N 27073 |

The suspension system probe consists of a combined reversible polarity solenoid horizontal shear-wave source ($S_H$) and compressional-wave source (P), joined to two biaxial receivers by a flexible isolation cylinder, as shown in Figure 1. The separation of the two receivers is 3.3 feet, allowing average wave velocity in the region between the receivers to be determined by inversion of the wave travel time between the two receivers. The total length of the probe as used in these surveys is 19 feet, with the center point of the receiver pair 12.1 feet above the bottom end of the probe.

The probe receives control signals from, and sends the amplified receiver signals to, instrumentation on the surface via an armored 4 conductor cable. The cable is wound onto the drum of a winch and is used to support the probe. Cable travel is measured to provide probe depth data, using a 3.28 foot circumference sheave fitted with a digital rotary encoder.

The entire probe is suspended in the boring by the cable, therefore, source motion is not coupled directly to the boring walls; rather, the source motion creates a horizontally propagating impulsive pressure wave in the fluid filling the boring and surrounding the source. This pressure wave is converted to P and $S_H$-waves in the surrounding soil and rock as it passes through the casing and grout annulus and impinges upon the wall of the boring. These waves propagate through the soil and rock surrounding the boring, in turn causing a pressure wave to be generated in the fluid surrounding the receivers as the soil waves pass their location. Separation of the P and $S_H$-waves at the receivers is performed using the following steps:

1. Orientation of the horizontal receivers is maintained parallel to the axis of the source, maximizing the amplitude of the recorded $S_H$ -wave signals.
2. At each depth, $S_H$-wave signals are recorded with the source actuated in opposite directions, producing $S_H$-wave signals of opposite polarity, providing a characteristic $S_H$-wave signature distinct from the P-wave signal.
3. The 6.3 foot separation of source and receiver 1 permits the P-wave signal to pass and damp significantly before the slower $S_H$-wave signal arrives at the receiver. In faster soils or rock, the isolation cylinder is extended to allow greater separation of the P- and $S_H$-wave signals.
4. In saturated soils, the received P-wave signal is typically of much higher frequency than the received $S_H$-wave signal, permitting additional separation of the two signals by low pass filtering.

5. Direct arrival of the original pressure pulse in the fluid is not detected at the receivers because the wavelength of the pressure pulse in fluid is significantly greater than the dimension of the fluid annulus surrounding the probe (meter versus centimeter scale), preventing significant energy transmission through the fluid medium.

In operation, a distinct, repeatable pattern of impulses is generated at each depth as follows:

1. The source is fired in one direction producing dominantly horizontal shear with some vertical compression, and the signals from the horizontal receivers situated parallel to the axis of motion of the source are recorded.
2. The source is fired again in the opposite direction and the horizontal receiver signals are recorded.
3. The source is fired again and the vertical receiver signals are recorded. The repeated source pattern facilitates the picking of the P and $S_H$-wave arrivals; reversal of the source changes the polarity of the $S_H$-wave pattern but not the P-wave pattern.

The data from each receiver during each source activation is recorded as a different channel on the recording system. The Suspension PS system has six channels (two simultaneous recording channels), each with a 1024 sample record. The recorded data is displayed on a CRT or LCD display as six channels with a common time scale. Data is stored on disk for further processing. Up to 8 sampling sequences can be summed to improve the signal to noise ratio of the signals.

Review of the displayed data on the recorder or computer screen allows the operator to set the gains, filters, delay time, pulse length (energy), sample rate, and summing number to optimize the quality of the data before recording. Verification of the calibration of the Suspension PS digital recorder is performed every twelve months using a NIST traceable frequency source and counter, as outlined in Appendix D.

## Caliper / Natural Gamma Instrumentation

Caliper and natural gamma data were collected using a Model 3ACS 3-leg caliper probe, serial number 2915, manufactured by Robertson Geologging, Ltd. With the short arm configuration used in these surveys, the probes permitted measurement of boring diameters between 1.6 and 16 inches. With this tool, caliper measurements were collected concurrent with measurement of natural gamma emission from the boring walls. The probe was 6.82 feet long, and 1.5 inches in diameter.

This probe is useful in the following studies:

- Measurement of boring diameter and volume
- Location of hard and soft formations
- Location of fissures, caving, pinching and casing damage
- Bed boundary identification
- Strata correlation between borings

The probe receives control signals from, and sends the digitized measurement values to, a Robertson Micrologger II, S/N 5310, on the surface via an armored 4 conductor cable. The cable is wound onto the drum of a winch and is used to support the probe. Cable travel is measured to provide probe depth data, using a 3.28 foot circumference sheave fitted with a digital rotary encoder. The probe and depth data are transmitted by USB link from the Micrologger unit to a laptop computer where it is displayed and stored on hard disk.

The caliper consists of three arms, each with a toothed quadrant at their base, pivoted in the lower probe body. A toothed rack engages with each quadrant, thus constraining the arms to move together. Linear movement of the rack is converted to opening and closing of the arms. Springs hold the arms open in the operating position. A motor drive is provided to retract the arms, allowing the probe to be lowered into the boring. The rack is coupled to a potentiometer which converts movement into a voltage sensed by the probe's microprocessor.

Natural gamma measurements rely upon small quantities of radioactive material contained in all rocks to emit gamma radiation as they decay. Trace amounts of Uranium and Thorium are present in a few minerals, where potassium-bearing minerals such as feldspar, mica and clays will include traces of a radioactive isotope of Potassium. These emit gamma radiation as they decay with an extremely long half-life. This radiation is detected by scintillation - the production of a tiny flash of light when gamma rays strike a crystal of sodium iodide. The light is converted into an electrical pulse by a photomultiplier tube. Pulses above a threshold value of 60 KeV are counted by the probe's microprocessor. The measurement is useful because the radioactive elements are concentrated in certain rock types e.g. clay or shales, and depleted in others e.g. sandstone or coal.

## Resistivity / Spontaneous Potential / Natural Gamma Instrumentation

Resistivity, spontaneous potential and natural gamma data were collected using a Model ELXG electric log probe, S/N 5490, manufactured by Robertson Geologging, Ltd. This probe measures Single Point Resistance (SPR), short normal (16") resistivity, long normal (64") resistivity, Spontaneous Potential (SP) and natural gamma. The probe is 8.20 feet long, and 1.73 inches in diameter.

This probe is useful in the following studies:

- Bed boundary identification
- Strata correlation between borings
- Strata geometry and type (shale indication)

The probe receives control signals from, and sends the digitized measurement values to, a Robertson Micrologger II, S/N 5310, on the surface via an armored 4 conductor cable. The cable is wound onto the drum of a winch and is used to support the probe. Cable travel is measured to provide probe depth data, using a 3.28 foot circumference sheave fitted with a digital rotary encoder. The probe and depth data are transmitted by USB link from the Micrologger unit to a laptop computer where it is displayed and stored on hard disk.

The resistivity section of the probe operates by driving an alternating current into the formation from the central SPR/DRIVE electrode. The current returns via the logging cable armor. To ensure adequate penetration of the formation the logging cable is insulated for approximately 30 feet from the cablehead. Voltages are measured between the 16" and 64" electrodes and the remote earth connection at surface, as noted below:

- Single Point Resistance (SPR): The current flowing to the cable armor is measured along with the voltage at the SPR electrode. The voltage divided by current gives resistance.

- Spontaneous Potential (SP): This is the DC bias of the 16" electrode with respect to the voltage return at the surface (ground stake).

Data quality depends upon good grounding at the surface. This is achieved with a metal stake driven into the mud-pit.

### Acoustic Televiewer / Boring Deviation Instrumentation

An acoustic image and boring deviation data were collected in all eight borings using a High Resolution Acoustic Televiewer probe (HiRAT), serial number 5500, manufactured by Robertson Geologging, Ltd. The probe is 7.58 feet long, and 1.9 inches in diameter, and is fitted with upper and lower four-band centralizers.

In this application, this probe is useful in the following studies:

- Measurement of boring inclination and deviation from vertical
- Determination of need to correct soil and geophysical log depths to true vertical depths
- Acoustic imaging of the boring wall to identify fractures, dikes, and weathered zones, and determine dip and azimuth of these features

The probe receives control signals from, and sends the digitized measurement values to, a Robertson Micrologger II, S/N 5310, on the surface via an armored 4 conductor cable. The cable is wound onto the drum of a winch and is used to support the probe. Cable travel is measured to provide probe depth data, using a 3.28 foot circumference sheave fitted with a digital rotary encoder. The probe and depth data are transmitted by USB link from the Micrologger unit to a laptop computer where it is displayed and stored on hard disk.

This system produces images of the boring wall based upon the amplitude and travel time of an ultrasonic beam reflected from the formation wall. The ultrasonic energy is generated by a piezoelectric transducer at a frequency of 1.4 MHz. A periodic acoustic energy wave is emitted by the transducer and travels through the acoustic head and boring fluid until it reaches the interface between the boring fluid and the boring wall. Here a portion of the energy is reflected back to the transducer, the remainder continuing on into the formation. By careful time sequencing, the piezoelectric transducer acts as both the transmitter of the ultrasonic pulse and receiver of the reflected wave. The travel time of the energy wave is the period between transmission of the source energy pulse and the return of the reflected wave measured at the point of maximum wave amplitude. The magnitude of the wave energy is measured in dB, a unit-less ratio of the detected echo wave amplitude divided by the amplitude of the transmitted wave. The strength of the reflected signal depends primarily upon the impedance contrast of the boring fluid and the boring wall formation. In these rock borings, the contrast between the clear water filling the boring and the rock formation generally provides high contrast. The changes in contrast between native rock and dikes provides imaging of fracture fillings.

The acoustic wave propagates along the axis of the probe and then is reflected perpendicular to this axis by a reflector that focuses the beam to a 0.1-inch diameter spot about 2 inches from the central axis of the probe. This reflector is mounted on the shaft of a stepper motor enabling the position of the measurement to be rotated through 360°. Sampling rates of 90, 180 and 360 measured points per revolution are available. During these surveys, data were collected at 360 samples per revolution. It should be noted that during logging the probe is moving in the boring, so that the measured points describe a very fine pitch spiral.

The probe contains a fluxgate magnetometer to monitor magnetic north, and all raw televiewer data are referenced to magnetic north. Also, a three-axis accelerometer is enclosed in the probe, and boring deviation data are recorded during the logging runs, to permit correction of structure dip angle from apparent dip, (referenced to boring axis), to true dip (referenced to a vertical axis) in non-vertical borings.

The data are presented on a computer screen for operator review during the logging run, and stored on hard disk for later processing.

# MEASUREMENT PROCEDURES

## Suspension Measurement Procedures

All eight borings were logged as partially cased borings, filled with clear water or polymer based drilling mud, with a 4-inch PVC casing grouted in to the top 40 to 60 feet of softer soils above bedrock contact. Measurements followed the **GEO***Vision* Procedure for P-S Suspension Seismic Velocity Logging, revision 1.3, as presented in Appendix E. These procedures were supplied and approved in advance of the work. In each boring, the probe was positioned with the top of the probe at the top of the casing, and the electronic depth counter was set to 6.6 feet, the distance between the mid-point of the receiver and the top of the probe, minus the height of the casing stick-up, as verified with a tape measure, and recorded on the field logs. The probe was lowered to the bottom of the boring, and then returned to the surface, stopping at 1.6 foot intervals to collect data, as summarized in Table 2.

At each measurement depth the measurement sequence of two opposite horizontal records and one vertical record was performed, and the gains were adjusted as required. The data from each depth was printed on paper tape, checked, and recorded on diskette before moving to the next depth.

Upon completion of the measurements, the probe zero depth indication at the depth reference point was verified prior to removal from the boring.

## Caliper / Natural Gamma Measurement Procedures

All eight borings were logged as uncased borings, filled with bentonite or polymer based drilling mud. Measurements followed the ASTM D6167 Conducting Borehole Geophysical Logging – Mechanical Caliper, as presented in Appendix E.

Prior to and following each logging run, the caliper tool was verified, using the manufacturer's supplied three point calibration jig, which is a circular plate with a series of holes in the top surface into which the tips of the caliper arms fit. This has circles of diameters from 2" to 12", with NIST traceable calibration as documented in Appendix C. The calibration jig is placed over a bucket with the probe standing upright with its nose section passing through the jig's central hole. The caliper probe arms are opened under program control, and a log is recorded as the tips of the arms are placed in the holes on the calibration jig. The measured dimensions, as displayed on the recording computer screen was recorded on the field log sheet, as well as in the digital record, and compared with the calibration jig dimensions. If the verification records did not fall within +/- 0.05 inches of the calibration jig values, the caliper tool was re-calibrated, using the three point calibration jig, and the log repeated. As with the verification, the tips of the caliper arms are placed in the holes marked with the required diameter. During calibration, the value of the current calibration point, as stamped on the jig, is entered via the control computer. The system counts for 15 seconds to make an average of the response. The procedure is repeated for the second and third required openings.

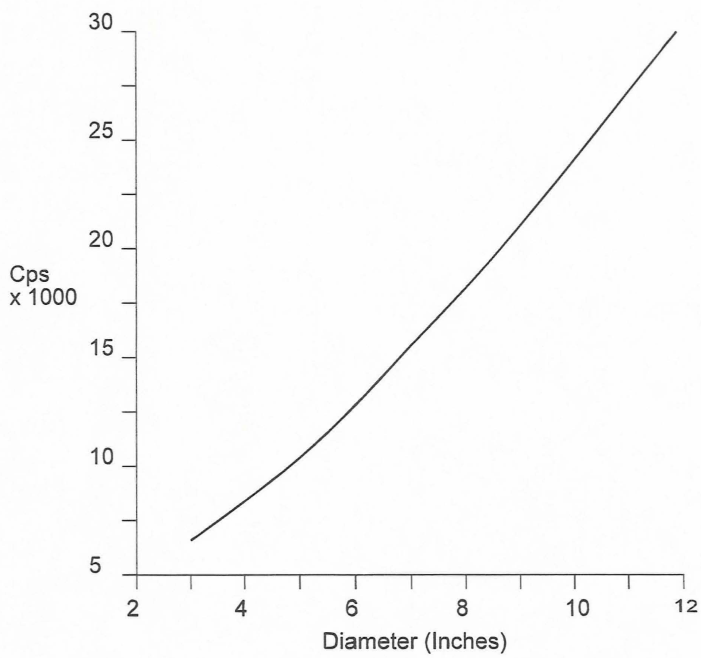


Figure 1. Example Calibration Curve for Caliper Probe

The computation and generation of the calibration coefficient file is entirely automatic. The calibration file is simply the set of coefficients of a quadratic curve which fits the three data points. Figure 1 shows the response of a caliper probe using data gathered during calibration.

Natural gamma was not calibrated in the field, as it is a qualitative measurement, not a quantitative value, and is used only to assist in picking transitions between stratigraphic units, as described in ASTM D6274, Conducting Borehole Geophysical Logging - Gamma, which is included in Appendix F.

In each boring, the probe was positioned with the top of the probe at the top of the mud box, and the electronic depth counter was set to 6.82 feet, the specified length of the probe, minus the height of the mud box, as verified with a tape measure, and recorded on the field logs. The probe was lowered to the bottom of the boring, where the caliper legs were opened, and data collection begun. The probe was then returned to the surface at 9.8 feet/minute, collecting data continuously at 0.05 foot spacing, as summarized in Table 2.

Upon completion of the measurements, the probe zero depth indication at the depth reference point was verified prior to removal from the boring, as summarized in Table 3.

## Resistivity / Spontaneous Potential Measurement Procedures

All eight borings were logged as uncased borings, filled with clear water or polymer based drilling mud. The probe was connected to the logging cable using a 32.8 foot long insulating cable section or "yoke". The probe head was insulated by wrapping all exposed metal of the cablehead and probe with self-amalgamating insulation tape. The 32.8 foot insulating yoke was checked for any damage, and repaired with self-amalgamating insulation tape as needed.

The reference ground stake was driven firmly into the mud pit, and connected to the ground socket on the winch switch box.

This sonde was not calibrated in the field, as it is used to provide qualitative measurements, not quantitative values, and is used only to assist in picking transitions between stratigraphic units, as described in ASTM D5753, Planning and Conducting Borehole Geophysical Surveys, which is included in Appendix E.

In each boring, the probe was positioned with the top of the probe at the top of the casing or mud box, and the electronic depth counter was set to 8.2 feet, the specified length of the probe, minus the height of the casing stick-up or mud box, as verified with a tape measure. When logging on smaller drill rigs, the depth was zeroed to the top of the yoke, and 32.8 feet was added to the zero depth, as recorded in the field logs. The probe was lowered to the bottom of the boring, where data collection was begun. The probe was then returned to the surface at 10 feet/minute, collecting data continuously at 0.05 foot spacing, as summarized in Table 2. The natural gamma data collected in these logs is redundant with the data collected in the caliper / natural gamma logs, and the caliper / natural data may be used to verify the natural gamma data collected in these logs.

Normally, when the un-insulated section of the logging cable leaves the boring fluid, the log is terminated, as the electrical measurements do not function under these conditions. However, in these surveys, the log was continued, in order to collect as much natural gamma data as possible before the yoke connector reached the measuring wheel.

Upon completion of the measurements, the probe zero depth indication at the depth reference point was verified prior to removal from the boring, as summarized in Table 3.

## Acoustic Televiewer / Boring Deviation Measurement Procedures

All eight borings were logged as partially cased borings, filled with clear water or polymer based drilling mud, with a 4-inch PVC casing grouted in to the top 40 to 60 feet of softer soils above bedrock contact. Although the acoustic televiewer cannot image through PVC casing, the logs were run to the surface in order to provide a deviation log for the entire boring depth. Measurements followed the **GEO***Vision* standard field procedures, as presented in Appendix F.

Prior to use, the HiRAT probe tiltmeter and compass functions were checked by comparison with a Brunton surveyors' compass.

In each boring, the HiRAT probe was positioned with the top of the probe at the top of the casing, and the electronic depth counter was set to 4.71 feet, the specified length of the probe, minus the height of the casing stick-up, as verified with a tape measure, and recorded on the field logs. The probe was lowered to the bottom of the boring, and data collection begun. The probe was then returned to the surface at 3.0 feet/minute, collecting data continuously at 0.008 foot intervals, as summarized in Table 2.

Upon completion of the measurements, the probe zero depth indication at grade was verified prior to removal from the boring. The log was reviewed in the field, and the un-processed log images, in .htm web-browser format was supplied to the client with the raw data on CDR at the end of each field day. These .htm files are included in the boring specific sub-directories of the data directory on volume 2 of 2 (DVD-R) of this report.

| BORING NUMBER | TOOL AND RUN NUMBER | DEPTH RANGE (FEET) | OPEN HOLE (FEET) | DEPTH TO BOTTOM OF CASING (FEET) | SAMPLE INTERVAL (FEET) | DATE LOGGED |
|---|---|---|---|---|---|---|
| B-201 | CALIPER/GAMMA 1 | 350.0 – 3.5 | 350.0 | 49.8 PVC | 0.05 | 6/22/06 |
| B-201 | CALIPER/GAMMA 2 | 348.0 – 3.5 | - | 49.8 PVC | 0.05 | 6/22/06 |
| B-201 | ELOG/GAMMA 1 | 350.0 – 39.5 | - | 49.8 PVC | 0.05 | 6/22/06 |
| B-201 | SUSPENSION 1 | 1.6 – 334.6 | - | 49.8 PVC | 1.6 | 6/22/06 |
| B-201 | ACOUSTIC TELEVIEWER 1 | 3.2 – 347.6 | - | 49.8 PVC | .008 | 6/23/06 |
| B-201 | ACOUSTIC TELEVIEWER 2 | 49.0 – 347.5 | - | 49.8 PVC | .008 | 6/23/06 |
| B-206 | SUSPENSION 1 | 6.6 – 50.9 | - | 49.0 PVC | 1.6 | 6/24/06 |
| B-206 | SUSPENSION 2 | 49.2 – 191.5 | - | 49.0 PVC | 1.6 | 6/25/06 |
| B-206 | ACOUSTIC TELEVIEWER 1 | 3.2 – 66.2 | - | 49.0 PVC | .008 | 6/25/06 |
| B-206 | ACOUSTIC TELEVIEWER 2 | 60.0 – 198.5 | - | 72.5 STEEL | .008 | 6/25/06 |
| B-206 | ACOUSTIC TELEVIEWER 3 | 198.5 – 0 | - | 72.5 STEEL | .008 | 6/25/06 |
| B-206 | CALIPER/GAMMA 1 | 200.0 – 0 | 200.0 | 72.5 STEEL | 0.05 | 6/25/06 |
| B-206 | ELOG/GAMMA 1 | 200.0 – 68.0 | - | 72.5 STEEL | 0.05 | 6/25/06 |
| B-206 | CALIPER/GAMMA 2 | 90.0 - 0 | - | 72.5 STEEL | 0.05 | 6/25/06 |
| B-207 | SUSPENSION 1 | 1.6 – 162.4 | 175.5 | 42.3 PVC | 1.6 | 7/7/06 |
| B-207 | ACOUSTIC TELEVIEWER 1 | 3.2 – 67.8 | - | 42.3 PVC | .008 | 7/7/06 |
| B-207 | ACOUSTIC TELEVIEWER 2 | 40.0 – 174.1 | - | 42.3 PVC | .008 | 7/7/06 |
| B-207 | CALIPER/GAMMA 1 | 173.0 – 0 | - | 42.3 PVC | 0.05 | 7/7/06 |
| B-207 | ELOG/GAMMA 1 | 174.0 – 32.0 | - | 42.3 PVC | 0.05 | 7/7/06 |
| B-211 | ACOUSTIC TELEVIEWER 1 | 3.2 – 174.5 | 174.5 | 42.1 PVC | .008 | 7/7/06 |
| B-211 | CALIPER/GAMMA 1 | 173.0 – 2.3 | - | 42.1 PVC | 0.05 | 7/7/06 |
| B-211 | ELOG/GAMMA 1 | 174.5 – 36.5 | - | 42.1 PVC | 0.05 | 7/7/06 |
| B-211 | SUSPENSION 1 | 1.6 – 160.8 | 174.2 | 42.1 PVC | 1.6 | 7/7/06 |
| B-211A | SUSPENSION 2 | 1.6 – 26.3 | 38.4 | NO CASING | 1.6 | 7/8/06 |
| B-301 | SUSPENSION 1 | 3.3 – 337.9 | 351.0 | 54.9 PVC | 1.6 | 7/8/06 |
| B-301 | ACOUSTIC TELEVIEWER 1 | 2.7 – 351.5 | 351.5 | 54.9 PVC | .008 | 7/8/06 |
| B-301 | CALIPER/GAMMA 1 | 350.0 – 0.5 | - | 54.9 PVC | 0.05 | 7/9/06 |
| B-301 | ELOG/GAMMA 1 | 351.5 – 35.0 | 351.5 | 54.9 PVC | 0.05 | 7/9/06 |
| B-306 | CALIPER/GAMMA 1 | 220.0 – 4.0 | 220.0 | 44.1 PVC | 0.05 | 6/20/06 |
| B-306 | CALIPER/GAMMA 2 | 40.0 – 21.5 | - | 44.1 PVC | 0.05 | 6/20/06 |
| B-306 | ELOG/GAMMA 1 | 220.0 – 39.5 | - | 44.1 PVC | 0.05 | 6/20/06 |
| B-306 | SUSPENSION 1 | 3.3 – 206.7 | - | 44.1 PVC | 1.6 | 6/21/06 |
| B-306 | ACOUSTIC TELEVIEWER 1 | 42.0 – 54.7 | - | 44.1 PVC | .008 | 6/21/06 |
| B-306 | ACOUSTIC TELEVIEWER 2 | 44.0 – 220.0 | - | 44.1 PVC | .008 | 6/21/06 |
| B-306 | ACOUSTIC TELEVIEWER 3 | 60.0 – 3.0 | - | 44.1 PVC | .008 | 6/21/06 |
| B-307 | SUSPENSION 1 | 41.0 – 164.0 | 176.2 | 39.6 PVC | 1.6 | 6/22/06 |
| B-307 | ACOUSTIC TELEVIEWER 1 | 3.7 – 176.2 | 176.2 | 39.6 PVC | .008 | 6/22/06 |
| B-307 | CALIPER/GAMMA 1 | 176.0 – 3.2 | - | 39.6 PVC | 0.05 | 6/22/06 |

| | | | | | | |
|---|---|---|---|---|---|---|
| B-307 | ELOG/GAMMA 1 | 176.5 – 39.5 | 176.5 | 39.6 PVC | 0.05 | 6/22/06 |
| B-307A | SUSPENSION 2 | 1.6 – 26.3 | 39.3 | NO CASING | 1.6 | 7/8/06 |
| B-311 | SUSPENSION 1 | 3.3 – 164.0 | 176.4 | 52.5 PVC | 1.6 | 6/20/06 |
| B-311 | CALIPER/GAMMA 1 | 175.0 – 3.7 | - | 52.5 PVC | 0.05 | 6/20/06 |
| B-311 | ELOG/GAMMA 1 | 176.5.0 – 17.6 | 176.5 | 52.5 PVC | 0.05 | 6/20/06 |
| B-311 | ACOUSTIC TELEVIEWER 1 | 47.0 – 173.0 | - | 52.5 PVC | .008 | 6/21/06 |
| B-311 | ACOUSTIC TELEVIEWER 2 | 72.0 – 3.1 | - | 52.5 PVC | .008 | 6/21/06 |

- PROBE DID NOT TOUCH BOTTOM OF BORING

Table 2. Logging dates and depth ranges

| BORING NUMBER | TOOL AND RUN NUMBER | TOOL HIT BOTTOM DEPTH (FEET) | DRILLER DEPTH (FEET) | STARTING DEPTH REF. (FEET) | ENDING DEPTH REF. (FEET) | ASDE (FEET) |
|---|---|---|---|---|---|---|
| B-201 | CALIPER/GAMMA 1 | 350.0 | 350.0 | 5.32 | 5.32 | 0.0 |
| B-201 | CALIPER/GAMMA 2 | - | | 5.32 | 5.32 | 0.0 |
| B-201 | ELOG/GAMMA 1 | - | | 39.5 | 39.5 | 0.0 |
| B-201 | SUSPENSION 1 | - | | 5.06 | 4.92 | -0.1 |
| B-201 | ACOUSTIC TELEVIEWER 1 | - | | 3.22 | 3.18 | 0.0 |
| B-201 | ACOUSTIC TELEVIEWER 2 | - | | 3.22 | 3.18 | 0.0 |
| B-206 | SUSPENSION 1 | - | | 5.06 | 5.06 | 0.0 |
| B-206 | SUSPENSION 2 | - | | 5.06 | 5.06 | 0.0 |
| B-206 | ACOUSTIC TELEVIEWER 1 | - | | 3.22 | 3.22 | 0.0 |
| B-206 | ACOUSTIC TELEVIEWER 2 | - | | 2.02 | 2.02 | 0.0 |
| B-206 | ACOUSTIC TELEVIEWER 3 | - | | 2.02 | 2.02 | 0.0 |
| B-206 | CALIPER/GAMMA 1 | 200.0 | 214.8 | 4.12 | 3.95 | -0.1 |
| B-206 | ELOG/GAMMA 1 | - | | 38.3 | 38.2 | 0.0 |
| B-206 | CALIPER/GAMMA 2 | - | | 5.32 | 5.25 | 0.0 |
| B-207 | SUSPENSION 1 | 175.5 | 175.0 | 5.06 | 5.06 | 0.0 |
| B-207 | ACOUSTIC TELEVIEWER 1 | - | | 3.22 | 3.20 | 0.0 |
| B-207 | ACOUSTIC TELEVIEWER 2 | - | | 3.22 | 3.20 | 0.0 |
| B-207 | CALIPER/GAMMA 1 | - | | 5.32 | 5.32 | 0.0 |
| B-207 | ELOG/GAMMA 1 | - | | 39.5 | 39.5 | 0.0 |
| B-211 | ACOUSTIC TELEVIEWER 1 | 174.5 | 175.0 | 3.22 | 3.20 | 0.0 |
| B-211 | CALIPER/GAMMA 1 | - | | 5.32 | 5.32 | 0.0 |
| B-211 | ELOG/GAMMA 1 | - | | 39.5 | 39.5 | 0.0 |
| B-211 | SUSPENSION 1 | 174.2 | | NA | NA | NA |
| B-211A | SUSPENSION 2 | 38.4 | 39.0 | 0.0 | 0.0 | 0.0 |
| B-301 | SUSPENSION 1 | 351.0 | 351.5 | 4.56 | 4.49 | -0.1 |
| B-301 | ACOUSTIC TELEVIEWER 1 | 351.5 | | 2.72 | 2.62 | -0.1 |
| B-301 | CALIPER/GAMMA 1 | - | | 4.82 | 4.82 | 0.0 |
| B-301 | ELOG/GAMMA 1 | 351.5 | | 39.0 | 39.0 | 0.0 |
| B-306 | CALIPER/GAMMA 1 | 220.0 | 215.0 | 5.42 | 5.32 | -.01 |
| B-306 | CALIPER/GAMMA 2 | - | | 5.42 | 5.32 | -.01 |
| B-306 | ELOG/GAMMA 1 | - | | 39.6 | 39.5 | -.1 |
| B-306 | SUSPENSION 1 | - | | 5.16 | 5.05 | -.01 |
| B-306 | ACOUSTIC TELEVIEWER 1 | - | | 3.32 | 3.32 | 0.0 |
| B-306 | ACOUSTIC TELEVIEWER 2 | - | | 3.32 | 3.32 | 0.0 |
| B-306 | ACOUSTIC TELEVIEWER 3 | - | | 3.32 | 3.32 | 0.0 |
| B-307 | SUSPENSION 1 | 176.2 | 175.0 | 5.06 | 4.95 | -0.1 |
| B-307 | ACOUSTIC TELEVIEWER 1 | 176.2 | | 3.22 | 3.22 | 0.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| B-307 | CALIPER/GAMMA 1 | - | | 5.32 | 5.32 | 0.0 |
| B-307 | ELOG/GAMMA 1 | 176.5 | | 39.5 | 39.5 | 0.0 |
| B-307A | SUSPENSION 2 | 39.3 | 38.0 | 0.0 | 0.0 | 0.0 |
| B-311 | SUSPENSION 1 | 176.4 | 175.0 | 5.25 | 5.18 | -0.1 |
| B-311 | CALIPER/GAMMA 1 | - | | 5.52 | 5.32 | -0.2 |
| B-311 | ELOG/GAMMA 1 | 176.5 | | 39.7 | 39.7 | 0.0 |
| B-311 | ACOUSTIC TELEVIEWER 1 | - | | 3.42 | 3.42 | 0.0 |
| B-311 | ACOUSTIC TELEVIEWER 2 | - | | 3.42 | 3.42 | 0.0 |

- PROBE DID NOT TOUCH BOTTOM OF BORING

Table 3. Boring Bottom Depths and After Survey Depth Error (ASDE)

## DATA ANALYSIS

### Suspension Analysis

Using the proprietary OYO program PSLOG.EXE version 1.0, included in volume 2 of 2 (DVD-R) of this report, the recorded digital waveforms were analyzed to locate the most prominent first minima, first maxima, or first break on the vertical axis records, indicating the arrival of P-wave energy. The difference in travel time between receiver 1 and receiver 2 (R1-R2) arrivals was used to calculate the P-wave velocity for that 3.3 foot segment of the soil column. When observable, P-wave arrivals on the horizontal axis records were used to verify the velocities determined from the vertical axis data. The time picks were then transferred into an EXCEL template (EXCEL version 2003 SP2) to complete the velocity calculations based upon the arrival time picks made in PSLOG. The PSLOG pick files and the EXCEL analysis files are included in the boring specific directories on volume 2 of 2 (DVD-R) of this report.

The P-wave velocity over the 6.3 foot interval from source to receiver 1 (S-R1) was also picked using PSLOG, and calculated and plotted in EXCEL, for quality assurance of the velocity derived from the travel time between receivers. In this analysis, the depth values as recorded were increased by 4.8 feet to correspond to the mid-point of the 6.3 foot S-R1 interval. Travel times were obtained by picking the first break of the P-wave signal at receiver 1 and subtracting 3.0

milliseconds, the calculated and experimentally verified delay from source trigger pulse (beginning of record) to source impact. This delay corresponds to the duration of acceleration of the solenoid before impact.

As with the P-wave records, using PSLOG, the recorded digital waveforms were analyzed to locate the presence of clear $S_H$-wave pulses, as indicated by the presence of opposite polarity pulses on each pair of horizontal records. Ideally, the $S_H$-wave signals from the 'normal' and 'reverse' source pulses are very nearly inverted images of each other. Digital FFT - IFFT lowpass filtering was used to remove the higher frequency P-wave signal from the $S_H$-wave signal. Different filter cutoffs were used to separate P- and $S_H$-waves at different depths, ranging from 600 Hz in the slowest zones to 4000 Hz in the regions of highest velocity. At each depth, the filter frequency was selected to be at least twice the fundamental frequency of the $S_H$-wave signal being filtered.

Generally, the first maxima were picked for the 'normal' signals and the first minima for the 'reverse' signals, although other points on the waveform were used if the first pulse was distorted. The absolute arrival time of the 'normal' and 'reverse' signals may vary by +/- 0.2 milliseconds, due to differences in the actuation time of the solenoid source caused by constant mechanical bias in the source or by boring inclination. This variation does not affect the R1-R2 velocity determinations, as the differential time is measured between arrivals of waves created by the same source actuation. The final velocity value is the average of the values obtained from the 'normal' and 'reverse' source actuations.

As with the P-wave data, $S_H$-wave velocity calculated from the travel time over the 6.3 foot interval from source to receiver 1 was calculated and plotted for verification of the velocity derived from the travel time between receivers. In this analysis, the depth values were increased by 4.8 foot to correspond to the mid-point of the 6.3 foot S-R1 interval. Travel times were obtained by picking the first break of the $S_H$-wave signal at the near receiver and subtracting 3.0 milliseconds, the calculated and experimentally verified delay from the beginning of the record at the source trigger pulse to source impact.

These data and analysis were reviewed by John Diehl and Tony Martin as a component of **GEO***Vision*'s in-house QA-QC program.

Figure 2 shows an example of R1 - R2 measurements on a sample filtered suspension record. In Figure 2, the time difference over the 3.3 foot interval of 1.88 milliseconds for the horizontal signals is equivalent to an $S_H$-wave velocity of 1745 feet/second. Whenever possible, time differences were determined from several phase points on the $S_H$-waveform records to verify the data obtained from the first arrival of the $S_H$-wave pulse. Figure 3 displays the same record before filtering of the $S_H$-waveform record with a 1400 Hz FFT - IFFT digital lowpass filter, illustrating the presence of higher frequency P-wave energy at the beginning of the record, and distortion of the lower frequency $S_H$-wave by residual P-wave signal.

## Caliper / Natural Gamma Analysis

No analysis is required with the caliper or natural gamma data, however depths to identifiable boring features were compared to verify compatible depth readings on all logs. Using Robertson Geologging Winlogger software version 3.74J, these data were combined with the resistivity, ELOG based natural gamma and spontaneous potential (SP) logs, and converted to LAS and PDF formats for transmittal to the client.

## Resistivity / Natural Gamma / Spontaneous Potential Analysis

No analysis is required with the resistivity, natural gamma or spontaneous potential data, however depths to identifiable boring features were compared to verify compatible depth readings on all logs. Using Robertson Geologging Winlogger software version 3.74J, these data were combined with the caliper and caliper-based natural gamma logs, and converted to LAS and PDF formats for transmittal to the client.

## Acoustic Televiewer / Boring Deviation Analysis

The collected Acoustic Televiewer data was processed with Robertson Geologging's RGLDIP program, version 6.2, to identify boring features and to extract the deviation data and produce an ASCII file and plots of deviation data.

Sinusoidal projections of both open and healed fractures and dikes in the boring walls were interactively picked on the acoustic reflection image or acoustic travel time image, and are presented on the logs as red sinusoids superimposed over the televiewer images. Bedrock contact, where visible, was picked on the same images, and is presented on the logs as a green sinusoid. The sinusoidal projections were processed to correct for the plunge of the borings using the recorded data from the accelerometers located in the probe, and presented graphically, in what is referred to as "tadpole", or "arrow" format, with true dip indicated by the position of the arrow head on the plot. Direction of dip (not strike) is indicated by the direction of the arrow tail, with true north being "up". These values are presented numerically in columns to the left of the arrow graphic plots. These depth and dip data of the joints and foliation are also presented as .txt files in the boring specific sub-directories in the data directory on volume 2 of 2 (DVD-R) of this report.

The televiewer images were processed to create a simulated core image of the borings. It should be considered that the pseudo-core represents a core that would have the full 3.75-inch diameter of the boring, not the 2.5-inch diameter of the cores removed during drilling, so that direct comparison is not possible. Also, the unwrapped image is viewed from the perspective of an observer in the center of the boring looking outward. The simulated core image is viewed from the "outside" of the boring looking inward, so there is a reversal of the position of east and west relative to north between the two images.

# RESULTS

## Suspension Results

Suspension R1-R2 P- and $S_H$-wave velocities are plotted in Figures 5, 8, 9, 11, 14, 17, 20, 23 and 26. The suspension velocity data presented in these figures are presented in Tables 5 - 12. The PSLOG and EXCEL analysis files for each boring are included in the boring specific directories on volume 2 of 2 (DVD-R) of this report, along with the raw and filtered waveforms.

P- and $S_H$-wave velocity data from R1-R2 analysis and quality assurance analysis of S-R1 data are plotted together in Figures A-1 through A-8 to aid in visual comparison. It must be noted that R1-R2 data is an average velocity over a 3.3 foot segment of the soil column; S-R1 data is an average over 6.3 feet, creating a significant smoothing relative to the R1-R2 plots. S-R1 data are presented in Tables A-1 through A-8, and included in the EXCEL analysis files for each boring on volume 2 of 2 (DVD-R) of this report.

Calibration procedures and records for the suspension measurement system are presented in Appendix C.

The **GEO***Vision* standard field log sheets for all borings are reproduced in Appendix E.

The **GEO***Vision* standard field procedures are reproduced in Appendix F.

## Caliper/ Natural Gamma Results

Caliper and natural gamma data is presented in combined log plots with resistivity and spontaneous potential as single page logs in Figures 6, 9, 12, 15, 18, 21, 24 and 27, as well as multi-page logs in Appendix B. LAS 2.0 data and Acrobat files of the plots for each boring are included in the boring specific sub-directories in the data directory on volume 2 of 2 (DVD-R) of this report.

### Resistivity / Spontaneous Potential Results

Resistivity and spontaneous potential data is presented in combined log plots with caliper and natural gamma data as single page logs in Figures 6, 10, 13, 16, 19, 22, 25, 28, 31 and 34, as well as multi-page logs in Appendix B. LAS 2.0 data and Acrobat files for each boring are included in the boring specific sub-directories in the data directory on volume 2 of 2 (DVD-R) of this report.

### Acoustic Televiewer / Boring Deviation Results

Acoustic televiewer amplitude images and simulated core images are presented in Appendix C, with identified features super-imposed on the images. Features were picked only as planar features (as identified as features only present on the amplitude display) and fractures (as identified as features present on both amplitude and travel-time displays). The same logs are presented in .pdf format in the boring specific sub-directories of the data directory on volume 2 of 2 (DVD-R) of this report. Fracture and planar feature depth, dip angle and azimuth of dip data are provided numerically on the log sheets, as well as in text format on volume 2.

Boring deviation data is presented graphically in Figures 7, 10, 13, 16, 19, 22, 25 and 28, and summarized in Table 4. Deviation data plots in Acrobat format and deviation data at 1.0 foot stations are presented in text format in the boring specific sub-directories of the data directory on volume 2 of 2 (DVD-R) of this report.

## SUMMARY

### Discussion of Suspension Results

Suspension PS velocity data is ideally collected in an uncased fluid filled boring, drilled with rotary mud (rotary wash) methods. The lower portion of the borings at this site were ideal for collection of suspension PS velocity data. The upper portion of the borings provided mixed results due to poor grout coupling of the PVC casing, as well as the inability to hold fluid to ground level. Each boring is discussed in more detail below.

Suspension PS velocity data quality is judged based upon 5 criteria:

1. Consistent data between receiver to receiver (R1 – R2) and source to receiver (S – R1) data.
2. Consistent relationship between P-wave and $S_H$ -wave (excluding transition to saturated soils)
3. Consistency between data from adjacent depth intervals.
4. Clarity of P-wave and $S_H$-wave onset, as well as damping of later oscillations.
5. Consistency of profile between adjacent borings, if available.

B-201: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. $S_H$-wave onsets are generally clear, and later oscillations are well damped. P-wave arrivals are weak, as is generally the case in hard rock borings, and above water table in soil. This is an excellent rock velocity data set, with fair soil velocity data.

B-206: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. $S_H$-wave onsets are generally clear, and later oscillations are well damped. P-wave arrivals are weak, as is generally the case in hard rock borings, and above water table in soil. The soil portion of this boring produced poor quality data due to poor coupling of the PVC casing. This is an excellent rock velocity data set, with poor soil velocity data.

B-207: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. $S_H$-wave onsets are generally clear, and later oscillations are well damped. P-wave arrivals are weak, as is generally the case in hard rock borings, and above water table in soil. The soil portion of this boring produced fair quality data. This is an excellent rock velocity data set, with fair soil velocity data.

B-211: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. P-wave and $S_H$-wave onsets are generally clear, and later oscillations are well damped. The first suspension PS data set collected in the PVC casing of B-211 was of poor quality, so a parallel boring, designated B-211A was drilled 10 feet away and logged uncased. This provided excellent data in the soil section. This combined data provides an excellent velocity data set for rock and soil.

B-301: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. $S_H$-wave onsets are generally clear, and later oscillations are well damped. P-wave arrivals are weak, as is generally the case in hard rock borings, and above water table in soil. The grouting of the casing in this boring held well, and this is an excellent rock velocity data set, with good soil velocity data.

B-306: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. $S_H$-wave onsets are generally clear, and later oscillations are well damped. P-wave arrivals are weak, as is generally the case in hard rock borings, and above water table in soil. The grouting of the casing in this boring was problematic, as void space could be seen though an open joint in the PVC casing. The data from the cased portion of this boring was not interpretable. This is an excellent rock velocity data set, with no soil velocity data.

B-307: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. P-wave and $S_H$-wave onsets are generally clear, and later oscillations are well damped. The first suspension PS data set collected in B-307 was limited to a depth of 41 feet, due to very rapid drilling mud loss. A parallel boring, designated B-307A was drilled 10 feet away and logged uncased to a depth of 26 feet. This boring provided fair data in the soil section. This combined data provides an excellent velocity data set for rock with fair data in the soil section.

B-311: These data show excellent correlation between R1 – R2 and S – R1 data, as well as excellent correlation between P-wave and $S_H$-wave velocities. $S_H$-wave onsets are generally clear, and later oscillations are well damped. P-wave arrivals are weak, as is generally the case in hard rock borings, and above water table in soil. The grouting of the casing in this boring held well, and this is an excellent rock velocity data set, with good soil velocity data.

## Discussion of Caliper / Natural Gamma Results

Caliper and natural gamma data was collected for the entire depth of each boring, as natural gamma data can be collected through PVC casing. The caliper logs for all these borings show very consistent gauge in competent rock, with minor tapering downhole due to bit wear. Some fracturing is noted, but below approximately 100 feet, all borings are tight. Natural gamma was collected with this tool in all the borings, as well as with the ELOG probe, and the comparison between the two data sets provides an almost exact match, verifying the performance of the natural gamma measuring systems.

## Discussion of Resistivity / Spontaneous Potential Results

These electrical methods are not well suited to this site, or any hard rock site. Resistivities in these materials are generally in excess of the 10,000 ohm-meter range of this and other resistivity instruments, as discussed in ASTM D5753, Planning and Conducting Borehole Geophysical Surveys, which is included in Appendix E. Single Point resistance does provide some useable data, showing drops in resistivity at weathered zones in the rock. The electrical data is not valid above 40 feet, as the upper yoke electrode moves out of the boring fluid at this depth. The natural gamma data remains valid up into the casing, and agrees well with the caliper probe. The comparison between the two data sets provides an almost exact match, verifying the performance of the natural gamma measuring systems.

## Discussion of Acoustic Televiewer / Boring Deviation Results

The acoustic televiewer data quality in all eight borings is very good, providing clear images of a number of fractures, dikes and weathered zones. Many of the borings exhibit diagonal banding (zebra striping) caused by rapid reaming down the boring with new core bits that are slightly larger than the gauge of the original boring. This creates a spiral wear pattern in the boring that alters the characteristic smooth surface of diamond cored borings. This wear pattern can have a significant impact on acoustic televiewer image quality, and in these borings may conceal smaller dikes. It will not conceal fractures, however.

Location of fractures and weathered zones on the televiewer logs correspond precisely with increases in caliper log diameter and suspension PS velocity drops.

All eight borings were inclined at 4.0 degree, or less, from vertical, and the maximum error in depth value was 1 foot in 350 ft, or 0.3 percent, as presented in Table 4. This error is less than depth errors from other causes, and no adjustment of log depth is indicated.

| BORING NUMBER | MEAN DEVIATION AND AZIMUTH (DEGREES) | SURVEY DEPTH (FEET) | VERTICAL DEPTH (FEET) | DEPTH ERROR (FEET) | HORIZONTAL OFFSET (FEET) |
|---|---|---|---|---|---|
| B-201 | 4.0 – N33 | 348.7 | 347.7 | 1.0 | 24.3 |
| B-206 | 2.2 – N55 | 198.4 | 198.2 | 0.2 | 7.7 |
| B-207 | 2.0 – N98 | 174.1 | 174.0 | 0.1 | 6.0 |
| B-211 | 0.5 – N103 | 174.7 | 174.7 | 0.0 | 1.4 |
| B-301 | 3.9 – N204 | 351.5 | 350.7 | 0.9 | 23.6 |
| B-306 | 1.5 – N342 | 220.0 | 219.9 | 0.1 | 5.7 |
| B-307 | 1.7 – N300 | 176.4 | 176.3 | 0.1 | 5.1 |
| B-311 | 1.0 – N163 | 173.4 | 173.3 | 0.1 | 3.1 |

Table 4. Boring Deviation Data Summary

## Quality Assurance

These boring geophysical measurements were performed using industry-standard or better methods for measurements and analyses. All work was performed under **GEO***Vision* quality assurance procedures, which include:

- Use of NIST-traceable calibrations, where applicable, for field and laboratory instrumentation
- Use of standard field data logs
- Use of independent verification of velocity data by comparison of receiver-to-receiver and source-to-receiver velocities
- Independent review of calculations and results by a registered professional engineer, geologist, or geophysicist.

## Suspension Data Reliability

P- and $S_H$-wave velocity measurement using the Suspension Method gives average velocities over a 3.3 foot interval of depth. This high resolution results in the scatter of values shown in the graphs. Individual measurements are very reliable with estimated precision of +/- 5%. Standardized field procedures and quality assurance checks contribute to the reliability of these data.

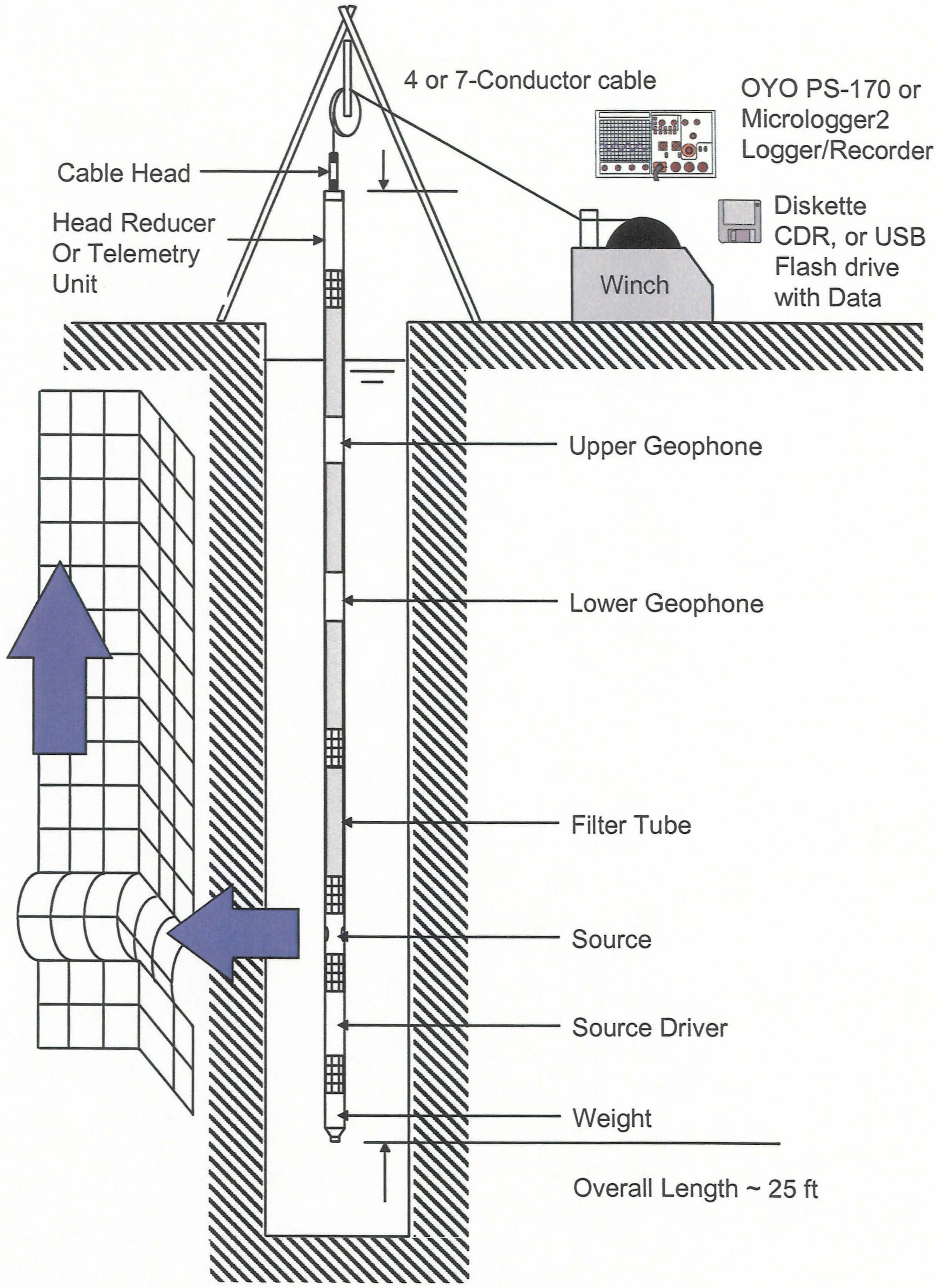


Figure 2: Concept illustration of P-S logging system

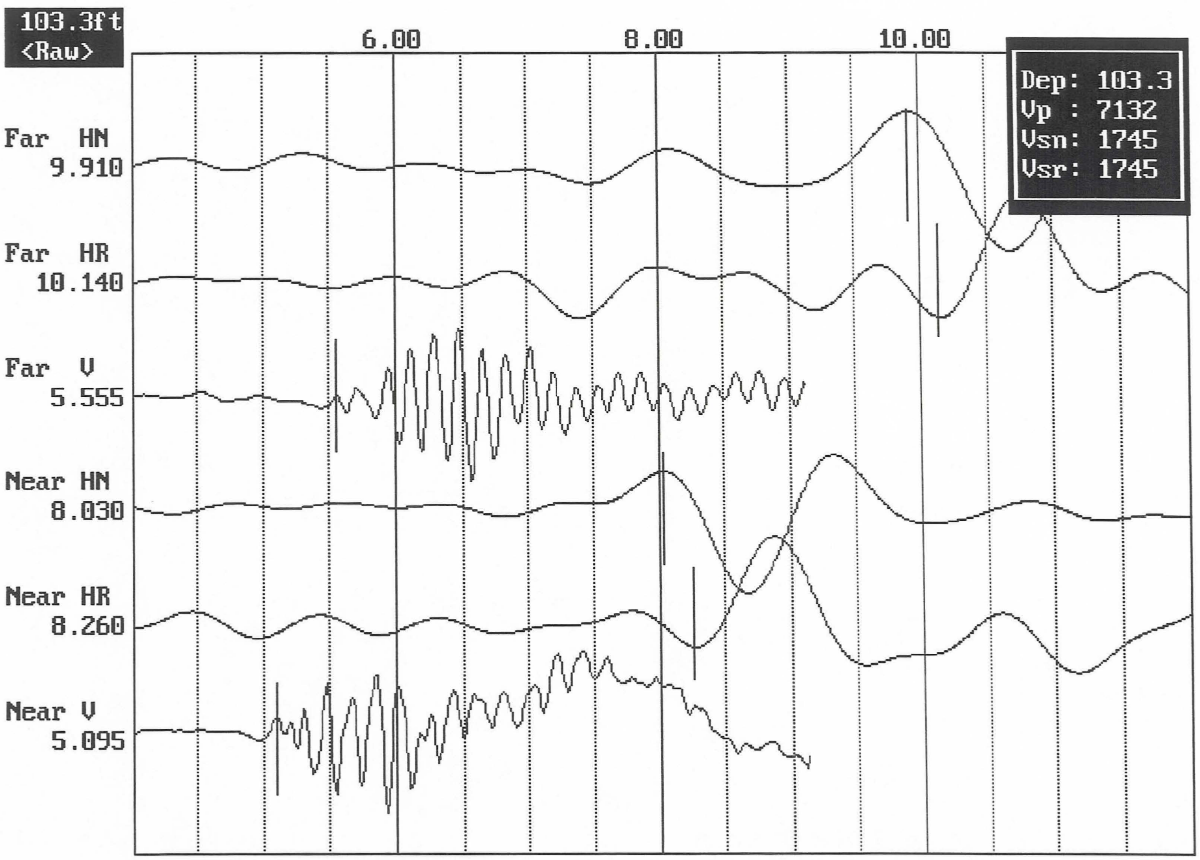


Figure 3: Example of filtered (1400 Hz lowpass) record

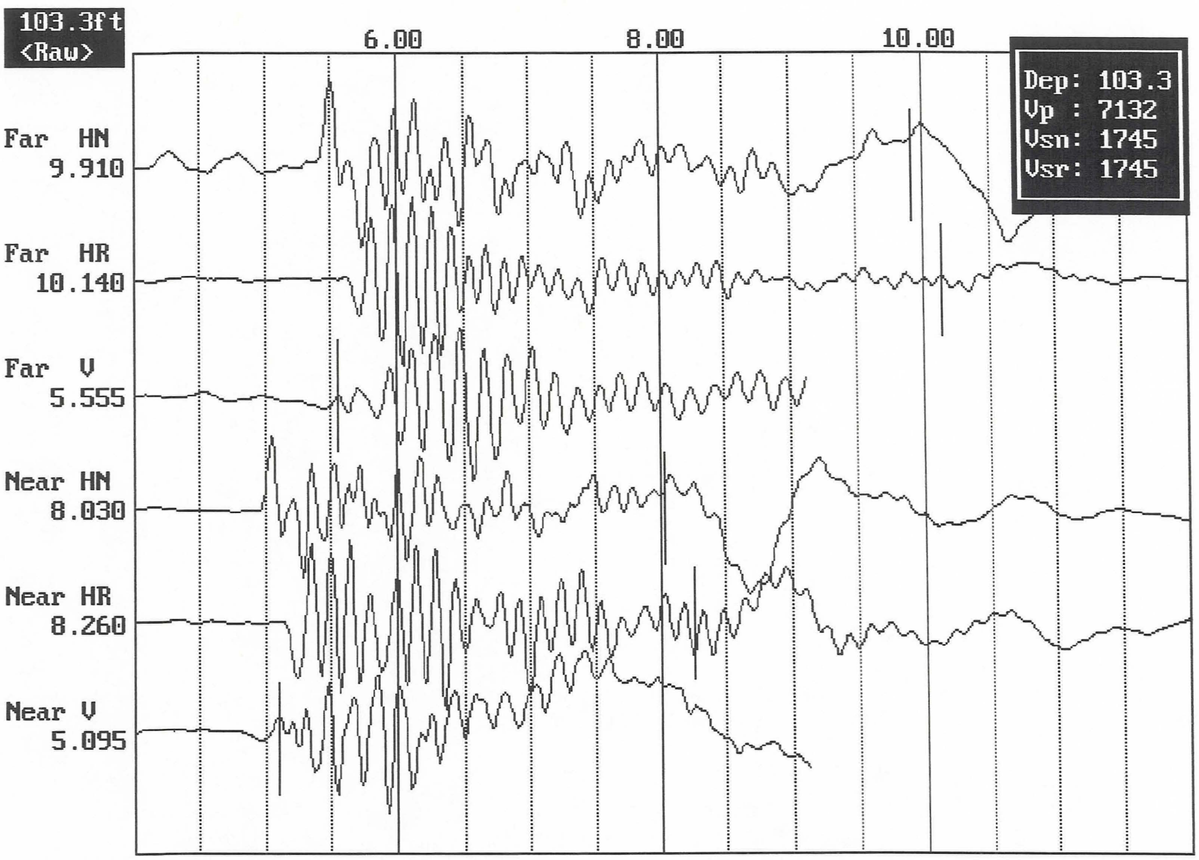


Figure 4. Example of unfiltered record

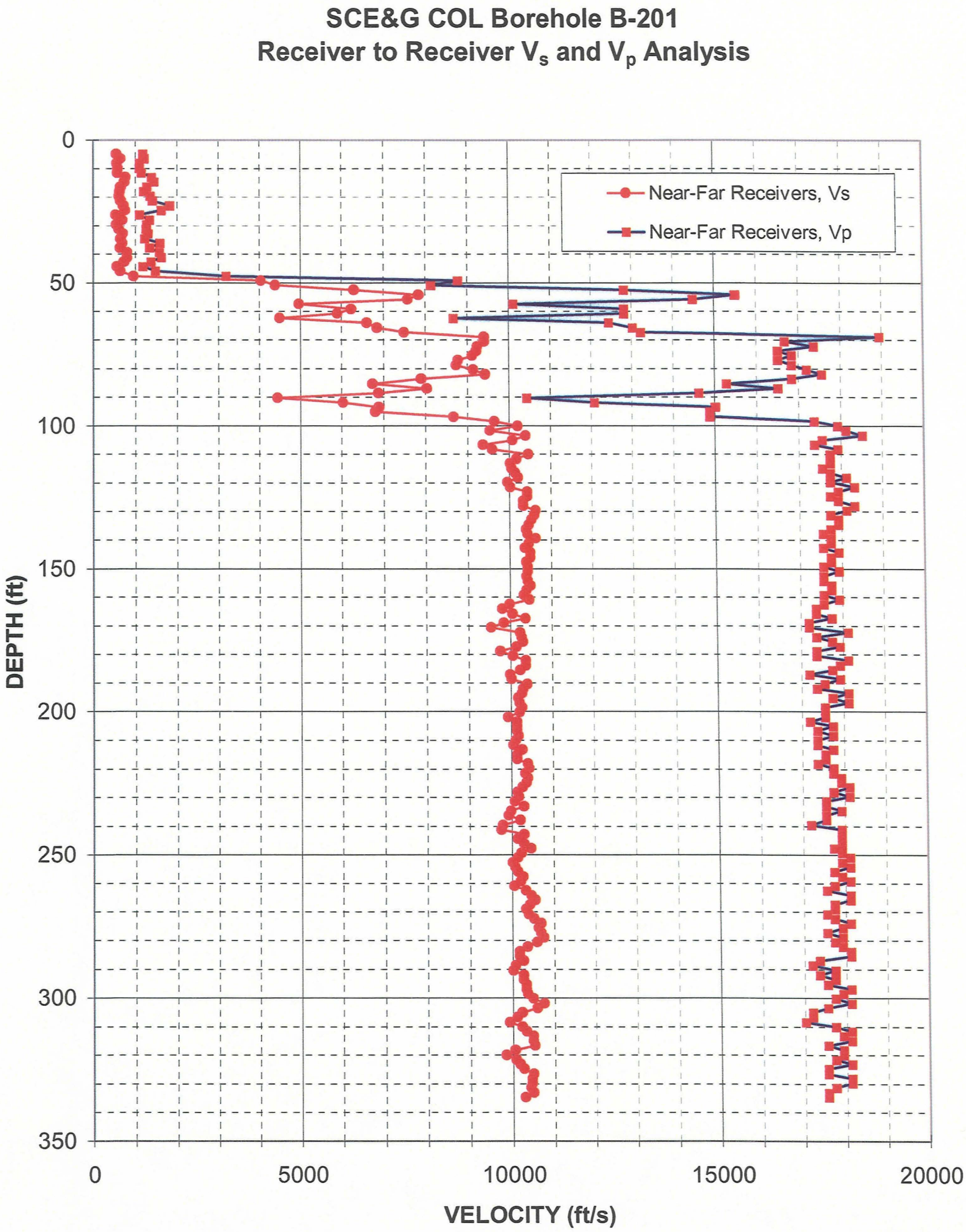


Figure 5: Boring B-201, Suspension R1-R2 P- and $S_H$-wave velocities

| Depth (feet) | $V_s$ (feet/sec) | $V_p$ (feet/sec) |
|---|---|---|
| 4.9 | 560 | 1170 |
| 6.6 | 640 | 1210 |
| 8.2 | 560 | 1100 |
| 9.8 | 580 | 1090 |
| 11.5 | 570 | 1150 |
| 13.1 | 760 | 1390 |
| 14.8 | 740 | 1440 |
| 16.4 | 650 | 1270 |
| 18.0 | 630 | 1200 |
| 19.7 | 620 | 1360 |
| 21.3 | 650 | 1410 |
| 23.0 | 720 | 1810 |
| 24.6 | 750 | 1620 |
| 26.3 | 540 | 1100 |
| 27.9 | 680 | 1330 |
| 29.5 | 550 | 1260 |
| 31.2 | 600 | 1250 |
| 32.8 | 700 | 1300 |
| 34.5 | 650 | 1220 |
| 36.1 | 680 | 1590 |
| 37.7 | 640 | 1340 |
| 39.4 | 800 | 1570 |
| 41.0 | 800 | 1620 |
| 42.7 | 720 | 1380 |
| 44.3 | 560 | 1180 |
| 45.9 | 640 | 1470 |
| 47.6 | 950 | 3170 |
| 49.2 | 4040 | 8770 |
| 50.9 | 4390 | 8130 |
| 52.5 | 6290 | 12820 |
| 54.1 | 7840 | 15500 |
| 55.8 | 7580 | 14490 |
| 57.4 | 4980 | 10100 |
| 59.1 | 6230 | 12820 |
| 60.7 | 5900 | 12820 |
| 62.3 | 4500 | 8660 |
| 64.0 | 6600 | 12440 |
| 65.6 | 6840 | 13020 |
| 67.3 | 7490 | 13230 |
| 68.9 | 9390 | 18940 |
| 70.5 | 9390 | 16670 |
| 72.2 | 9230 | 17360 |
| 73.8 | 9210 | 16500 |
| 75.5 | 9110 | 16840 |
| 77.1 | 8770 | 16500 |
| 78.7 | 8730 | 16840 |
| 80.4 | 9130 | 17180 |
| 82.0 | 9420 | 17540 |
| 83.7 | 7900 | 16840 |
| 85.3 | 6730 | 15290 |
| 86.9 | 8030 | 16500 |
| 88.6 | 6870 | 14620 |
| 90.2 | 4440 | 10420 |
| 91.9 | 6030 | 12080 |
| 93.5 | 6890 | 15020 |
| 95.1 | 6800 | 14880 |
| 96.8 | 8660 | 14880 |
| 98.4 | 9630 | 17360 |
| 100.1 | 10190 | 17920 |
| 101.7 | 9520 | 18120 |
| 103.4 | 10380 | 18520 |
| 105.0 | 10070 | 17540 |
| 106.6 | 9360 | 17360 |
| 108.3 | 9580 | 17920 |
| 109.9 | 10450 | 17730 |
| 111.6 | 10160 | 17730 |
| 113.2 | 10010 | 17730 |
| 114.8 | 10040 | 17540 |
| 116.5 | 10130 | 17730 |
| 118.1 | 10190 | 18120 |
| 119.8 | 9950 | 17730 |
| 121.4 | 10010 | 18320 |
| 123.0 | 10420 | 17920 |
| 124.7 | 10420 | 17730 |
| 126.3 | 10320 | 17920 |
| 128.0 | 10320 | 18320 |
| 129.6 | 10620 | 18120 |
| 131.2 | 10580 | 17730 |
| 132.9 | 10520 | 17920 |
| 134.5 | 10450 | 17920 |
| 136.2 | 10380 | 17730 |
| 137.8 | 10420 | 17540 |
| 139.4 | 10620 | 17730 |
| 141.1 | 10450 | 17730 |
| 142.7 | 10350 | 17540 |
| 144.4 | 10480 | 17920 |
| 146.0 | 10480 | 17730 |
| 147.6 | 10380 | 17730 |
| 149.3 | 10420 | 17540 |
| 150.9 | 10420 | 17920 |
| 152.6 | 10380 | 17540 |
| 154.2 | 10420 | 17540 |
| 155.8 | 10480 | 17730 |
| 157.5 | 10380 | 17730 |
| 159.1 | 10320 | 17540 |
| 160.8 | 10450 | 17920 |
| 162.4 | 9980 | 17540 |
| 164.0 | 9800 | 17360 |
| 165.7 | 10040 | 17360 |
| 167.3 | 10350 | 17730 |
| 169.0 | 9830 | 17180 |
| 170.6 | 9520 | 17180 |
| 172.2 | 10220 | 18120 |
| 173.9 | 10260 | 17360 |
| 175.5 | 10290 | 17730 |
| 177.2 | 10130 | 17920 |
| 178.8 | 9750 | 17360 |
| 180.5 | 10040 | 17360 |
| 182.1 | 10350 | 18120 |
| 183.7 | 10350 | 17920 |
| 185.4 | 10220 | 17730 |
| 187.0 | 9980 | 17180 |
| 188.7 | 10010 | 17920 |
| 190.3 | 10380 | 17540 |
| 191.9 | 10290 | 17360 |
| 193.6 | 10260 | 18120 |
| 195.2 | 10160 | 17730 |
| 196.9 | 10190 | 18120 |
| 198.5 | 10260 | 17540 |
| 200.1 | 10190 | 17540 |
| 201.8 | 9920 | 17540 |
| 203.4 | 10130 | 17180 |
| 205.1 | 10130 | 17730 |
| 206.7 | 10130 | 17360 |
| 208.3 | 10160 | 17730 |
| 210.0 | 10100 | 17360 |
| 211.6 | 10040 | 17360 |
| 213.3 | 10260 | 17730 |
| 214.9 | 10130 | 17540 |
| 216.5 | 10130 | 17540 |
| 218.2 | 10380 | 17360 |
| 219.8 | 10420 | 17730 |
| 221.5 | 10320 | 17730 |
| 223.1 | 10380 | 17920 |
| 224.7 | 10350 | 17920 |
| 226.4 | 10260 | 18120 |
| 228.0 | 10130 | 17730 |
| 229.7 | 10160 | 18120 |
| 231.3 | 10070 | 17540 |
| 232.9 | 10290 | 17540 |
| 234.6 | 9980 | 17920 |
| 236.2 | 9920 | 17540 |
| 237.9 | 10190 | 17540 |
| 239.5 | 9780 | 17180 |
| 241.1 | 9750 | 17920 |
| 242.8 | 10290 | 17920 |
| 244.4 | 10130 | 17920 |
| 246.1 | 10290 | 17920 |
| 247.7 | 10450 | 17730 |
| 249.3 | 10220 | 17920 |

Table 5. Boring B-201, Suspension R1-R2 depths and P- and $S_H$-wave velocities

| Depth (feet) | $V_s$ (feet/sec) | $V_p$ (feet/sec) |
|---|---|---|
| 251.0 | 10130 | 18120 |
| 252.6 | 10010 | 17920 |
| 254.3 | 10070 | 18120 |
| 255.9 | 10130 | 17730 |
| 257.6 | 10260 | 17920 |
| 259.2 | 10190 | 18120 |
| 260.8 | 10040 | 17730 |
| 262.5 | 10320 | 17540 |
| 264.1 | 10450 | 18120 |
| 265.8 | 10550 | 18120 |
| 267.4 | 10420 | 17730 |
| 269.0 | 10320 | 17730 |
| 270.7 | 10380 | 17540 |
| 272.3 | 10520 | 17730 |
| 274.0 | 10680 | 18120 |
| 275.6 | 10620 | 17920 |
| 277.2 | 10680 | 17540 |
| 278.9 | 10750 | 17920 |
| 280.5 | 10580 | 17730 |
| 282.2 | 10350 | 17920 |
| 283.8 | 10160 | 18120 |
| 285.4 | 10160 | 18120 |
| 287.1 | 10260 | 17360 |
| 288.7 | 10070 | 17180 |
| 290.4 | 10010 | 17730 |
| 292.0 | 10260 | 17360 |
| 293.6 | 10260 | 17730 |
| 295.3 | 10320 | 17540 |
| 296.9 | 10320 | 18120 |
| 298.6 | 10350 | 17920 |
| 300.2 | 10480 | 17730 |
| 301.8 | 10750 | 18120 |
| 303.5 | 10580 | 17540 |
| 305.1 | 10220 | 17180 |
| 306.8 | 10100 | 17180 |
| 308.4 | 9920 | 17010 |
| 310.0 | 10220 | 17730 |
| 311.7 | 10320 | 18120 |
| 313.3 | 10480 | 17920 |
| 315.0 | 10480 | 18120 |
| 316.6 | 10520 | 17540 |
| 318.2 | 10040 | 17920 |
| 319.9 | 9830 | 17920 |
| 321.5 | 10070 | 17730 |
| 323.2 | 10160 | 18120 |
| 324.8 | 10260 | 17540 |
| 326.4 | 10480 | 17540 |
| 328.1 | 10450 | 18120 |
| 329.7 | 10450 | 18120 |
| 331.4 | 10420 | 17730 |
| 333.0 | 10480 | 17540 |
| 334.7 | 10290 | 17540 |

Table 5, Continued. Boring B-201, Suspension R1-R2 depths and P- and $S_H$-wave velocities

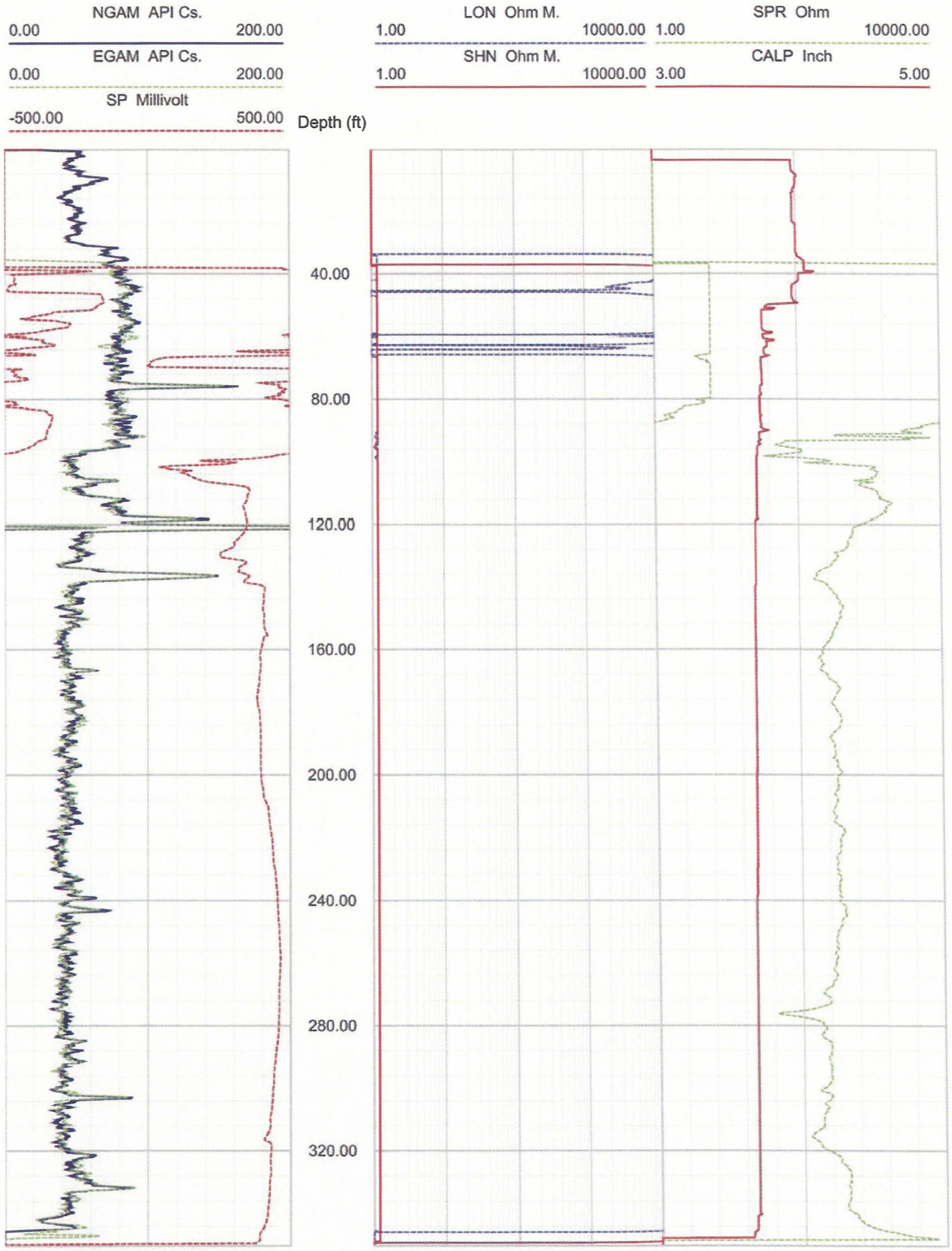


Figure 6. Boring B-201, Caliper, Natural gamma, Resistivity and SP logs

Deviated borehole in orthographic projection, viewed from N45


Borehole: B-201
Zone from: 3.440 - 348.720ft
North ref is true
Mean deviation: 4.00 to N33.23
End coordinates .....
North: 20.362
East : 13.339
Down : 347.739
Azimuth of end: N33.23
Distance start-end: 24.342ft
Viewpoint: N45
Data extrapolated to the surface from 3.440ft
23 Jun 2006

Figure 7. Boring B-201, Deviation Projection (dimensions in feet)

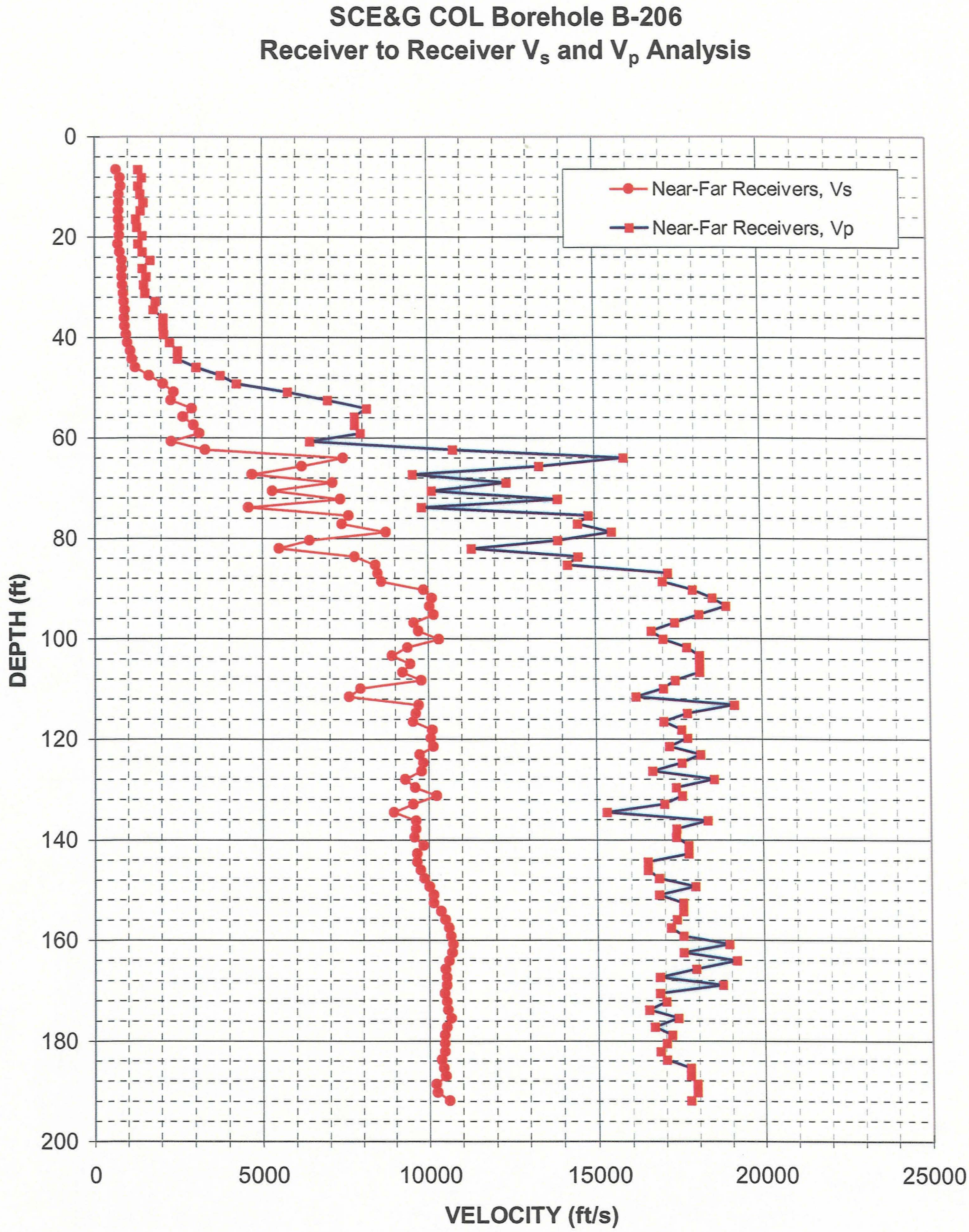


Figure 8. Boring B-206, Suspension R1-R2 P- and $S_H$-wave velocities