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ENVIRONMENTAL RESTORATION PROGRAM

Additional Borehole Geophysical Logging at Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee

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Energy Systems Environmental Restoration Program
ORNL Environmental Restoration Program

Additional Borehole Geophysical Logging at Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee

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ACRONYMS

BGS	below ground surface
BHTV	borehole televiewer
BNI	Bechtel National, Inc.
ORNL	Oak Ridge National Laboratory
QA/QC	quality assurance/quality control
RI	remedial investigation
SP	self-potential
SPR	single-point resistance
TM	technical memorandum
VDL	variable density acoustic log
WAG	waste area grouping

EXECUTIVE SUMMARY

This technical memorandum describes the borehole geophysical logging performed at selected coreholes at Waste Area Grouping 1 between March and November 1991 in support of the remedial investigation. The primary objectives of the borehole geophysical logging program were to (1) identify fractured bedrock zones and identify those fractured bedrock zones participating in active groundwater flow, (2) correlate the fractured intervals with the regional stratigraphy described by Lee and Ketelle (1988), and (3) further characterize local bedrock geology and hydrogeology and gain insight about the bedrock aquifer flow system. A secondary objective was to provide stratigraphic correlations with existing logs for coreholes CH001 through CH005.

Fractured bedrock zones and active or open fractures were identified in all coreholes logged. The fracture identification and analysis process was intended to distinguish between open or active fractures participating in active groundwater flow and closed or inactive fractures that are partially or completely filled (such as with calcite mineralization) and do not support groundwater circulation. Most of the fractures identified are bedding plane. Fracture occurrence varies with the different units of the Chickamauga Group; the greatest density of fractures and active fractures occurs in the upper 150 ft of stratum cored. Fractures actively contributing to groundwater flow were also identified, and direction of fluid movement within fractures was identified for those coreholes with flowmeter data.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE

This technical memorandum (TM) documents the locations, methodology, equipment used, and results of the borehole geophysical logging performed on selected coreholes as part of the remedial investigation (RI) of Waste Area Grouping (WAG) 1. The results of this study will be used to help develop the conceptual model of groundwater flow at WAG 1, which in turn will be used to identify contaminant transport pathways.

This TM is organized into three sections and six attachments. The remainder of this section discusses the objectives of the logging program and summarizes the logging program as conducted. Section 2 describes specific log types, logging tools and equipment, logging procedures, equipment decontamination, health and safety measures, and data output format. Section 3 presents a discussion of findings based on evaluation of the borehole geophysical logs. Attachments 1 through 6 are the actual logs for each corehole logged; the Environmental Sciences Division at Oak Ridge National Laboratory (ORNL) maintains the raw data files for these logs.

1.2 OVERVIEW

1.2.1 Logging Program Objectives

Five deep coreholes [generally 184 to 490 ft below ground surface (BGS)] were drilled to assess groundwater quality, hydrogeology, and geology at depth within the bedrock aquifer. (Packer tests were also completed in these coreholes; results are reported under separate cover.) Following drilling, all five boreholes were geophysically logged. Corehole FT10, drilled by ORNL in the 1970s, was also logged.

The primary objectives of the borehole geophysical logging program were to (1) identify fractured bedrock zones and determine which fractures were participating in active groundwater flow, (2) correlate the fractured intervals with the regional stratigraphy described by Lee and Ketelle (1988), and (3) further characterize local bedrock geology and hydrogeology and gain insight about the bedrock aquifer flow system. A secondary objective was to provide stratigraphic correlations with existing logs for coreholes CH001 through CH005 (Lee and Ketelle 1988).

The fracture identification and analysis process was intended to distinguish between open or active fractures participating in active groundwater flow and closed or inactive fractures that are partially or completely filled (such as with calcite mineralization) and do not support groundwater circulation.

1.2.2 Logging Program Description

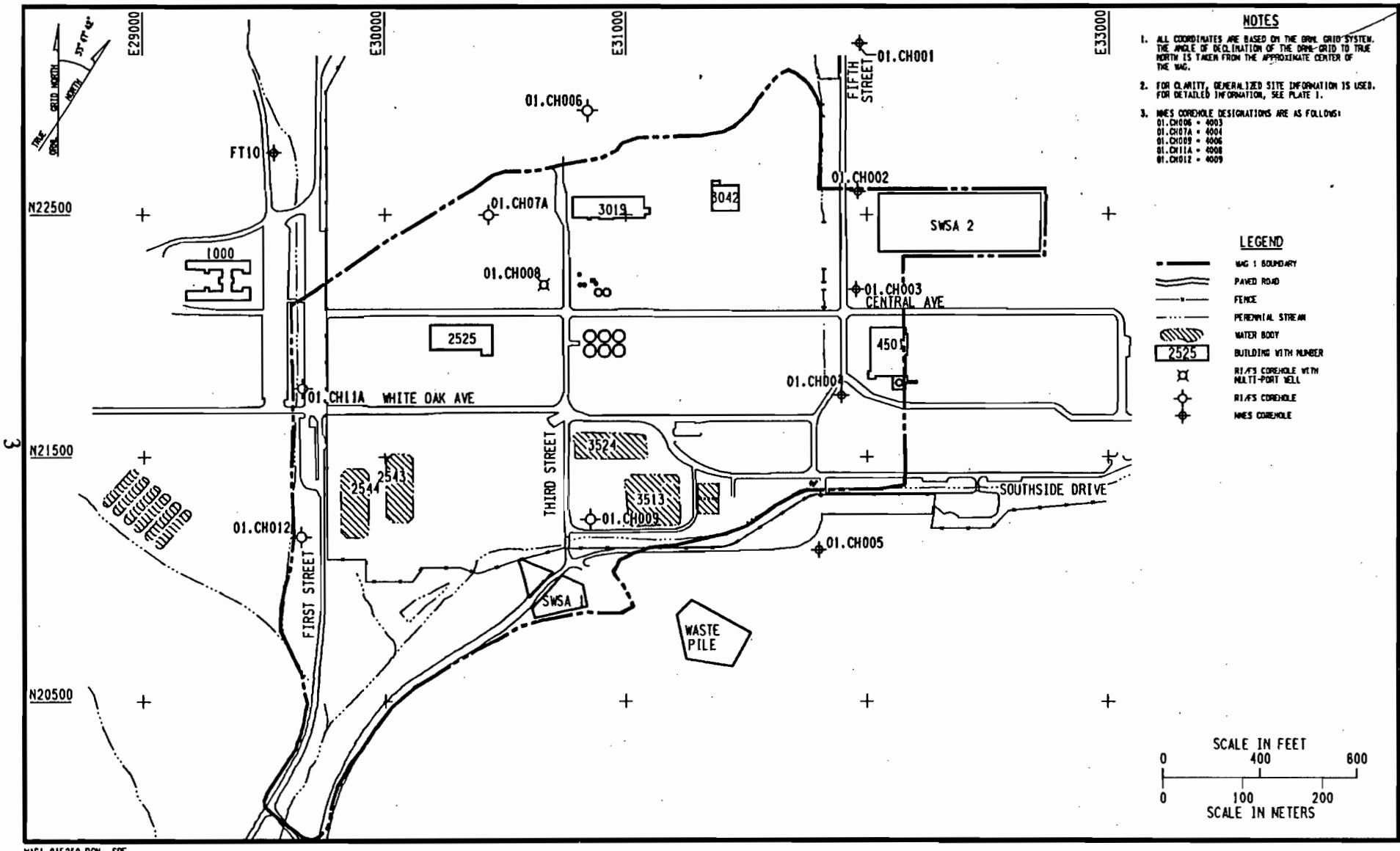
Borehole geophysical logging was completed on five water-filled coreholes drilled in association with the WAG 1 RI (CH006, CH07A, CH009, CH11A, and CH012) and one corehole (FT10)

drilled for a previous investigation. With the exception of FT10 and CH006, the coreholes are within the WAG 1 boundary. FT10 is northwest of WAG 1, approximately 50 ft west of First Creek and north of West End Circle. Figure 1 shows the locations of the WAG 1 coreholes logged and the coreholes Lee and Ketelle (1988) used in defining the subsurface geology at ORNL. Plate 1 of their publication was used for stratigraphic correlation with the coreholes studied in this investigation.

Initially, it was intended that the coreholes would be cored to a depth not to exceed 500 ft and the full suite of geophysical logs would be run on the open coreholes using ORNL's logging capabilities. The criterion used to terminate drilling on a particular hole was a decrease in the number of fractures observed during drilling. Logging occurred intermittently from March 19 through November 7, 1991. Table 1 summarizes pertinent location and borehole information for the six holes logged. ORNL performed borehole televiewer and deviation surveys to total depth on all six coreholes, with three exceptions. Deviation surveys were not performed on FT10 and CH012 because the inclinometer was out for repairs, and the borehole televiewer survey was only run to 138 ft BGS on CH11A. Table 2 summarizes the scope of the logging program performed as part of the WAG 1 RI. Table 3 summarizes the intervals logged by ORNL.

No geophysical logs were run in CH008 because that hole was completed at a relatively shallow depth to allow for installation of a multiport well.

Ambient flowmeter surveys were run on CH009 and CH012 (Moore and Young 1991). Flow was measured through the length of the borehole through which it was anticipated, but not for the entire length of the borehole, as time constraints were imposed on use of the TVA equipment. Additionally, not all coreholes could be logged, due to denied access, corehole condition (e.g., suspected of containing natural oil), and schedule constraints. The opportunity to use the flowmeter was not part of the original scope of work, and investigators tried to log as much corehole as possible within the constraints of the equipment availability.



WAG1 01F260.DGN SRF, 2/17/92

Fig. 1. Corehole locations.

Table 1. WAG 1 borehole information

Corehole[a]	ORNL grid location North (ft)	ORNL grid location East (ft)	Ground elevation[b] (ft)	Surface casing elevation[c] (ft)	Driller's total depth[d] (ft)	Surface casing depth[d] (ft)
CH006	22919.02	30839.76	870.1	871.83	404.0	70.8
CH07A	22499.99	30430.54	851.9	853.77	184.6	34.6
CH009	21244.27	30850.47	781.3	784.80	404.7	17.0
CH11A	21784.79	29656.75	786.6	788.98	282.5	15.3
CH012	21171.97	29651.05	777.5	780.11	490.4	17.0
FT10	22750.55	29540.00	807.6	809.50	403.5	75.0

[a]Energy Systems designations for these coreholes:

CH006 = 4003
CH07A = 4004
CH009 = 4006
CH11A = 4008
CH012 = 4009

[b]As measured at ground surface (not top of concrete pad).
[c]At time of logging.
[d]Below ground surface.

Table 2. WAG 1 borehole geophysical logging program summary

	Corehole					
Log type	CH006	CH07A	CH009	CH11A	CH012	FT10
Natural gamma ray	X	X	X	X	X	X
Caliper	X	X	X	X	X	X
Temperature	X	X	X	X	X	X
Differential temperature	X	X	X	X	X	X
Self-potential	X	X	X	X	X	X
Borehole televiewer	X	X	X	X	X	X
Variable density acoustic log	X	X	X	X	X	X
Short/long normal resistivity	X	X	X	X	X	X
Single-point resistance	X	X	X	X	X	X
Deviation survey	X	X	X	X	N/A	N/A
4-Pi density	X	X	X	X	X	N/A
Neutron	X	X	X	X	X	X
Sonic	X	X	X	X	X	X
Borehole flowmeter	N/F	N/A	X	N/F	X	N/A

Notes:
X–Logging performed by ORNL.
N/A–Logging not performed.
N/F–Logging not performed due to overhead interference such as power lines or downhole interference such as installed packers.

Table 3. WAG 1 borehole geophysical logging intervals

	Corehole depth (ft)					
Log type	CH006	CH07A	CH009	CH11A	CH012	FT10
Natural gamma ray	0.0–403.2	0.0–183.4	0.0–404.1	0.0–281.2	0.0–489.8	0.0–400.3
Caliper	53.1–402.6	0.0–183.0	0.0–403.9	0.1–281.4	0.0–490.4	0.0–389.9
Temperature	0.0–400.6	0.0–181.2	0.0–400.0	0.0–283.7	0.0–490.0	0.0–403.5
Differential temperature	1.0–399.6	1.0–180.2	1.0–399.0	1.0–283.7	5.0–485.0	72.3–397.6
Self-potential	0.0–403.2	0.0–183.4	0.0–404.1	0.0–281.2	0.0–486.4	0.0–369.9
Borehole televiewer	70–400	50–180	15–395	13–138	15–485	80–390
Variable density acoustic log	45.4–400.1	46.0–180.0	0.0–400	3.4–279.1	0.0–486.1	72.8–397.6
Short/long normal resistivity	77.9–402.7	41.9–182.7	31.4–400.1	37.0–283.5	29.4–490.4	63.0–400.5
Single-point resistance	41.9–399.7	18.3–174.1	0.0–405.1	0.0–280.4	0.0–480.3	0.0–391.6
Deviation survey	60–400	0.0–182	0.0–400	0.0–280	N/A	N/A
4-Pi density	29.8–401.8	11.5–182.0	0.8–401.6	0.0–281.0	0.0–488.8	N/A
Neutron	28.7–402.2	0.0–182.5	0.0–402.3	0.0–281.0	0.0–489.0	0.0–400.3
Sonic	45.4–400.1	46.0–180.0	0.0–400	3.4–279.1	0.0–486.1	72.8–397.6
Borehole flowmeter	N/A	N/A	140–345	N/A	20–330	N/A
Geologist's log	0.0–404.0	0.0–184.6	0.0–404.7	0.0–282.5	0.0–490.4	N/A

Note: All depths shown are measured in feet below ground surface.
N/A–Log not prepared or run.

2. METHODOLOGY

A full suite of geophysical logs was run on each open hole as shown in Table 2, with exceptions as noted. The following paragraphs describe each method employed.

The natural gamma ray log measures naturally occurring gamma emissions (potassium, uranium, and thorium) associated with clay minerals present in the formation surrounding the borehole. Gamma ray logs are excellent indicators of shale content and, therefore, lithology and are widely used for correlation purposes. Gamma ray logs can be used with both cased and open boreholes.

Caliper logs record the average diameter (and shape) of the borehole with depth; the tool used was a three-arm summation caliper. Caliper logs are useful in confirming well construction, identifying bridging and washouts, locating large open fractures and other cavities, and correcting log responses from other tools.

The temperature log continuously records the temperature of fluids in the borehole as the tool is lowered. Temperature logs are widely used to identify water-bearing zones, liquid levels, fluid entry points, and zones of lost circulation encountered during drilling.

The differential temperature log is used to identify and graphically display minute temperature anomalies that are often not apparent from the gradient temperature log displays. The slope of the temperature at each point is computed for a given spacing; 4-ft spacing was used for this log.

The self-potential (SP) log, also known as spontaneous potential, uses a graphic plot of the natural direct voltage potential differences measured between a downhole electrode and a fixed reference electrode at the surface. The SP log is measured in millivolts and is used to identify lithology, bed thickness, and formation water salinity.

The borehole televiewer (BHTV) log makes use of an acoustic tool that produces a 360° view of the wellbore by measuring the minute changes in sonic wave amplitude caused by the lithology and discontinuities in the formation exposed in the borehole. The radial output image is magnetometer-oriented so that bedding, fracture dip angle, and direction can be determined. Generally, fractures discordant to bedding are indicated by dark bands. Bedding plane fractures may be difficult to recognize. The BHTV data are recorded as a series of photographs.

The variable density acoustic log (VDL) is primarily used to identify fractured intervals; it can also be used as a cement bond log to assess annular grouting.

The short/long normal resistivity log (also known as 16-64 normal logs) measures shallow and deep voltage potentials at electrodes spaced at 16 in. and 64 in. from a current-emitting electrode in the tool to determine formation water quality. The short (16-in.) normal curve displays resistivity near the borehole, and the long (64-in.) normal curve records resistivity further from the borehole within the formation.

The single-point resistance (SPR) log measures the apparent resistance of in situ materials (water and rock) in the borehole. Because SPR logging has a very small radius of investigation, it is very sensitive to changes in borehole fluid resistivity and hole diameter and can be used to identify formation discontinuities such as fractures or thin bed changes. For this reason, it is often used for determining stratigraphic boundaries and changes in lithology and identifying fractures in highly resistive bedrock.

The deviation (or directional) survey records borehole inclination and azimuths continuously against depth to determine how straight a borehole is and to determine the bottom hole location at total depth. Sharp deviations in the borehole may indicate changes in formation dip and faulting and fracturing.

The 4-Pi density log, also known as the gamma-gamma density log, measures the bulk density of the formation exposed in the borehole. It is not borehole-compensated. A detector in the tool counts the rate of backscattered radiation emitted into the formation from a cesium-137 source within the tool. The bulk density of the formation is proportionally related to the attenuation and backscattering of the gamma photons by the formation. This tool is widely used for lithology determinations in coreholes.

The neutron log measures the hydrogen ion concentration in the exposed formation. A detector in the tool measures the attenuation and backscattering of neutrons emitted from an americium and beryllium (Am/Be) source within the tool by hydrogen ions present in the formation. In water-filled holes, the neutron log measures fluid-filled porosity (often considered as total porosity) and rock composition. Above the water table, the neutron log is used to measure moisture content. Neutron logs can be used in both cased and open boreholes.

The sonic or acoustic velocity log measures the transmission rate and attenuation of pulsed acoustic energy transmitted through the borehole fluid and adjacent rocks. The attenuation of the sonic signal is related to the porosity and lithology of the formation. Because sonic wave propagation through the formation is confined to solid rock, vugs and fractures are bypassed. Cycle-skipping is caused by excessive signal attenuation by formation, fracture, and/or fluid discontinuities or equipment malfunctions. Typically, cycle-skipping is interpreted as an indicator of fracturing.

ORNL performed a borehole flowmeter survey for two of the coreholes (Moore and Young 1991). These surveys measure flow within the corehole at the ambient natural gradient. The flowmeter device, which consists of two chloride electrodes and a magnetic coil inside a hollow cylinder, measures the interaction of the conductor and magnetic field as a voltage. To complete the circuit, some dissolved solids in the fluid being measured are necessary. A positive voltage measurement indicates flow up the hole.

The geologist's log included a description of fractures per foot. A plot of these fractures with depth was prepared for all coreholes installed by the Bechtel Team. A broad interpretation of fractures was used in preparing the geologist's log. Project Procedure 1643, "Rock Coring," defines fractures as "core separations along any discontinuity (joints, bedding, faults, foliation) in the rock mass." Care was taken not to count mechanical breaks from drilling or sleeve handling as fractures.

2.1 EQUIPMENT AND PROCEDURES

ORNL used truck-mounted logging rigs with on-board microcomputers capable of providing on-site data processing. All tools were stored in tubes contained within the logging rig. All sources were tightly controlled and (when not in use) were stored in locked pigs (radioactive transport shield) mounted within the logging rigs. Long handling tools were used to insert and remove the Am/Be and cesium-137 sources. ORNL logging equipment used a 3-Ci Am/Be-241 neutron source and a 125-mCi cesium-137 gamma source.

All logging was performed in accordance with standard ORNL logging procedures in effect at the time. Before the six deep coreholes were logged, the ORNL logging unit was used to log CH002, located within the main plant area and designated the calibration hole for all borehole logging on the Oak Ridge Reservation.

With the exception of the BHTV logs, all geophysical logs were digitally recorded in increments of 0.10 ft. The borehole geophysical logs were produced as hard copies, and log data were provided in digital (ASCII) form.

Several runs were required to complete the full logging suite shown in Table 2. Logging tools were generally run in the following order: temperature/differential temperature (downhole); natural gamma ray; SP; caliper; resistivity; sonic; neutron; gamma-gamma density; long/short normal resistivity; BHTV; and deviation survey.

Temperature and differential temperature logs were recorded first to minimize disturbance of the ambient temperature profile by multiple trips of the logging tools. Temperature and differential temperature were recorded at a rate of 5 ft/min as the first tool was lowered into each borehole, except that the differential temperature for FT10 was recorded at a rate of 7 ft/min. Sufficient time (e.g., a minimum of 5 days for CH11A, but more typically 3 weeks or more) had elapsed between the completion of corehole drilling and borehole logging to allow the borehole temperature to reach equilibrium.

All other logs were run uphole as each tool was removed from the borehole. Uphole logging was performed at a rate of 7 to 18 ft/min; the most common logging speed was 15 ft/min. The sonic and variable density logs were run at 7 to 8 ft/min.

BHTV photos were obtained for each 5-ft interval, composited as a single log, and reproduced with depth annotations.

Flowmeter logging was performed by setting a packer around the interval to be tested so that all flow passed through the center hole in the flowmeter (Moore and Young 1991). The packer had to be reset each time a new interval was tested. Logging was terminated when the flow dropped off dramatically with depth. Flowmeter logging occurred in October and November 1991.

Coreholes were logged approximately in the order in which they were finished. However, FT10, drilled in the 1970s, was logged last, after fluid was circulated in the borehole to clean it out.

2.2 EQUIPMENT DECONTAMINATION

The decontamination procedure consisted of collecting and analyzing wipe samples of the probes and cable between coreholes and, if no contamination was detected, moving on to the next corehole. If contamination was detected, the rig and all equipment would be steam cleaned/decontaminated in accordance with Project Procedure 1250, "Equipment Decontamination and Release for Unrestricted Use."

As the tools were removed from the borehole, they were wrapped in plastic sleeves, taped shut, and staged on plastic sheeting until logging was completed for each well. Upon completion of the logging, all tools were wipe-sampled and returned to the tool storage tubes on the logging rig if clean.

When the nuclear source tools were removed from the borehole, the external casings of the cesium-137 and Am/Be sources were cleaned using a laboratory detergent and water wash and distilled water rinse while still attached to the tool. The sources were then quickly removed from the tool and returned to the pig using a long-handled tool. Total exposure time was minimal (45 to 60 s).

3. LOG EVALUATION

Borehole geophysical logs for coreholes CH006, CH07A, CH009, CH11A, CH012, and FT10 are included as Attachments 1 through 6, respectively. For each corehole, the logging data are presented in the following order: summary table of fractures identified, composite figure of geophysical logs and fracture intervals, VDLs, BHTV logs, deviation surveys, and (for CH009 and CH012) flowmeter data and graphs.

In fulfillment of the scope of the objectives for borehole geophysical logging, logs run for this study were evaluated to identify fracture intervals and water-bearing fracture zones, to provide further insight regarding the hydrogeologic system, and to provide correlations with other logged wells in WAG 1 (Lee and Ketelle 1988).

3.1 FRACTURE IDENTIFICATION

3.1.1 Diagnostic Log Responses

Fractures were first identified using the geologist's log, the BHTV, and the VDL. Interpretation of the VDL was based on subjective observation of signal disintegration. The fractures were then characterized by one or more diagnostic log responses.

Of the geophysical logs available, the most useful for identifying active fractures were the temperature and differential temperature logs and the available flowmeter logs. Shifts in the temperature logs, especially if the shifts coincided with a shift in the caliper log, were used as presumptive indications of open fractures supporting groundwater circulation; peaks in the differential temperature logs were also used as indications of fluid entry. The geologist's logs were consulted to check for any notation concerning calcite mineral in filling of the fracture(s) noted at that depth.

Those intervals displaying temperature and differential temperature log responses supported by other log responses were interpreted as significant active or open fractures. When flowmeter data were available, fluid entry or exit through the fractures could be identified, provided that a sufficient head differential existed to drive flow; without the flowmeter data, only fluid movement could be identified. Active fracture intervals are identified in Table 4.

The sonic log and the inverse of the neutron log are related to lithology in that their traces are near-perfect overlays of the lithologically controlled gamma ray trace; therefore, they did not provide additional data on fracture occurrence and characteristics. The inverses of the sonic log and the SPR, SP, and neutron logs were in many cases nearly identical and thus did not provide much additional information.

Borehole televiewer. Fractures were readily identifiable on BHTV photo logs as dark bands that generally followed dip and bedding features. BHTV logs were available for all coreholes except CH11A (BHTV available only to 138 ft BGS). The BHTV-identified fractures correlated well with

Table 4. Fracture intervals with active groundwater flow (ft BGS)

Corehole					
CH006	FT10	CH07A	CH11A	CH009	CH012
50–52	50–54	37.6–41.6	23–27	33–37	30.4–33.4
61.8-63.8	85-88	50-59.1	28-35	45-48	34.4-37.4
70.8-75.8	93-96	64.1-67	39-42	54-58	44.4-46.4
82-90.8	102-106	69.1-73.1	43-46	59-64	65-68.4
92.8-94.8	112-116	76.1-78.1	48-51	66-68	86-88.4
98.8-108.5	120-122	82.1-88.1	63-67	70-72	95-97
124.5-127.5	141-143	89.1-92.1	83-87	75-79	101-103
128-5-135.1	160-164	93.1-98	94-98	85-89	126-129.2
136.1-140.5	168-172	109-113	101-104	94-97	141-145
144.1-152	173-186	125-9-128.9	112-115	98-100	151-154.2
157-163	186-190	129.9-131.9	120-123	123-125	181-183
166.1-171.1	192-196	133-136.9	124-130	129-133	228.1-230.1
198.1-200.1	200-207	137.9-139.9	141-143	146-148	249-251
217.1-219	214-218	155-158.6	231-234	150-154	260-262
223.1-225	236-241	160.6-169.6	278-280	158-161	286-289
226.1-229	249-253			179-183	299-304.7
247.4-252.4	259-265			195-198	319.7-322.7
294-297	273-277			211-214	332.7-337
323-327	293-299			237-240	377.7-379.7
386-389	306-312			258-261	412.7-415.7
	319-322			332-334	440.4-444.4
	345-349				463-468
	360-363				481.4-485.4

the fractures noted in the geologist's logs. The dark bands apparent on the BHTV photos reflect both healed (mineral-filled) and open fractures, but this determination could not be made from the BHTV logs. Comparison with the geologist's logs showed that most of the fractures were open.

Variable density acoustic log. Fractured intervals were readily identifiable on the VDL because the third and fourth waveforms attenuated in fractured intervals. These logs correlated well with the geologist's logs and the BHTV and provided useful confirmation. They were also useful for determining the overall fractured nature of individual units of the Chickamauga Group and of different lithologies identified within the units (Lee and Ketelle 1988).

Temperature. Temperature anomalies were identified as distinct spikes and baseline shifts in the normal temperature gradient. In some cases, rather than increasing with depth, the temperature showed marked cooling with depth before returning to gradient. Temperature responses (indicating fluid entry points) generally displayed good correlation with BHTV and VDL.

Differential temperature. Differential temperature responses were identified as distinct spikes that correlated with the BHTV and VDL log responses and often with the caliper and deviation survey responses.

The software package Grapher was used to expand the horizontal scale for both temperature and differential temperature logs. Expanded scales more clearly showed subtle shifts in temperature or differential temperature peaks that may not be apparent on the smaller scale of the figures in the attachments.

Caliper. Individual open fractures can sometimes be identified using caliper logs. Caliper increases, in part, confirmed other log responses to fracturing and were principally used as secondary evidence.

Self-potential. In intervals identified as fractured using other log responses, SP signatures generally showed sharp but minor decreases followed by an increase. In some cases, large baseline shifts not readily associated with lithology were noted; these shifts correlated well with temperature anomalies.

Single-point resistance. In massive resistive rocks, SPR anomalies are usually seen as sharp decreases in ohms. Because of the interbedded nature of the bedrock at WAG 1, fracture anomalies were not discernible.

Fractures per foot. The fractures-per-foot log, available for all coreholes but FT10 (which has no geologist's log) showed a response that was generally correlatable to lithology when used in conjunction with other geophysical evidence. The fractures-per-foot log was prepared by the on-site geologist on the basis of visual inspection and measurement of the fractures in the core. Fractures that appeared very fresh or exhibited other features indicating that they may have been caused by the drilling process were not counted for the fractures-per-foot log.

Borehole flowmeter survey. Ambient flowmeter surveys are available for CH009 and CH012 for the approximate interval between 20 and 340 ft BGS. The 223- to 338-ft interval had upward

flow in CH009 (ranging from 0.084 to 0.161 gpm), and the 60- to 302-ft interval had upward flow in CH012 (ranging from 0.091 to 0.124 gpm). About 80% of the depth intervals measured that had upward flow also had fractures noted on either the geologist's log, the BHTV log, or the VDL. However, not all intervals with numerous fractures were noted as increased upward flow on the flowmeter log.

Deviation surveys. When used in conjunction with other logs, deviation surveys were useful in some cases for confirming fractured intervals. In many cases, the same depth interval would show as fractured on more than one plot for a particular corehole.

3.2 CHICKAMAUGA GROUP AND FRACTURE OCCURRENCE

All the coreholes drilled for this study penetrated the middle Ordovician Chickamauga Group, which consists generally of interbedded limestone and siltstone. The eight mappable units of the Chickamauga Group (Units A through H as described in subsequent sections), as defined by Stockdale (1951) and slightly modified by Lee and Ketelle (1988), are used in this TM. Unit A is the oldest and Unit H is the youngest penetrated. Figure 2 shows the units penetrated in each corehole. To facilitate comparisons among cores and between cores and geophysical logs, thicknesses reported from both this study and Lee and Ketelle (1988) are structural thicknesses in downhole ft BGS, as opposed to bedding thickness.

3.2.1 Unit A

Lee and Ketelle (1988) characterize Unit A (penetrated only in CH001 in their study) as consisting of thick, interbedded sections of calcareous siltstone and calcarenite and as one of the most lithologically diverse units of the Chickamauga Group. In this study Unit A was penetrated in CH006 (at depths ranging from 327 ft to the total corehole depth of 404 ft) and in FT10 from 366 ft to the total corehole depth of 403.5 ft. In CH006, Unit A consists of silty, fine-to-medium-grained, fossiliferous limestone with chert nodules and beds and calcareous siltstone, which exists as stringers to medium beds.

Unit A, easily identified on the gamma ray log, is represented by a sharp drop in the gamma ray count from an average of 50 cps in Unit B to an average of 25 cps. The gamma ray traces of the upper 55 to 60 ft of Unit A in FT10 and CH006 correlate very well, and moderately well with the composite log of Unit A in CH001 [Plate 1 of Lee and Ketelle (1988)].

Unit A is relatively unfractured compared with the other units penetrated during this study. Fractures noted in the geologist's log for CH006 were predominantly bedding plane fractures (dips of 24–40° south, based on the ORNL grid system), followed by two dip-normal fracture sets and one high-angle fracture surface. Calcite mineral ingrowth of the fractures was noted in many cases, and fractures ranged from slightly open to tight. The fractures-per-foot log for CH006 shows more unfractured intervals in Unit A and fewer fractures per foot than the overlying Unit B. The VDL logs for both FT10 and CH006 also show thicker unfractured intervals and smaller fractured intervals. An example of a fractured interval is the 300- to 306-ft interval in the VDL for CH006. The BHTV logs for both CH006 and FT10 show the relative absence of fractures; the superior quality of the CH006 log most graphically displays the unfractured nature of the formation.

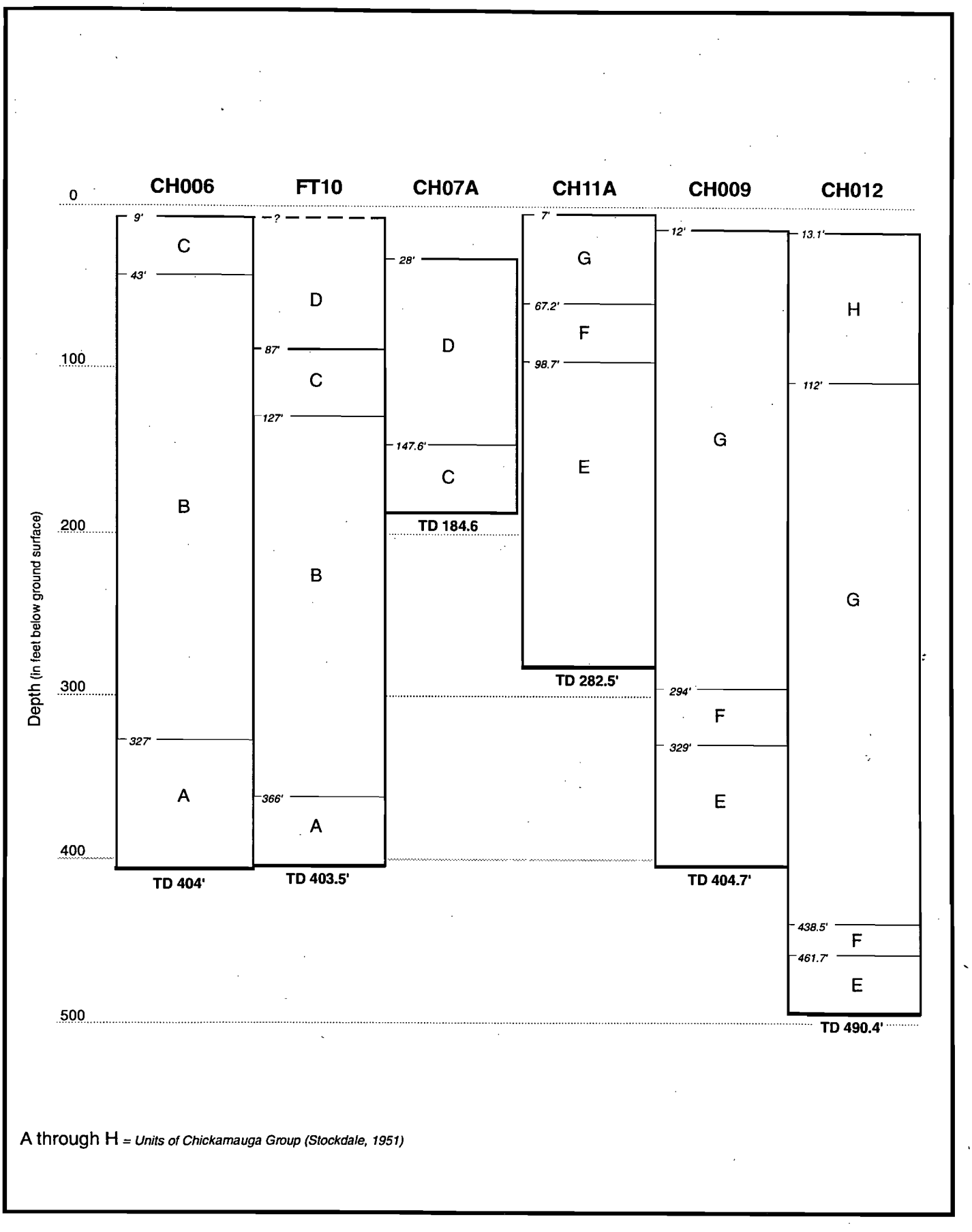


Fig. 2. Borehole stratigraphy.

5.33F 6066.91

Other evidence for fracturing found on the caliper, temperature, differential temperature, SP, and deviation surveys is presented by corehole in Tables A1.1 and A6.1. A summary of the fracture intervals, including the active fractures, found in both coreholes is presented in Fig. 3; Table 4 shows depth intervals of the active fractures supporting groundwater circulation. Both Fig. 3 and Table 4 were derived from Tables A1.1 through A6.1 by arbitrarily excluding fractured intervals of 1 ft or less and by considering the preponderance of evidence in the tables before deciding if a fracture was actively supporting groundwater circulation. Unit A has relatively few fractures, and relatively few of those are active, based on the infrequent, slight shifts in the temperature and differential log responses and on the numerous notations of calcite infilling in the geologist's log for CH006.

3.2.2 Unit B

Unit B, penetrated in CH001 and CH002 of Lee and Ketelle (1988), is characterized in general as a massive, maroon, calcareous, and shaley siltstone with many fine- to medium-grained calcarenite beds. In this study Unit B is penetrated at depths of 43 to 327 ft in CH006 and from 127 to 366 ft in FT10. The geologist's log for CH006 describes the unit as "predominantly a massive bedded, calcareous, maroon siltstone with several light gray, fine- to medium-grained limestone beds."

Unit B has a distinctive gamma ray trace that is correlatable between CH006, FT10, and the composite log of Lee and Ketelle (1988). The gradually increasing silt content in the upper 30 to 35 ft of the unit is shown on the gamma ray trace as a gradually increasing gamma ray count (beginning at 15 to 20 cps) that remains at an average of 50 cps for the remainder of the unit. The massive nature of the unit is reflected in the generally consistent nature of the gamma ray trace.

Unit B is one of the more fractured units encountered in this study; fractures per foot range from none to seven. Dip-normal fracture sets were found more frequently in the upper 100 ft of this unit than in any other unit in this study and were typically slightly open to open. Low-angle fracture surfaces were more common in the lower portion of the unit and were usually open. Bedding plane fractures were the most frequently occurring and were generally slightly open to open with no calcite infilling.

Different types of fractures are not distinguishable on the VDLs for CH006 and FT10, but the pattern of fracturing is. VDLs from both coreholes show consistent fracturing throughout the thickness of the unit, with fractured and unfractured intervals interlayered. The BHTV logs show the same pattern of intermixed fractured and unfractured intervals. A typical example is found in the interval between 95 and 135 ft in CH006 on the BHTV. Fractures are visible in discrete zones between 99 and 102 ft, 105 and 107 ft, 113 and 115 ft, and 128 and 133 ft. The rock between these zones is relatively free of fractures.

Tables A1.1 and A6.1 summarize the other evidence for fracturing and for identifying the open fractures, and Fig. 3 shows the distribution of the fractured intervals. The active fractures in Unit B occur throughout the unit but appear to be slightly more prevalent in its upper portion (Table 4). The lack of calcite mineralization noted on the geologist's log and the frequent temperature and differential temperature shifts were the principal criteria used to determine which fractures were supporting groundwater circulation.

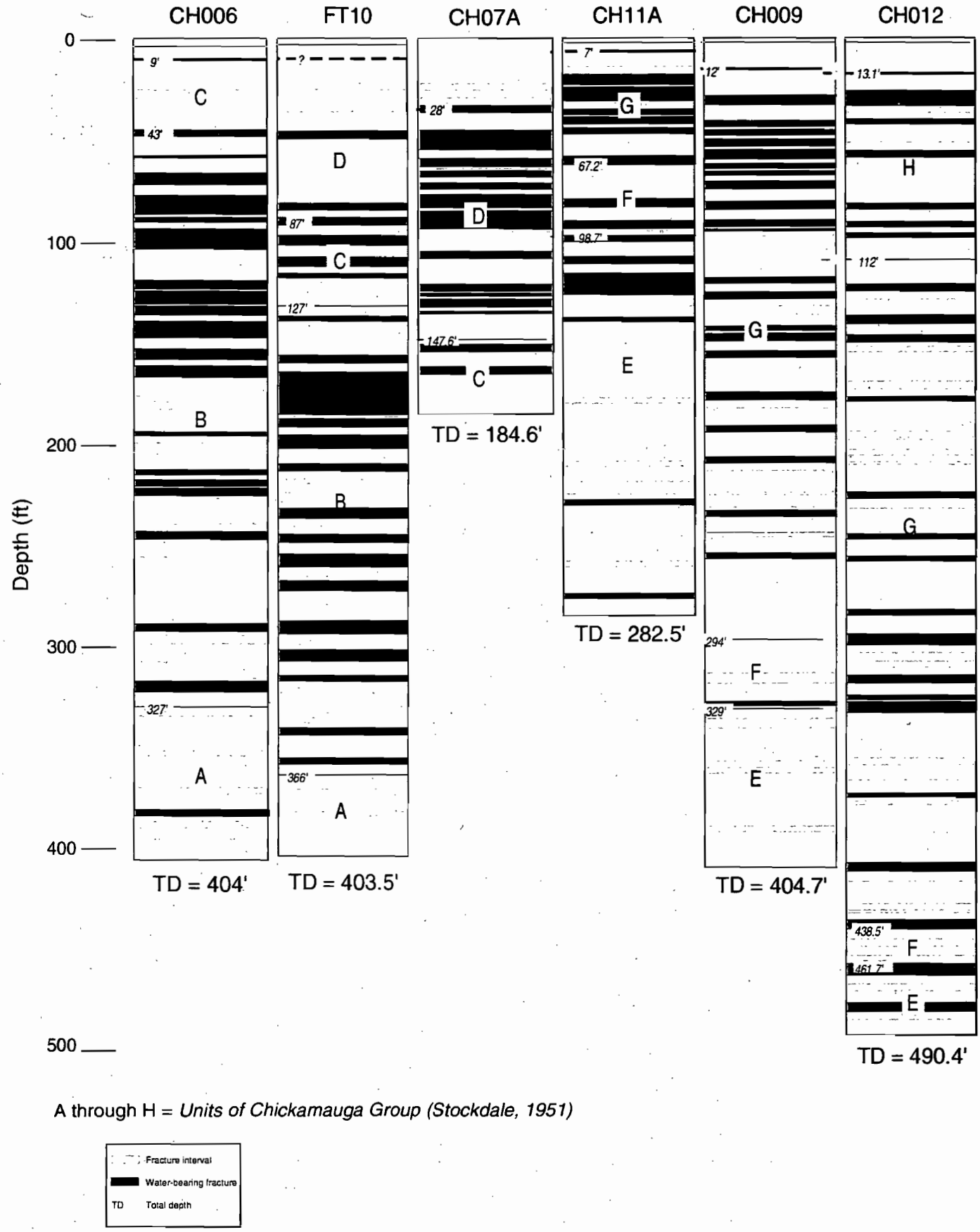


Fig. 3. Occurrence of fractures and active fractures.

5.33F 6066.90

3.2.3 Unit C

Approximately 40 ft of Unit C occur in CH006, FT10, and CH07A, ranging in depths from 9 to 43 ft, 87 to 127 ft, and 147.6 to 184.6 ft, respectively. Lee and Ketelle (1988) describe Unit C as interbedded fine- to medium-grained, stylolitic, unfossiliferous, crystalline calcarenite, and dark gray calcareous siltstone; small chert nodules are common. The geologist's log for CH006 describes Unit C as a massive bedded, fine- to medium-grained, hard, stylolitic limestone with some thin beds of siltstone and some cherty zones in the lower portions of the unit. In contrast, Unit C in CH07A is interbedded siltstone and limestone; the siltstone consists of 50 to 75% of the interval, and the limestone contains chert beds and nodules.

The gamma ray traces for CH006, CH07A, and FT10 and the composite log in Lee and Ketelle (1988) correlate only partially, due in part to the variable lithology and to different portions of the unit occurring in each corehole. The gamma ray traces for CH006 and CH07A seem to correlate with the lower unit shown on Plate 1 of Lee and Ketelle. The FT10 gamma ray log correlates only moderately well with the other data.

Unit C is moderately fractured, with the fractures ranging from none to five per foot. Most fractures are of bedding plane type, ranging in dip from 26° to 39° from horizontal and ranging from tight to open. The VDLs for the three coreholes show evidence of fracturing, but it is not possible to correlate among the coreholes for this unit with this log. The BHTV logs for CH07A and FT10 verify that most of the fractures are the bedding plane type.

Tables A1.1, A2.1, and A6.1 summarize the other geophysical evidence for fracturing and for identifying the active fractures, and Fig. 3 shows the distribution of the fractured intervals. The fractures contributing to groundwater flow in Unit C occur more frequently in FT10 (Table 4) based on a comparison of the number of fractures occurring within Unit C for the three coreholes. No calcite was noted on the geologist's log, and the frequent temperature and differential temperature shifts were the principal criteria used to assess which fractures were active.

3.2.4 Unit D

Unit D is comprised of diverse limestone lithologies such as dense, medium-grained, stylolitic calcarenite; bird's-eye micrite; and nodular limestone. Bedded and nodular chert frequently occurs as a distinctive feature (Lee and Ketelle 1988). In this study Unit D is found in FT10 (to a depth of 87 ft; the upper contact is not known) and in CH07A (from 28 to 147.6 ft). The limestone lithologies noted on the geologist's log include thin to massive-bedded, micritic- to medium-grained, nodular and fossiliferous, with stylolites, chert nodules, and thin chert beds. Thinly bedded siltstone, bioturbated, soft and fresh, also occurs in the upper portion of Unit D.

The gamma ray trace for Unit D is a characteristic pattern of upper and lower intervals of low gamma ray counts with the middle portion of the trace containing two distinctive peaks. The most complete pattern for the unit is found on Plate 1 of Lee and Ketelle (1988) and on CH07A, which correlate well. Unit D is the uppermost unit encountered in FT10; based on the correlation between this gamma ray trace and the 70- to 145-ft interval in CH07A, only the lowermost portion of Unit D is encountered in FT10.

Unit D is moderately fractured in FT10 and contains numerous fractured intervals in CH07A. Fractures range from none to seven per foot in CH07A. Most fractures are bedding plane (dips of 24° to 37° south) ranging from slightly open to tight. A few other types of fractures are noted, such as low- and high-angle and dip-normal fractures, some of which are partially healed and almost filled with calcite crystals. At approximately 90 ft, a 1-ft cavity was encountered.

Two strong fracture intervals shown on the VDL for CH07A (66 to 69 ft and 89 to 91 ft) correspond to intervals of high fractures per foot (three to six) on the geologist's log. The BHTV log for CH07A clearly shows these strongly fractured intervals and also shows that the frequency of fractures decreases with depth. Only 7 ft of BHTV log were photographed for FT10.

Tables A2.1, A4.1, and A6.1 summarize the other evidence for fracturing and for identifying the open fractures; Fig. 3 shows the distribution of the fractured intervals. Most of the fractures in Unit D in CH07A are active, and more active Unit D fractures occur in CH07A than in the other two coreholes that penetrated Unit D. This is based on the relatively prominent baseline shifts in the CH07A temperature log, the strong peaks on the differential temperature log, and the relative lack of calcite filling or healing of the fractures.

3.2.5 Unit E

Unit E was partially to totally penetrated in CH11A (98.7 to a total depth of 282.5 ft), CH009 (329 to total depth of 404.7 ft), and CH012 (461.7 to 490.4 ft) in this study. Unit E was also encountered in CH008, which was not logged. As described by Lee and Ketelle (1988), the unit is 350 ft thick; due to its diverse nature, it is divided into three separate lithologies. The middle and upper lithologies of Lee and Ketelle are represented in CH11A. They describe the middle lithology (about 56 ft thick) as consisting of unfossiliferous siltstone with light gray limestone laminae, and the geologist's log from the interval 194 to 245 ft in CH11A describes a shale with thin, light-gray limestone interbedding. A massive, fine- to medium-grained calcarenite characterizes the uppermost lithology of Lee and Ketelle; the interval from 98.7 to 194 ft in CH11A consists of limestone with shale partings and stringers.

The gamma ray log for CH11A correlates well with the composite gamma ray log from Lee and Ketelle; the peak patterns of the middle and upper lithologies are clearly matched on the two traces. Based on the strong correlation between the gamma ray traces of CH009 and CH11A, only the upper 75 ft of the upper lithology of Unit E were represented in CH009 before total depth was reached. In CH012, only the upper 30 ft of Unit E were penetrated before total depth was reached.

Unit E is a poorly to moderately fractured unit, and most of the fractures occur in its upper limestone member. However, in CH008 up to seven fractures per foot were identified in Unit E. Fractures most commonly range from none to three per foot and are bedding plane fractures (25° to 37° south) that are slightly open to open. In CH11A, few bedding plane fractures had any evidence of calcite minerals and very few were tight. In CH009 and CH012, the bedding plane fractures (dip 23° to 45° south) were generally noted as tight in the upper portions of the unit but with no evidence of calcite mineral.

The VDLs for Unit E show sequences of undisturbed rock interlayered with thicknesses of fractured rock. An example of this pattern can be seen on the VDL for CH11A in the intervals from 119 to 122 ft and 141 to 143 ft (disturbed) and from 122 to 141 ft (undisturbed). This pattern is reasonably apparent in the portion of Unit E in CH11A BHTV logs available, while the BHTV log for CH009 shows the decreasing fracture frequency with depth in this unit.

Tables A3.1, A4.1, and A5.1 summarize the other evidence for fracturing and for determining the active fractures; Fig. 3 shows the distribution of the fractured intervals. Most of the fractures in the upper lithology of Unit E in CH11A are open, and most active Unit E fractures occur in CH11A. This is based on the relatively prominent shifts in the CH11A temperature log (e.g., at approximately 85, 103, and 175 ft), the strong peaks on the differential temperature log, the relative lack of calcite filling or healing of the fractures, and the notation in the geologist's log that most of the fractures were open.

3.2.6 Unit F

Unit F is a laminated, maroon, calcareous, and shaley siltstone with thinly bedded limestone and argillaceous limestone (Lee and Ketelle 1988). In this study it ranges from 23 to 35 ft thick and occurs in CH009 (294 to 329 ft BGS), CH11A (67.2 to 98.7 ft BGS), and CH012 (438.5 to 461.7 ft BGS). It is described in this study as a maroon, calcareous shale, thin to massive bedded, interbedded with a shaley limestone, and micritic to fine-grained.

The gamma ray trace for Unit F correlates extremely well among each of the above coreholes and very well with the composite log in Lee and Ketelle (1988). It is characterized by two strong peaks of 50 cps or greater in the upper and lower portions of the unit and a single peak of about 45 cps between the two major peaks.

Unit F is a poorly to moderately fractured interval; fractures per foot range from none to six, and most commonly less than three. The most common type of fracture in this unit in all three coreholes is a bedding plane fracture (dips of 18° to 40° south). The fractures in CH11A are primarily slightly open to open, and the fractures in the deeper occurrences of this unit are mostly tight. No evidence of calcite growth was noted. The VDLs for the three coreholes show a pattern of thin intervals of fractures interlayered with thin intervals of unfractured material. The BHTV logs show the lightly fractured nature of this unit, with a slight increase in fracture density at the base of the unit. Upward flow was recorded throughout this unit, based on the flowmeter data for CH009, with good correlation among changes in flow rates and open fractures identified on the BHTV, VDL, and geologist's logs.

Tables A3.1, A4.1, and A5.1 summarize the other evidence for fracturing and for determining the active fractures; Fig. 3 shows the distribution of the fractured intervals.

3.2.7 Unit G

Portions of Unit G were encountered in three coreholes, ranging in thickness from 60 to approximately 289 ft. In CH11A it occurs from 7 to 67.2 ft BGS, in CH009 from 12 to 294 ft BGS, and in CH012 from approximately 150 to 438.5 ft BGS. Lee and Ketelle (1988) identified 319 ft

of this variable unit, which they subdivided into three different lithologies. The lower 116 ft consists of a fine- to medium-grained, fossiliferous nodular limestone; the middle 68-ft-thick lithology consists of fine-grained, dense calcarenite, which is less fossiliferous than the lithology below. The upper 135 ft are thinly interbedded siltstone and limestone grading upward to nodular and ribbon limestone. These general lithologies are mirrored in CH012 (the corehole with the most complete section of Unit G), except that the thicknesses are approximately 110, 60, and 120 ft for the lower, middle, and upper lithologies, respectively.

The composite gamma ray trace on Plate 1 of Lee and Ketelle (1988) and the gamma ray logs from CH009, CH11A, and CH012 strongly correlate, in that each of the three lithologies can be clearly identified on each log and between logs. The characteristic pattern consists of a lower interval with gamma counts averaging 10 to 25 cps, followed by the intermediate lithology with gamma counts averaging 5 to 10 cps, and the upper lithology with counts of 15 to 30 cps. All three lithologies are represented in CH012, the lower two and most of the upper are identified in CH009, and only the lower portion of the lower lithology is found in CH11A.

Unit G is one of the more fractured units in this study, with the number of fractures related to the three different lithologies. The highest number of fractures occurs in the upper lithology; in CH009, the range is from zero to eight fractures per foot. These fractures are generally bedding plane (dips of 16° to 45° south) ranging from slightly open to tight, although a few low-angle and high-angle fractures were noted. The middle lithology of Unit G averages two to three fractures per foot, and the lower lithology has up to five. The fractures of the middle lithology are essentially all bedding plane (dips of 18° to 40° south), slightly open to tight, and the fractures in the lower lithology are mostly bedding plane (dips of 10° to 60° south), slightly open to tight, with a few high- and low-angle fractures. The only evidence of calcite mineralization was noted in CH11A.

The VDLs also clearly show the differences in the fractured nature of the three different lithologies, as each lithology can be identified on the VDL based on the nature of the fractures. The upper unit (150 to 268 ft in CH012 and 0 to 109 ft in CH009) shows a fracture pattern of distinct sequences of unfractured rock interbedded with fractured intervals. The middle unit (268 to 329 ft in CH012 and 109 to 179 ft in CH009) as a whole appears to be more massive, with fewer, thinner fractured intervals; this corresponds to the fracture-per-foot log for that interval. The lower unit is fractured more than the middle and less than the upper unit, and the sequences of unfractured rock are slightly less distinct.

Flowmeter logs for CH009 and CH012 show that the majority of the active flow zone intervals occur in Unit G. About 80% of the depths with fluid entry points correspond to fractured intervals in the BHTV, VDL, and geologist's logs.

Tables A3.1, A4.1, and A5.1 summarize the other evidence for fracturing and for determining the active fractures, and Fig. 3 shows the distribution of the fractured intervals. Most of the Unit G fractures occur in CH009 and CH012. Fractures participating in groundwater flow are frequent and occur most often in CH009.

3.2.8 Unit H

Lee and Ketelle's study (1988) only penetrated the lower 28 ft of Unit H, which was characterized by interbedded calcareous siltstone and fine-grained limestone. In this study Unit H is the uppermost unit encountered in CH012, with a gradational contact to Unit G at approximately 150 ft. In CH012 the unit is characterized by finely interbedded limestone and siltstone, with some bioturbation.

The gamma ray trace correlates well with the lower 28 ft of the section available on Plate 1 from Lee and Ketelle (1988). The gamma ray count averages 25 cpm for this unit, with peaks up to 35 cpm.

Unit H is moderately fractured, with fracture incidence ranging from zero to five fractures per ft. The greatest number of fractures per foot occur in the upper 70 ft of the unit. Bedding plane fractures are the most common (dips of 22° to 40°), ranging about equally from tight to open; calcite filling is also common. Other fractures encountered in this unit include high- and low-angle fractures and one dip-normal, dip-parallel set. The VDL shows the more fractured nature of the upper unit and may show the transition to Unit G at about 150 to 154 ft. The BHTV log is of poor quality but does suggest more fractured intervals in the upper portion of the unit. Flowmeter data show upward flow between 31 and 150 ft (ranging from 0.078 to 0.099 gpm); correlation is good among the flowmeter depth intervals measuring changes in flow and the BHTV, VDL, and geologist's logs.

Table A5.1 summarizes the other evidence for fracturing and for determining the active fractures, and Fig. 3 shows the distribution of the fractured intervals.

3.3 ACTIVE FLOW ZONES

Coreholes CH009 and CH012. Flowmeter data available for CH009 and CH012 were used in conjunction with the temperature and differential temperature logs to identify the active flow zones in these coreholes. The flowmeter results are presented in Moore and Young (1991); some of the results are discussed here to complement the results of the geophysical surveys. Discrete points of entry and exit could be identified from the flowmeter logs. The temperature and differential temperature logs for coreholes without flowmeter data were used to identify active flow zones. It was not possible to distinguish between entry and exit points without a flowmeter log for these coreholes.

One flowmeter survey was run in CH012 from a depth of 20 to 330 ft. A plot of the data is found on Fig. A5.1. Negligible flow was recorded from 330 to 315 ft BGS. At 310 ft, a fluid entry point occurs, and a second, stronger fluid entry point occurs between 302 and 304 ft. This fluid entry point is also reflected on the temperature log, which shows a shift to the left (indicative of gaining flow) and on the differential temperature log. Moving up the borehole, a gradual increase in flow is recorded to a depth of about 200 ft. This is reflected on the temperature log as a relatively straight trace.

An exiting zone gradually begins between 180 and 200 ft BGS and is reflected on the temperature log by a gradual shift to the right (indicative of losing flow). The fluid loss becomes greater between

180 and 160 ft, when the flow rate drops from 0.114 to 0.099 gpm. A general loss of water continues until a depth of 30 ft. This upward losing zone is also reflected on the temperature log by a gradual shift to the right. Between 30 and 31 ft, a major exit of fluid occurs (flow is 0.078 gpm at 31 ft and 0.003 gpm at 30 ft). The temperature log also reflects this exit by the sharp shift to the right (indicative of losing flow) beginning at 31 ft. Negligible flow exists for the remainder of the borehole.

Portions of Units G and H were within the interval over which flow was logged. In general, the logged portion of Unit G was an upward gaining zone, and the portion of Unit H that was logged was an upward losing zone. The exit zone, especially between 180 and 160 ft, corresponds roughly to the gradational contact between these two units.

Two flowmeter logs were run on CH009 due to operational problems: between 20 and 340 ft (on October 16, 1991) and 140 and 345 ft (on November 5, 1991). A plot of both flowmeter logs is shown on Fig. A3.1.

For the October log, the first discrete entry point is between 320 and 340 ft BGS, when the flow increases from 0.008 to 0.159 gpm. A zone of positive upward flow persists until 180 ft, when an exit point occurs between 180 and 170 ft. Fluid entry begins again between 170 and 160 ft, although slightly less than the deeper flow zone, and continues until a discrete exit point between 134 and 135 ft (flow drops from 0.118 to 0.007 gpm). This exit point is obvious on the temperature log, as reflected by a sharp shift to a higher temperature, and on the differential temperature log, which shows a prominent peak. The remainder of the borehole has essentially negligible flow.

For the November log, fluid entry first occurs between 339 and 338 ft BGS. Upward flow continues to occur until between 223 and 221 ft, when the flow drops from 0.087 to 0.035 gpm. A second entry point occurs between 220 and 190 ft, with a gradual exit beginning between 170 and 150 ft.

Portions of Units E, F, and G are included in the two flowmeter logs for CH009. The lowermost point of fluid entry occurs at or near the upper contact of Unit E, and Unit F is entirely within a zone of upward flow. Unit G has discrete points of both fluid entry and exit.

Other coreholes. Because flowmeter data were not available for the remaining coreholes (due to hole conditions, denied access, and schedule constraints), differentiation between fluid entry and exit points is not possible. However, the temperature and differential temperature logs and, in some cases, the caliper logs, may be used to identify some of the areas with more obvious fluid entry or exit points.

An active fracture occurs in CH006 at approximately 325 ft BGS, which coincides with the formation contact between Units A and B. Other active fractured intervals occur at about 283 to 286 ft and between 220 and 229 ft BGS. Based primarily on the temperature log, a significant entry or exit point occurs between about 150 and 170 ft BGS. From 70 to about 150 ft, an overall fractured interval is encountered, based on the steps on the temperature log and the peaks on the differential temperature log.

Fluid entry or exit points are obvious on the caliper, temperature, differential temperature, and BHTV logs for CH07A. Intervals on the caliper log indicative of fractures, which are also visually obvious on the BHTV, at about 49-51, 66-67, 72-73, 89-90, and 162-163 ft BGS. Shifts in the temperature and differential temperature logs are also noted at these intervals, with the most dramatic shifts occurring at 49-51 and 89-90 ft.

Three active flow zones apparent on the temperature and differential temperature logs for CH11A occur at approximately 85, 105, and 180 ft BGS. The sharp shift to the left on the temperature log may be a reflection of a "dead" hole, where the fluid is cooling to ambient conditions.

The lowermost entry or exit point in FT10 is at a depth of approximately 348-350 ft BGS. Other points of entry or exit occur at about 276, 203, 159, and 93 ft BGS. A major point of fluid movement occurs at approximately 45-50 ft BGS.

3.4 SUMMARY OF OBSERVATIONS

The objective of identifying fractured bedrock zones and active fractures within those zones was accomplished for all coreholes to varying degrees, depending on types of data available. Geologist's logs, BHTV surveys, acoustic logs (VDL and velocity), electric logs (SPR and SP), and caliper logs all provide information on the presence and orientation of fractures and fracture zones. These logs do not provide objective information as to whether the fractures are open, healed, or partly healed, although subjective interpretations of fracture character can sometimes be made.

Temperature logs, both gradient and differential, proved to be the most sensitive indicators of fractures with associated groundwater circulation. Temperature gradient shifts associated with flow below the threshold detection limit of the flowmeter tool can be detected.

As noted previously, a temperature gradient shift at a depth coinciding with fracture identified on geologist's, BHTV, acoustic, electric, or caliper logs was interpreted as a positive indication of an open fracture. Temperature logs do not provide definitive data on either the rate or direction (up or down) of groundwater flow in the borehole, although subjective interpretations or inferences can sometimes be made. A flowmeter log is required to make accurate, quantitative measurements of interborehole flow and to determine the vertical flow direction.

Both active and inactive fractures occur in all coreholes, with some differences between coreholes and with depth. In general, it appears that both types of fractures are more common in the upper 200 ft of stratum penetrated. Coreholes CH006, CH07A (only completed to 185 ft), CH009, and CH11A seem to have the greatest number of active fractures in the upper 200 ft. However, more data are available for the upper 200 ft because not all coreholes were drilled to depths of 400 or more ft. For those deeper coreholes (Fig. 3) it appears that fractures are less frequent and active fractures occur less often with depth (except for FT10, which has an approximately even distribution with depth).

In all coreholes, the most common type of fracture is bedding plane, although there is an unusual number of dip-normal and dip-parallel fracture sets in the upper 150 ft of CH006.

CH012 and FT10 have the greatest number of fractures with depth. This reflects the stratigraphic position of Units B and G within these coreholes, as these units are two of the more fractured units encountered in this study. In contrast, CH11A shows a marked decrease in number of fractures and active fractures with depth. Fractured intervals were discussed relative to the regional stratigraphy described by Lee and Ketelle (1988).

Fracture occurrence seems to be controlled by lithology in that fractures are more common in the carbonate or shaley carbonate sequences. The relative abundance of fractures in the upper 200 ft may also be controlled by weathering, due to preferential enlargement of bedding planes from weathering.

Data from available flowmeter logs provided additional insight to the bedrock aquifer flow system. Flowmeter logs available for CH009 and CH012 include only portions of Units E, F, G, and H because schedule constraints only provided for logging the zones where flow was anticipated. These logs show that the majority of the active flow zone intervals occur in Unit G, which is an upward gaining zone. Unit G also has discrete points of both fluid entry and exit. Unit F is entirely within a zone of upward flow, and the portion of Unit H that was logged is an upward losing zone. Fluid entry and exit points correspond to formational contacts between Units E and F in CH009, and between Units G and H in CH012. Fluid entry and exit points can be identified but not distinguished in the coreholes without flowmeter logs.

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ATTACHMENT 1

CH006—GEOPHYSICAL AND GEOLOGIC DATA

Table A1.1. Summary of fractures identified in corehole CH006

Depth BGS (ft)[a]	Geologic unit	Fractures per ft[b]	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments[c]
31.1-32.1	C	5								26°, BP, open; fracture ⊥ to bedding plane, open; 15°, fracture surfaces, open
32.1-33.1		2							X	30°, BP, open
37.9-38.9		2								0°, fracture surface, open; ⊥ to bedding, fracture surface, open
44.8-45.8	B	3								5-10°, fracture surface, open
45.8-46.8		2		***						Fracture surface, open; 35°, BP, open
50-51				X			X			
51-52				X	***					
54-55				X						
57-58				X		X				
59-60				X			X			
61.8-62.8		3				X	X	***		30-35°, BP, sl. open
62.8-63.8		2		X		X				30-35°, BP, open
67.8-68.8		3	***	X		X	X			31°, BP, sl. open; dip-normal, dip-parallel fracture set, 30° and ⊥ to bedding, partially healed to sl. open
70.8-71.8		3		X					X	Dip-normal, dip-parallel fracture set; open
71.8-72.8		2								⊥ fracture
72-73			?				X			
73.5-74.5			?	X		B	X			
74.8-75.8						X				20-25°, fracture surface, open
77-78			?			X	X			
78-79			?	X		X	X			
81-82			X							
82-83			X		X	X				
83.8-84.8		3	X	X	X		X			Dip-normal, dip-parallel fracture set, 32° and ⊥ to bedding; 25°, BP, open
84.8-85.8		2		X			X			Dip-normal, dip-parallel fracture set, 25° and ⊥ to bedding, open
85.8-86.8		2	X							Dip-normal, dip-parallel fracture set, 30° and ⊥ to bedding, open

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Table A1.1 (continued)

Depth BGS (ft)[a]	Geologic unit	Fractures per ft[b]	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments[c]
86.8-87.8		3					X			Dip-normal, dip-parallel fracture set, 20° and ⊥ to bedding, open; 15°, fracture surface, open
87.8-88.8		2								Fracture surface, ⊥ to bedding, tight
88.8-89.8		4	X	X			X			Dip-normal, dip-parallel fracture set, 30° and ⊥ to bedding, sl. open; 30°, BP, open
89.8-90.8		5	X				X			Dip-normal, dip-parallel fracture set, 30° and ⊥ to bedding, open, 30°, BP, open
92.8-93.8		3	X	X		X	X			Dip-normal, dip-parallel fracture set, 31° and ⊥ to bedding, sl. open to tight
93.8-94.8		2	X	X	X		X			⊥ to bedding, fracture surface, open; 40°, BP, open
98.8-99.8		2	X	X			X	X		Dip-normal, dip-parallel fracture set, open to sl. open
101.5-102.5		2	X	X	X	B	X	X		15°, fracture surface, tight; ⊥ to bedding; sl. open
103.5-104.5		2	?	X						35°, BP, open
104.5-105.5		4		X						12-33°, BP, tight to open; dip-normal, dip-parallel fracture set, open
105.5-106.5		3	X	X		X	X			30°, BP, tight and open
106.5-107.5		3	X			X	X			Dip-normal, dip-parallel fracture set, open, heavy calcite mineralization on dip fracture
107.5-108.5		2		X		X	X			25-40°, BP, sl. open to open
110.5-111.5		2			X			X		20-30°, BP, open
111.5-112.5			X	X	X					
112.5-113.5		3	X	X						30°, BP, open; Dip-normal, dip-parallel fracture set, open
114.5-116			X	X	X					
116.5-117.5		3	X							Dip-normal, dip-parallel fracture set, open
121.5-123.5		2	X			B	X			⊥ to bedding, fracture surfaces
124.5-125.5		3				X				29-35°, BP, sl. open to open

Table A1.1 (continued)

Depth BGS (ft)[a]	Geologic unit	Fractures per ft[b]	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments[c]
125.5-126.5		7	X	X			X			Dip-normal, dip-parallel fracture set, open; low-angle fracture surface, open; 35°, BP, open
126.5-127.5		3	X	X						Dip-normal, dip-parallel fracture set, open to sl. open; 48°, BP, tight
128.5-129.5		2		X	X	B	X		X	40°, BP, open; low angle fracture surface, open
130.1-131.1		2	X	X	X					Low angle fracture surface, open
131.1-132.1		3	X	X						25-30°, BP, open; ⊥ to bedding
132.1-133.5		2	X	X	X					
134.1-135.1		2	?				X			35-43°, BP, sl. open to open
136.1-137.1		4	X			X	X			Dip-normal, dip-parallel fracture set, sl. open to tight; 31-34°, BP, sl. open to tight
137.1-138.1		2					X			22-25°, BP, sl. open to open
138.1-139.1		2	X	X		X	X			27-28°, BP, open to tight
139.1-140.5		4		X	X	B	X			Dip-normal, dip-parallel fracture set, open; 31°, BP, sl. open; ⊥ to bedding, sl. open
144.1-145.1		2	X	X	X		X	X		Dip-normal, dip-parallel fracture set, tight and open
145.1-146.5		5	X	X				X		Low angle fracture surfaces, open; 30-32°, BP, open to tight
147.1-48.1		3	?	X		B	X	X		30-35°, BP, open and tight
148.1-149.5		5	X	X		X	X			Dip-normal, dip-parallel fracture set, sl. open to open; ⊥ to bedding; 30°, BP, open; low angle fracture surface, tight
149.5-152		2	X	X	X	X	X		X	33-36°, BP, sl. open to open
154-155			X	X		B				
157-158			?		X	X	X			
158.1-159.1		2				X	X			⊥ to bedding, open
160-161			?	S	X	X	X	X		
161.1-162.1		2				X	X			⊥ to bedding, tight; low angle fracture surface, tight

Table A1.1 (continued)

Depth BGS (ft)[a]	Geologic unit	Fractures per ft[b]	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments[c]
162-163			X	X		X	X			
166.1-167.1		3	X	X		X				⊥ to bedding, sl. open 30°. BP, sl. open to open
167.1-168.1		2	X	X						23-24°, BP, sl. open to tight
168.1-169.1		2		X			X			Low angle fracture, sl. open to open
170.1-171.1		2		X		B				Low angle fracture surface, tight; 35°, BP, sl. open
175-176							X			
177.1-178.1		3	?	X	X		X			35°, BP sl. open; ⊥ to bedding, tight; low angle fracture surface, some calcite mineralization, open
178-179.1			X	X			X			Low angle fracture surfaces, some calcite mineralization, open; 41°, BP, heavy calcite mineralization, open
179.1-180.1		2	X	X				X		40-43°, BP, open
184.1-185.1		2	X	X			X			25-30°, BP, open and tight
185.1-186.1		2								30-40°, BP, open and tight
186-187				S						
189-190							X	X		40°, high angle fracture surface, open; low angle fracture surface, sl. open; ⊥ to bedding
193.1-194.1		3		X	X					
194.1-195.1		2	X	X	X	X				26-28°, BP, sl. open to open
195.1-196.1		3	X	X						Low angle fracture surfaces, open
196.1-197.1		6	X							30°, BP, open
197.1-198.1		2	X	X					X	32°, BP, open
198.1-199.1		5		X			X		X	Dip-normal, dip-parallel fracture set, calcite mineralization, open; 32°, BP, open
199.1-200.1		3	X	X			X		X	25-34°, BP; low angle fracture surface, open
202.1-203.1		2		X						31-33°, BP, slightly open to tight
203.1-204.5		2	X	X						31°, BP, sl. open

Table A1.1 (continued)

Depth BGS (ft)[a]	Geologic unit	Fractures per ft[b]	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments[c]
210.1-211.5		3	X	X				X		⊥ to bedding, heavy calcite mineralization, open; 23-25°, BP, open and tight
212.1-213.1		2		X	X	X				Low angle fracture surface, open
217.1-218.1		2			X			X		Low angle fracture surfaces, open; 23°, fracture surface, sl. open
218-219						B	X			
223.1-224.1		2		X			X			35°, BP, open; fracture surface, open
224-225			X		X					
226.1-227.1		2					X			Low angle fracture surface, open; ⊥ to bedding, tight
227.1-228.1		4	X				X		X	Low angle fracture surfaces, open
228-229			X	X						
231.1-232.1		3						X	X	20°, low angle fracture surface, open; low angle fracture surface, open; ⊥ to bedding, sl. open
232-233			X	X						
233.1-234.1		2	X	X		X				29°, BP, open
234.1-235.1		4						X		Low angle fracture surfaces, open
235.1-236.1		3								Low angle fracture surfaces, open
244.7-245.7		2								42°, fracture surface, sl. open; 35°, BP, open
246-247			X	X						
247.4-248.4		3		X			X	X		30-38°, BP, open and tight
248.4-249.4		3			X	X		X		Low angle fracture surfaces, open
250.4-251.4		4	X	X	X	X	X	X		26-40°, BP, open and tight
251.4-252.4		2	X	X		B				40°, BP, sl. open; low angle fracture surface, open
252.4-253.4		2	X	X	X					34-37°, sl. open
253-254			X	X						
254-255			X	X						
255.2-256.2		2	X	X					X	40°, BP, sl. open; low angle fracture surface, open

Table A1.1 (continued)

Depth BGS (ft)[a]	Geologic unit	Fractures per ft[b]	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments[c]
256.2-257.2		3		X						Low angle fracture surface, sl. open to tight
257.5-158.5			X	X						
259-260					X					
261-263			X							
264.5-265			X	X				X		
274				X	X					
276-277		3		X	X				X	Low angle fracture surfaces, <20°, open and tight
283.5			X	X		B				
291-292							X			
294-295		2		X	X			X	X	37°, BP, tight; low angle fracture, open
296-297		2	X	X	X		X			26-32°, BP, sl. open to open
300-301		3	X	X						Dip-normal, dip-parallel fracture set, sl. open to tight; 32°, BP, tight
302-303		4	X	X					X	23-27°, BP, sl. open to tight
303-304			X	X				X		
313-314.5		2	X		X			X		25°, BP, open; 45°, high angle fracture surface, open
315-316			X							
316-317			?		X					
317-318		3	X	X	X					25-28°, BP, sl. open to open
318-319		3	X	X						25°, BP, tight
319-320				S						
320-321		2	X					X		Low angle fracture surfaces, sl. open
323-324							X			
326-327		3	X	X		B		X	X	25-30°, BP, open
327-328			X	X						
328-329			X	X						
329-330		2	?	X					X	24-31°, BP, sl. open to open
330-331		2	X							28-35°, BP, heavy calcite mineralization, sl. open to open
336-337				X	X			X	X	

Table A1.1 (continued)

Depth BGS (ft)[a]	Geologic unit	Fractures per ft[b]	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments[c]
338-339			X		X			X		
347-348				X	X		S	X		
357-359		2	X	X	X	S		X	X	High angle fracture surface, sl. open; 34°, BP, calcite mineralization, sl. open
375-377				S					X	
378-379		2	X		X			X		Dip-normal, dip-parallel fracture set, dip 30°, heavy calcite mineralization, tight
383-384			X	X	X				X	
386-387			?				S		X	
387-388			X		X	B				
388-389		2	X	X	X					32-33°, BP, sl. open to tight
390-391		3	X	X	X					33-36°, BP, heavy calcite mineralization, sl. open to open
391-392		2								32°, BP, sl. open and tight
393-394			?	X	X					
395-396		2	X							30°, BP, tight and open
396-937			X	X						
397-398			X	X	X					
398-399		2	X	X	X					35-40°, BP, sl. open to tight
399-400		2	X	X	X					28-32°, tight
			+++							
402-403		3								Dip-normal, dip-parallel fracture set, tight; 30°, BP, sl. open to tight

[a]Only those depth intervals obtained from the geologist's logs have an accuracy of 0.1 ft. Depth intervals from other logs were not as accurate.
[b]From geologist's log.
[c]The general format for the fracture description is: fracture angle relative to horizontal, type of fracture, and degree of fracture openness. Fracture descriptions are separated by semicolons.

LEGEND

X	=	Log response
S	=	Slight log response
?	=	Questionable due to log quality
+++	=	Denotes end of log
B	=	Baseline shift in log curve
***	=	Denotes top of log

1. BP – Bedding plane fracture; a fracture that occurs along the plane of bedding, which typically ranged from 25–40° as measured perpendicular to the long axis of the core.
2. Dip-normal fracture – Any fracture that is perpendicular to bedding; typically either parallel or perpendicular to strike.
3. Dip-parallel fracture – Any fracture that is parallel to bedding.

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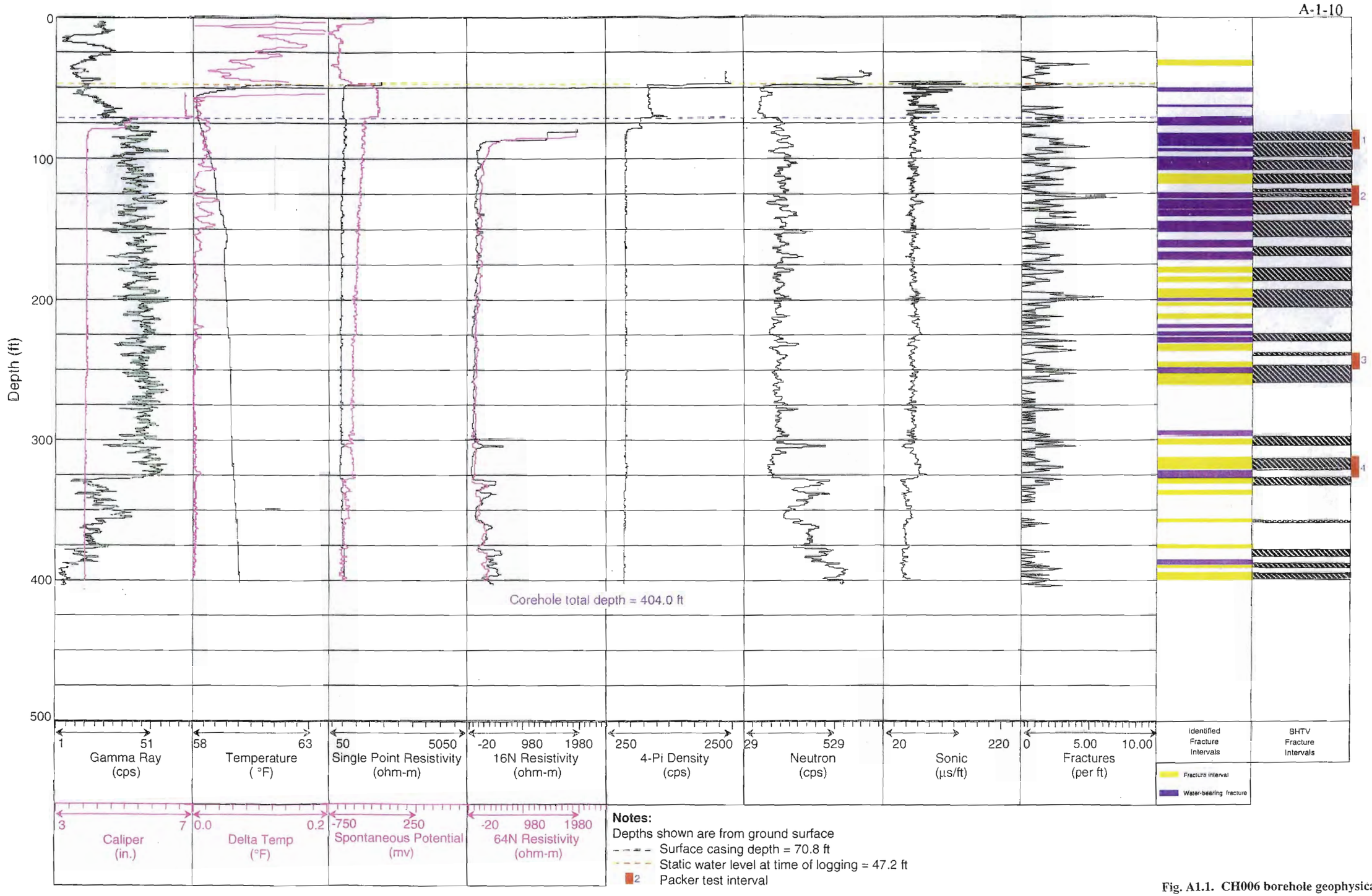
Table A1.1 (continued)

4. Low angle fracture – As measured perpendicular to the long axis of the core, a low angle fracture is generally at an angle less than bedding.
5. High angle fracture – As measured perpendicular to the long axis of the core, a high angle fracture is generally at an angle greater than bedding.
6. ⊥ – A dip-normal fracture; perpendicular to bedding.



Notes:
Depths shown are from ground surface
Surface casing depth = 70.8 ft
Static water level at time of logging = 47.2 ft
2 Packer test interval

Fig. A1.1. CH006 borehole geophysical logs.

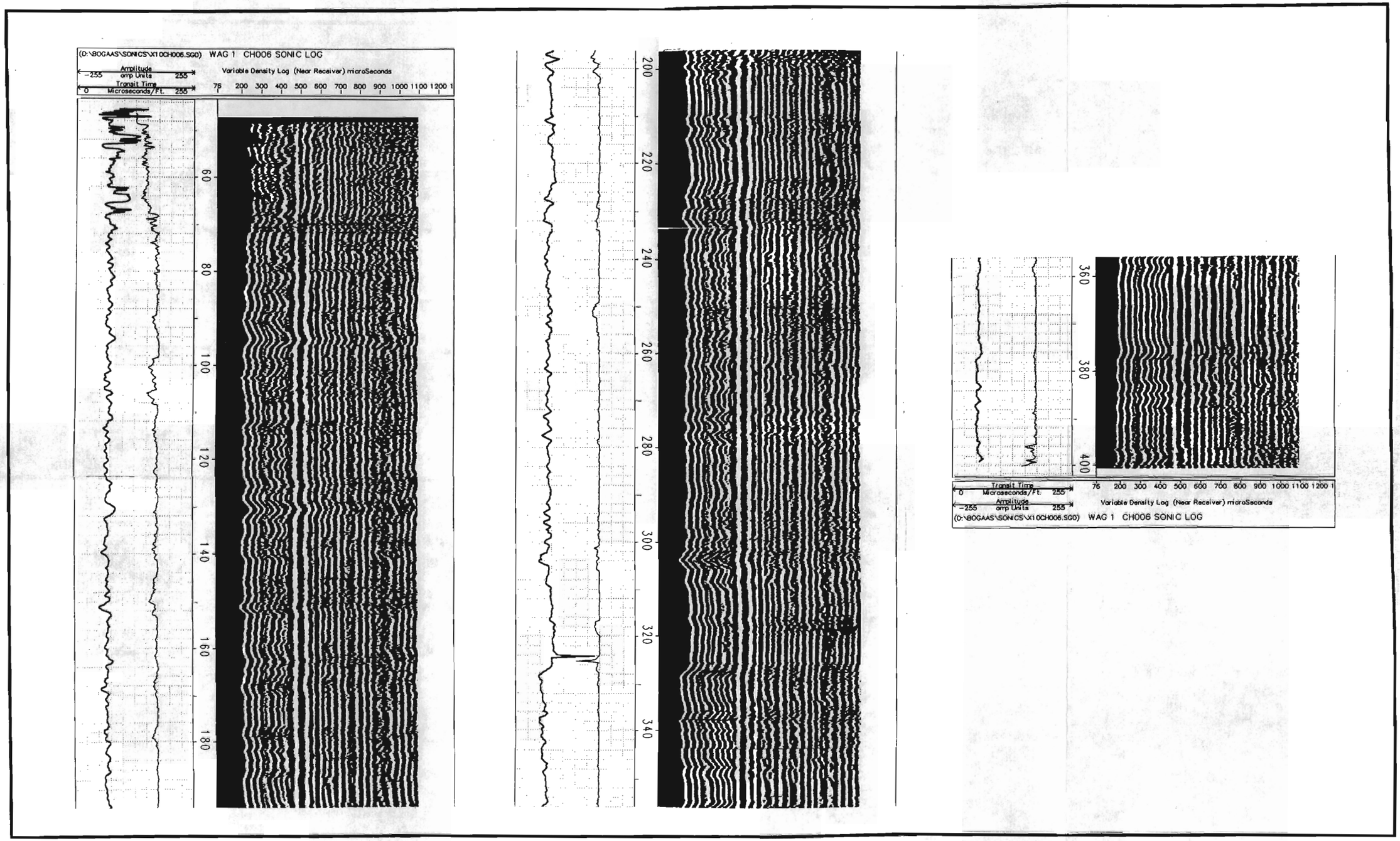


Fig. A1.2. CH006 variable density (acoustic) log.

ORNL DWG 91 10318

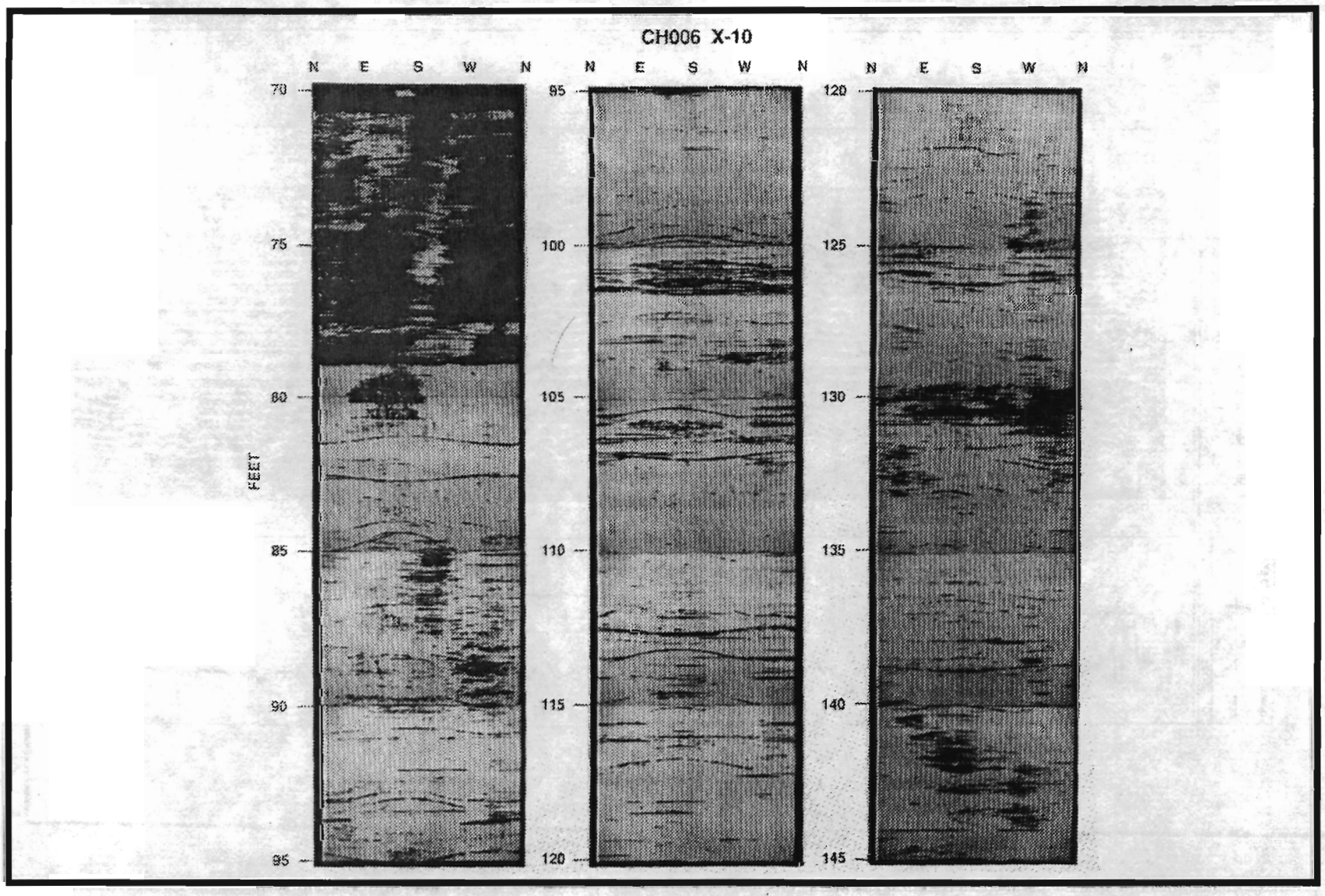


Fig. A1.3. CH06 borehole televiewer log.

5.27 5277.1

ORNL DWG 91 10319

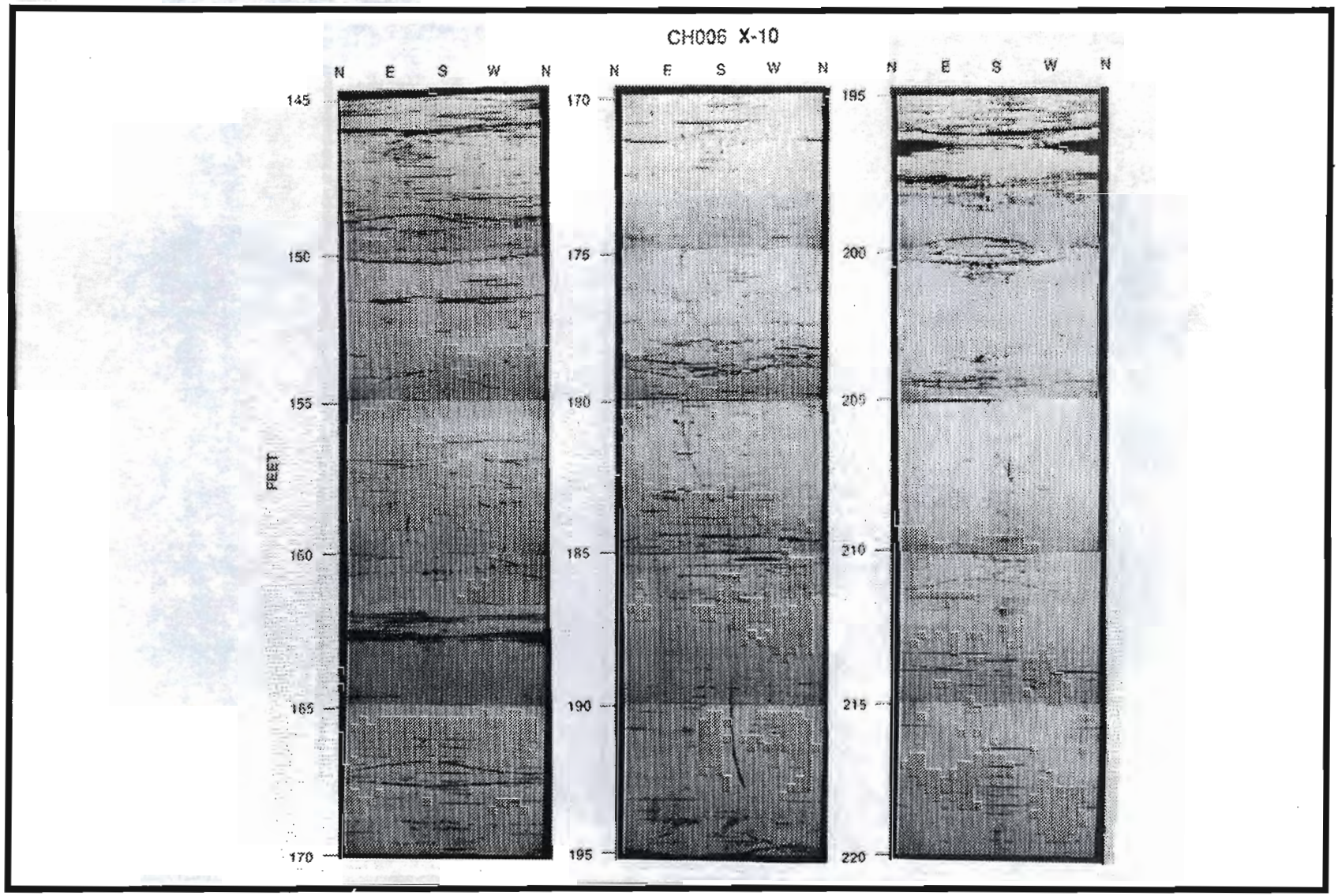


Fig. A1.3. (continued).

5.27 5277.2

ORNL DWG 91 10322

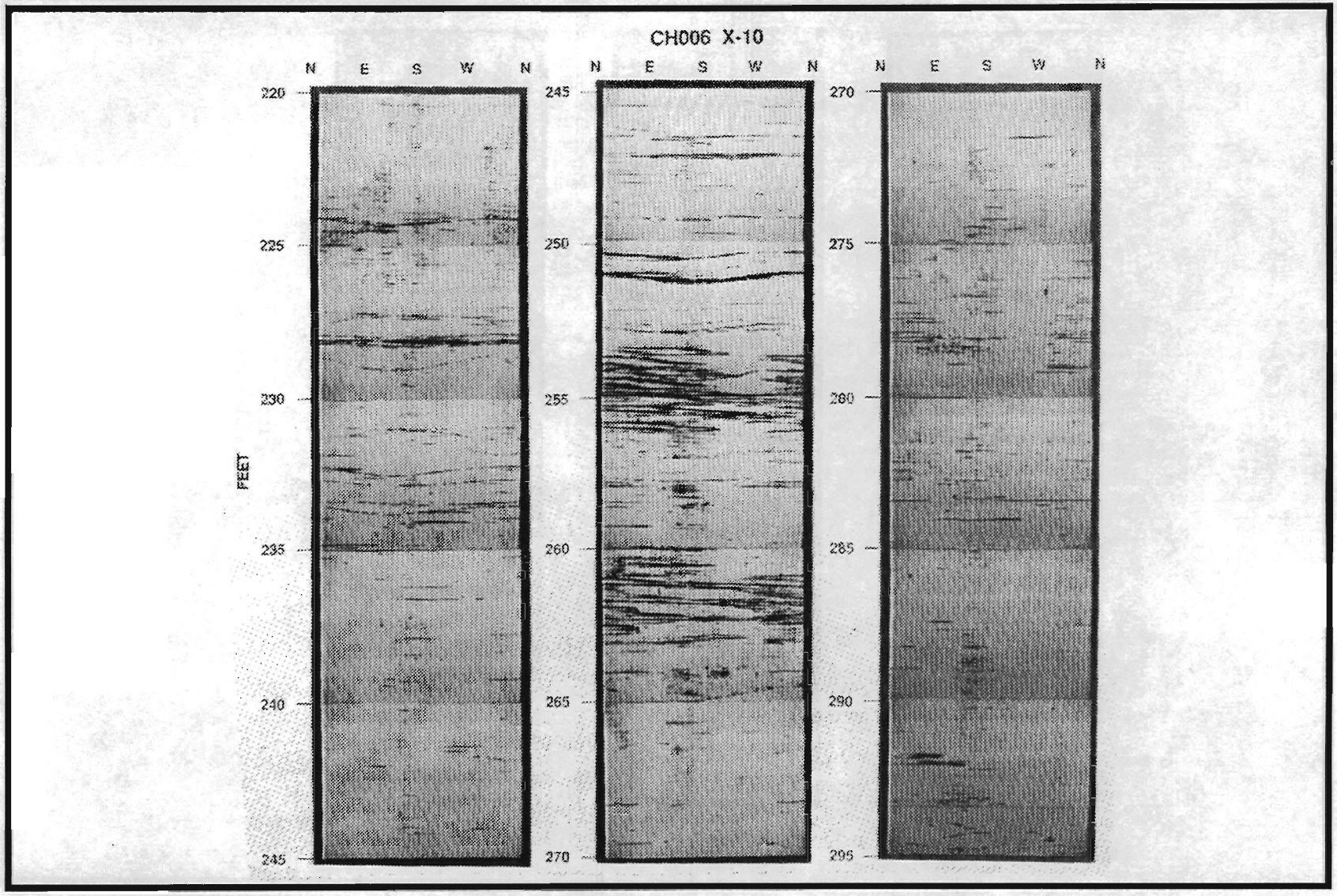


Fig. A1.3. (continued).

5.27 5277.3

ORNL DWG 91 10321

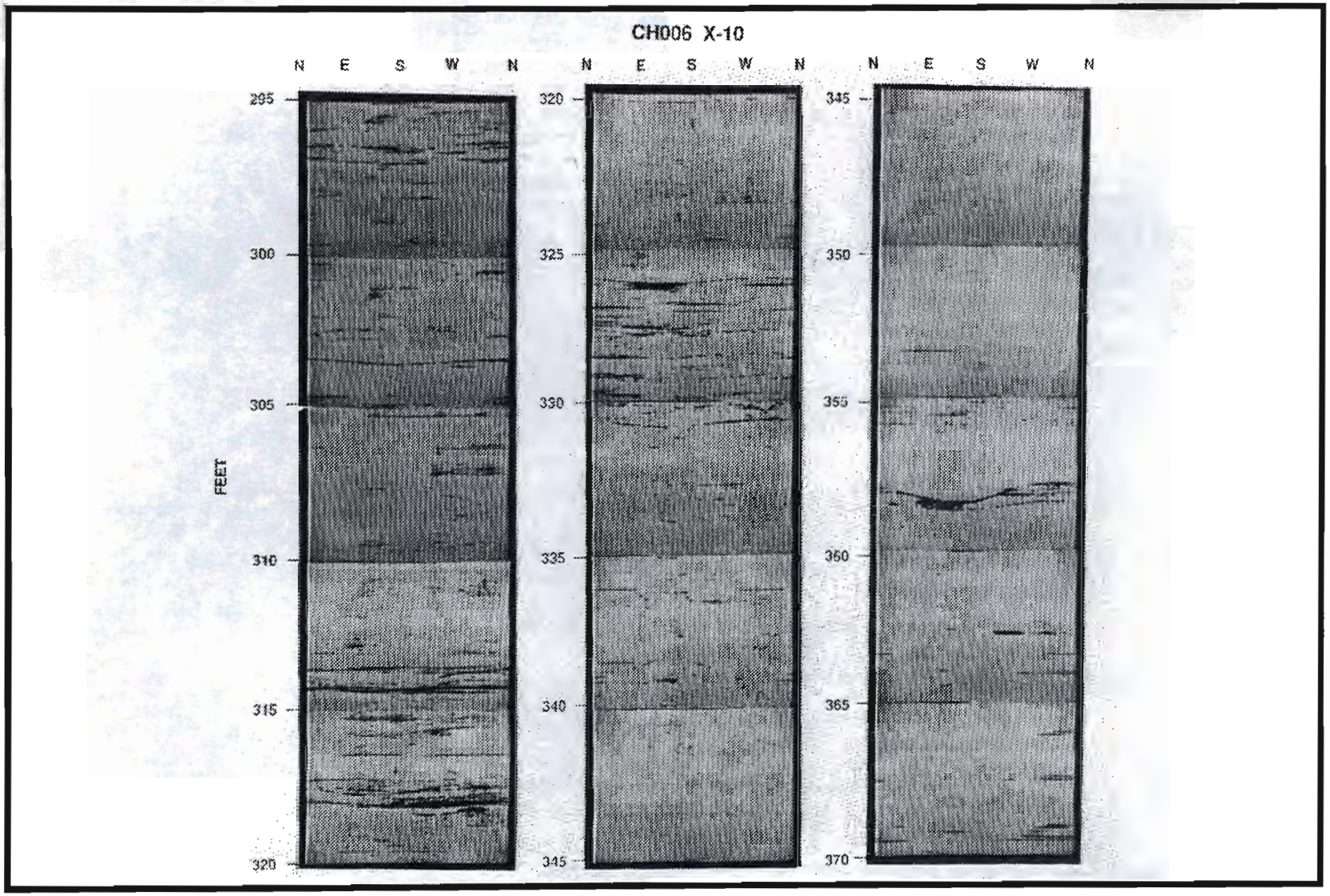


Fig. A1.3. (continued).

5.27 5277.4

ORNL DWG 91 103120

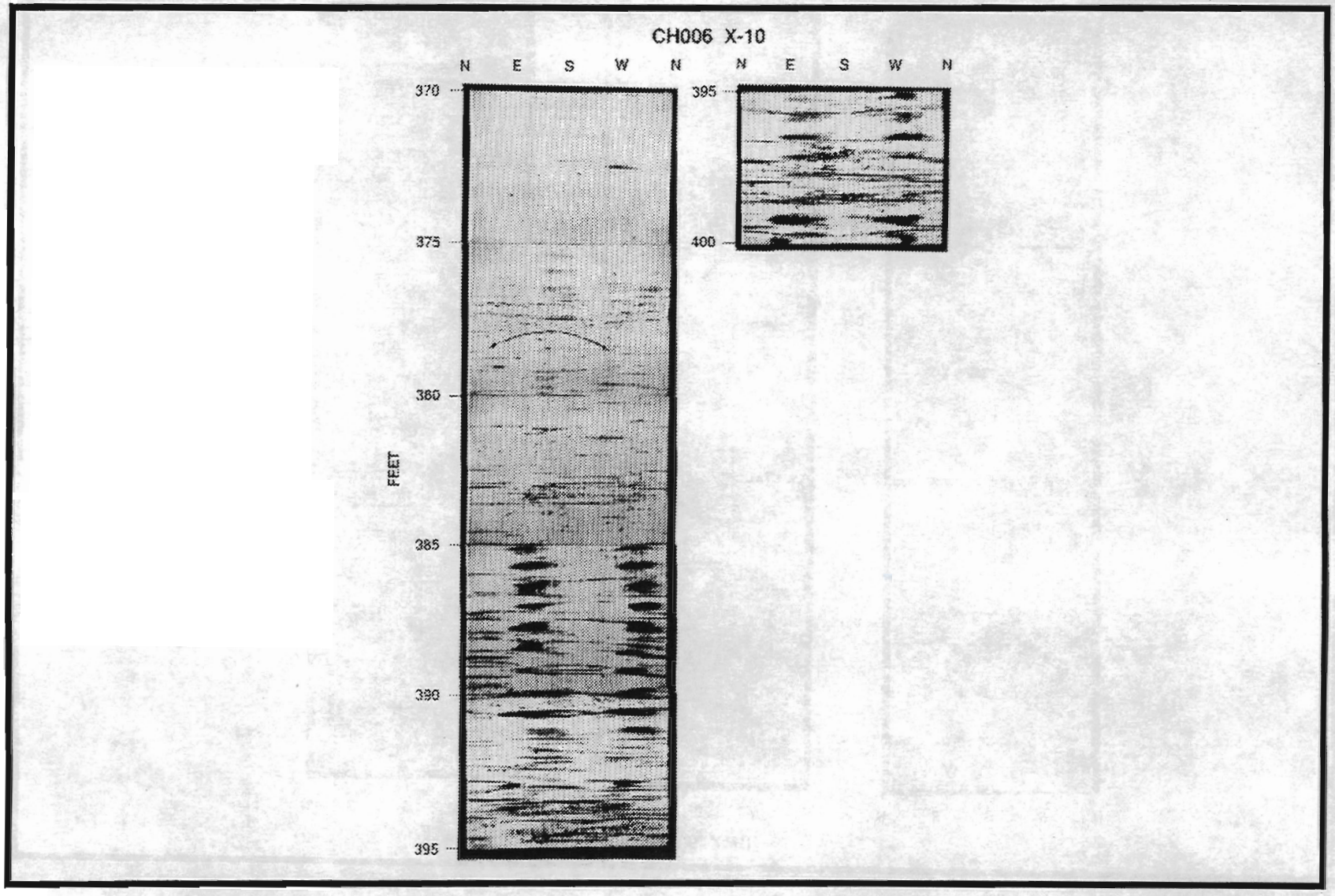


Fig. A1.3. (continued).

5.27 5277.5

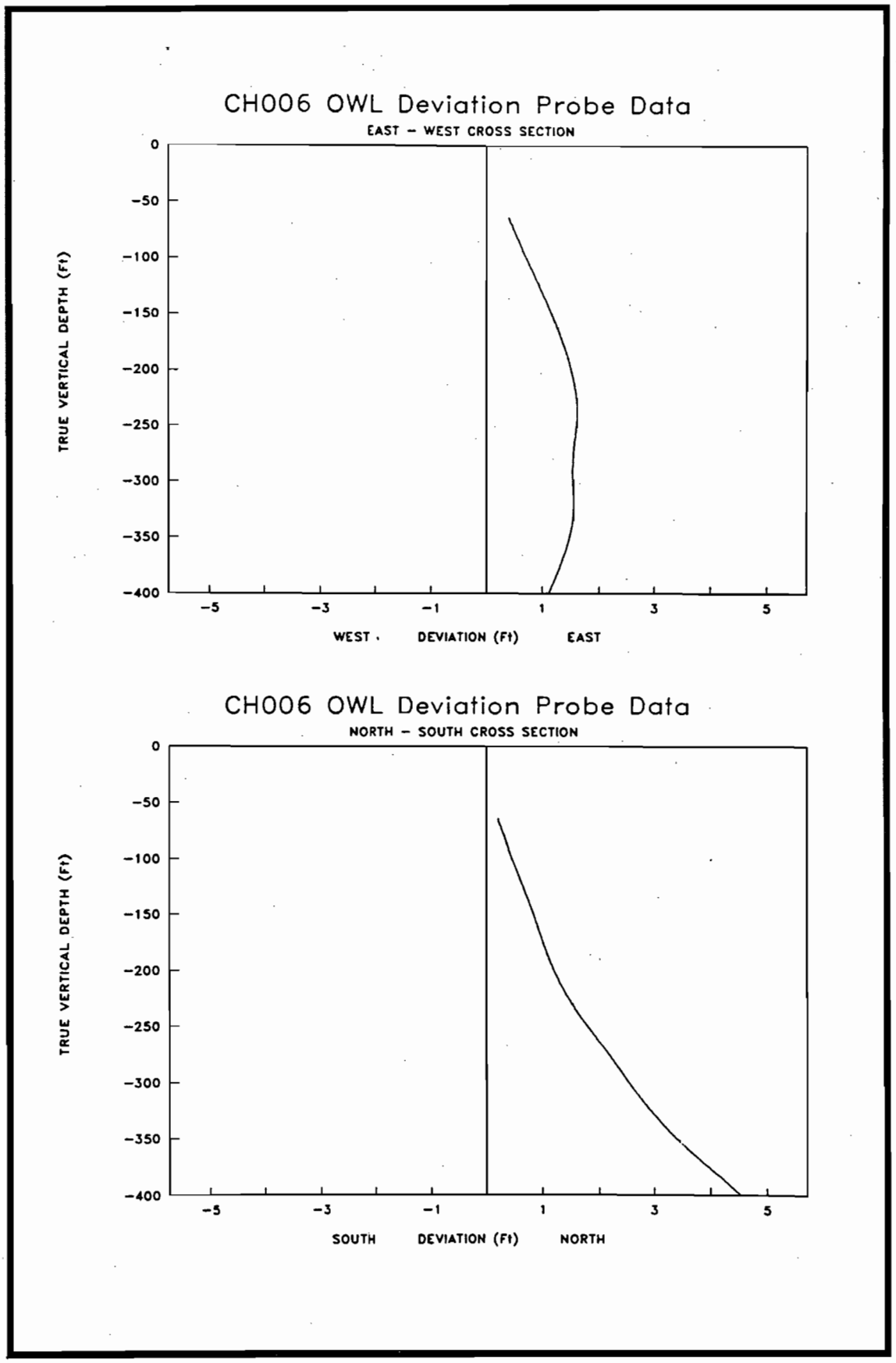
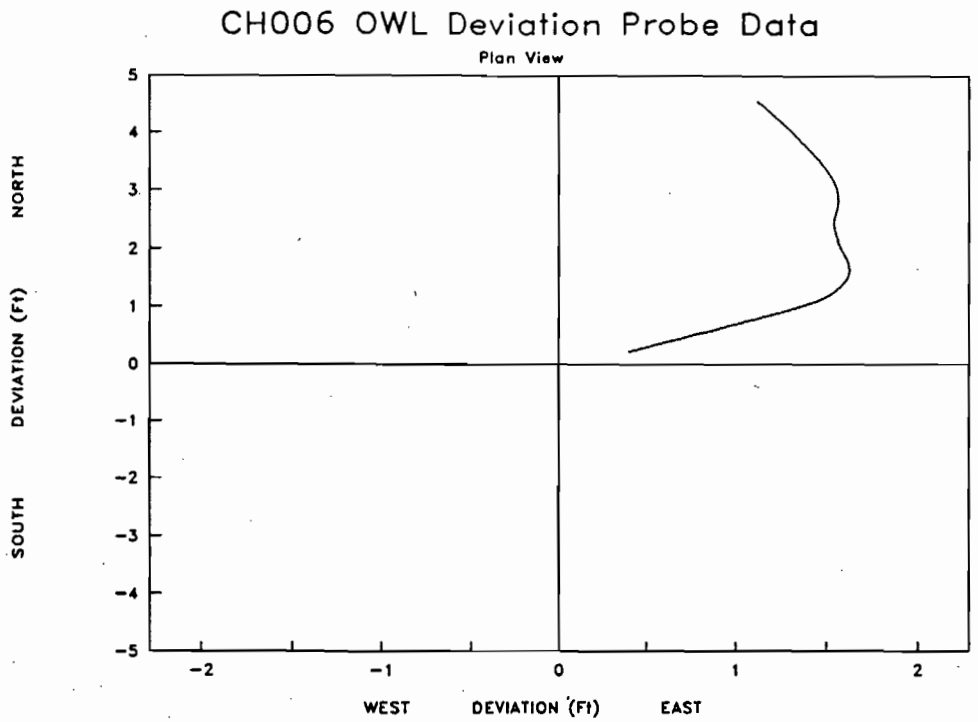


Fig. A1.4. CH006 OWL deviation probe data.



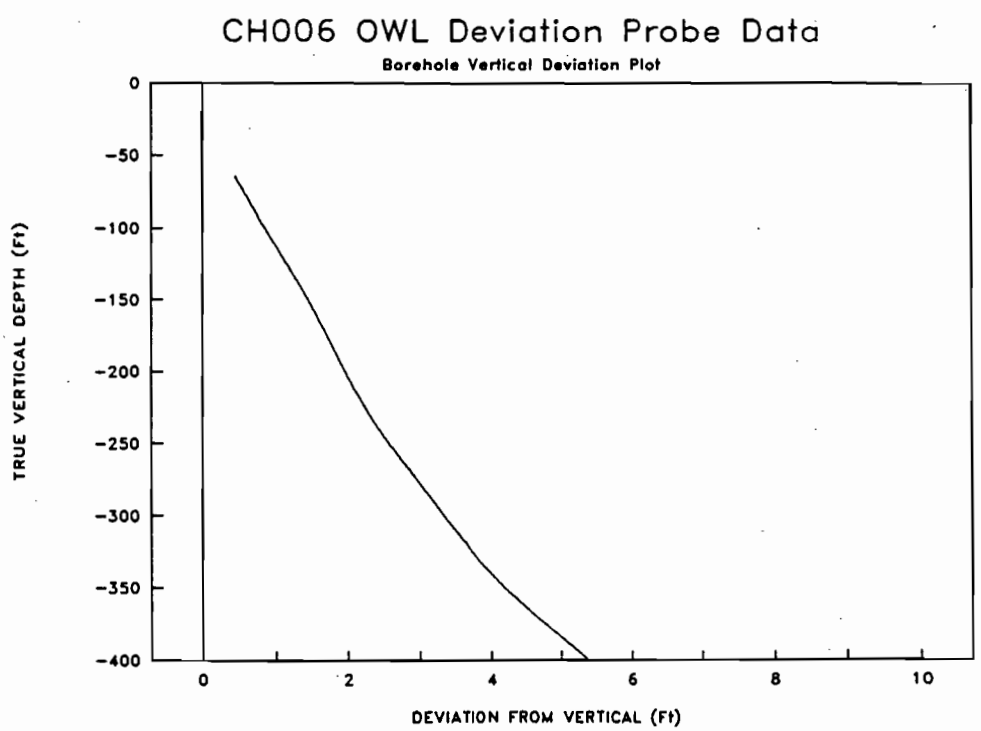


Fig. A1.4. (continued).

ATTACHMENT 2

CH07A—GEOPHYSICAL AND GEOLOGIC DATA

Table A2.1. Summary of fractures identified in corehole CH07A

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
28-29	D	4						X		30-31°, BP, sl. open to open
29-30		2						X		33°, BP, sl. open to open
32-33						X	X			
34.6-35.6		7								29-32°, BP, open to tight
35.6-36.6		6								Low angle, up to 30°, open to tight
36.6-37.6		6								30°, BP, open to tight
37.6-38.6		4					X			29-31°, BP, open to tight
38.6-39.6		2								30°, BP, sl. open
39.6-40.6		4					X	X		Low angle to 30°, sl. open to tight
40.6-41.6		2								30°, BP, sl. open to tight
44-45					X			X		
			***							
47.8-48.8		2			X			X	X	30°, BP, tight; low angle fracture surface, open
			***							
50-51			X			B	X		X	
51.1-52.1		5	X	X	X	B	X	X		30-31°, BP, tight and open
52.1-53.1		2	X		X	B	X			22-28°, BP, open
53-54			X			B	X			
54.1-55.1		3	X	X				X		32-35°, BP, sl. open to open
55.1-56.1		3	X							25-40°, BP, tight and open
56.1-57.1		2	X			X		X		25°, BP, tight
57-58			?							
58.1-59.1		2		X	X		X	X		29°, BP, tight
64.1-65.1		2	X	X		X	X	X	X	34°, BP, sl. open to tight
66-67			X	X		B				
67.1-68.1		4	X	X	X			X		30-32°, BP, sl. open to tight. 67.5-68.1 - Driller says either v. soft or a void
68.1-69.1		6	X	X						24-35°, BP, open; ⊥ to bedding, partially healed, almost filled with calcite crystals
69.1-70.1		2		X		X				30°, BP, tight; ⊥ to bedding, partially healed, almost filled with calcite crystals
70.1-71.1		2				X				25-32°, BP, sl. open to tight
71.1-72.1		5	X	X	X					30°, open to tight

Table A2.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
72.1-73.1		3	X				X	X		33-35°, BP, sl. open to open
74.1--75.1		2	X			X	X			37°, BP, sl. open; 22°, low angle fracture, open
76.1-77.1		2					X			30°, BP, open; low angle fracture, open
77.1-78.1		3				X	X			28-32°, BP, sl. open to tight
80-81			X	X	X	X		X		
82.1-83.1		2				B	X			32°, BP, sl. open; low angle fracture, sl. open to tight
84.1-85.1		2	X		X	B				35°, BP, open and tight
85.1-86.1		2	?	X		X	X			25-30°, BP, open
86.1-87.1		3								30-32°, BP, open and tight
87.1-88.1		2	?	X				X		28-33°, BP, tight
89.1-90.1		3	?	X	X	B			X	30-34°, BP, open at ~89.5 ft, 1-ft void zone
90.1-91.1		3	X	X		B	X		X	31°, BP, open and tight
91.1-92.1		3	?	?		B			X	31-32°, BP, open and tight
93.1-94.1		3	X	X		X				33-35°, BP, open and tight
94-95			X	X		X				
95.9-96.9		2	X							29° BP, open; high angle fracture surface, tight
97-98			X			B		X		
99.9-100.9		4	X		X					30°, BP, sl. open to tight
100.9-101.9		3	X	X			X	X	X	30°, BP, tight
101.9-102.9			X	X						29°, BP, sl. open to open; ⊥ to bedding (strike-dip set), tight
102.9-103.9		3		X	X				X	
109-110			?	X	X	B				
112-113					X		X			
118-119			?	X			X			
119.9-120.9		5	X	X		X	X	X		Fractured/broken cavity, heavy calcite mineralization; 1 partially healed ⊥ fracture
123-124			?					X		
125.9-126.9		2				X				Dip-normal, parallel fracture set, tight

Table A2.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
126.9-127.9		2	?			X	X			30°, BP, tight; high angle fracture surface, calcite mineralization, open
127.9-128.9			?		X	B		X		
129.9-130.9			X	X			X			
130.9-131.9		2-3	X	X	X	X	X			Dip-normal, dip-parallel fracture set, v. heavy calcite mineralization, open
133-134			X			X	X			
134.9-135.9		2	?					X		
135.9-136.9		2	?				X			
137.9-138.9			X			X	X			
138.9-139.9		3	X							
140.9-141.9		2				B				
143-144			X					X		
151-152	C		X		S		S			
155-156			X				X			39°, BP, tight
156.6-157.6		2	X	X						
157.6-158.6		4	X	X		B				34-37°, BP, open to tight
158.6-159.6		2	X	X				X		34°, BP, tight
159.6-160.6			?	X				X		
160.6-161.6			?				X			
162-163			X	X	X	X				34°, BP, sl. open to open
163.6-164.6		2	?	X						
165-166			X				X			
166-167			X				X			30-35°, BP, open to tight

Table A2.1 (continued)

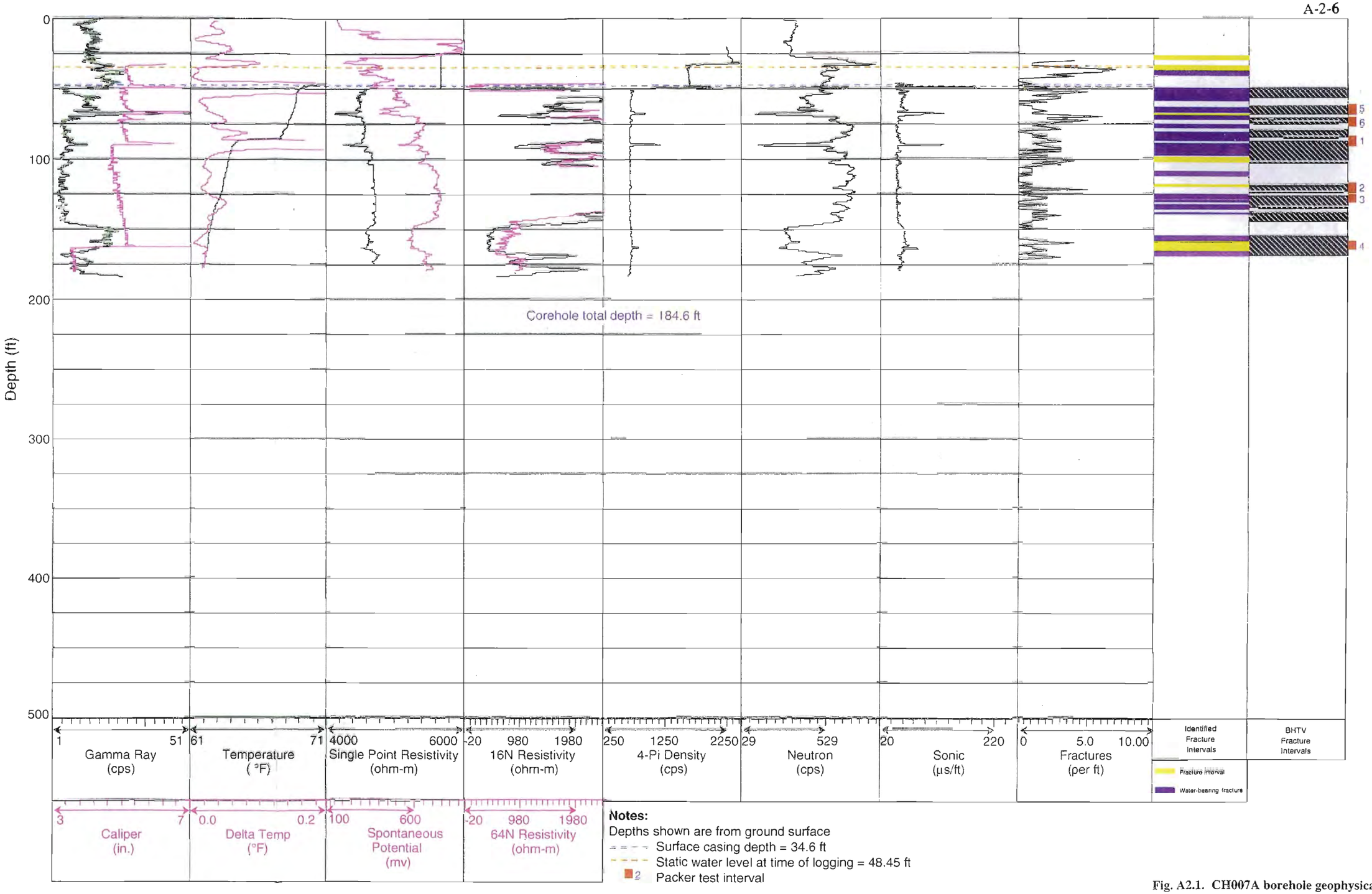
Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
167.6-168.6		2				B		X		
168.6-169.6		3	X			X		X		24-30°, BP, sl. open to open
177-178			X +++	X	X					

[a]Only those depth intervals obtained from the geologist's logs have an accuracy of 0.1 ft. Depth intervals from other logs were not as accurate.
[b]From geologist's log.
[c]The general format for the fracture description is: fracture angle relative to horizontal, type of fracture, and degree of fracture openness. Fracture descriptions are separated by semicolons.

LEGEND

X	=	Log response
S	=	Slight log response
?	=	Questionable due to log quality
+++	=	Denotes end of log
***	=	Denotes top of log
B	=	Baseline shift in log curve

1. BP - Bedding plane fracture; a fracture that occurs along the plane of bedding, which typically ranged from 25-40° as measured perpendicular to the long axis of the core.
2. Dip-normal fracture - Any fracture that is perpendicular to bedding; typically either parallel or perpendicular to strike.
3. Dip-parallel fracture - Any fracture that is parallel to bedding.
4. Low angle fracture - As measured perpendicular to the long axis of the core, a low angle fracture is generally at an angle less than bedding.
5. High angle fracture - As measured perpendicular to the long axis of the core, a high angle fracture is generally at an angle greater than bedding.
6. ⊥ - A dip-normal fracture; perpendicular to bedding.



Notes:
Depths shown are from ground surface
Surface casing depth = 34.6 ft
Static water level at time of logging = 48.45 ft
2 Packer test interval

Fig. A2.1. CH007A borehole geophysical logs.

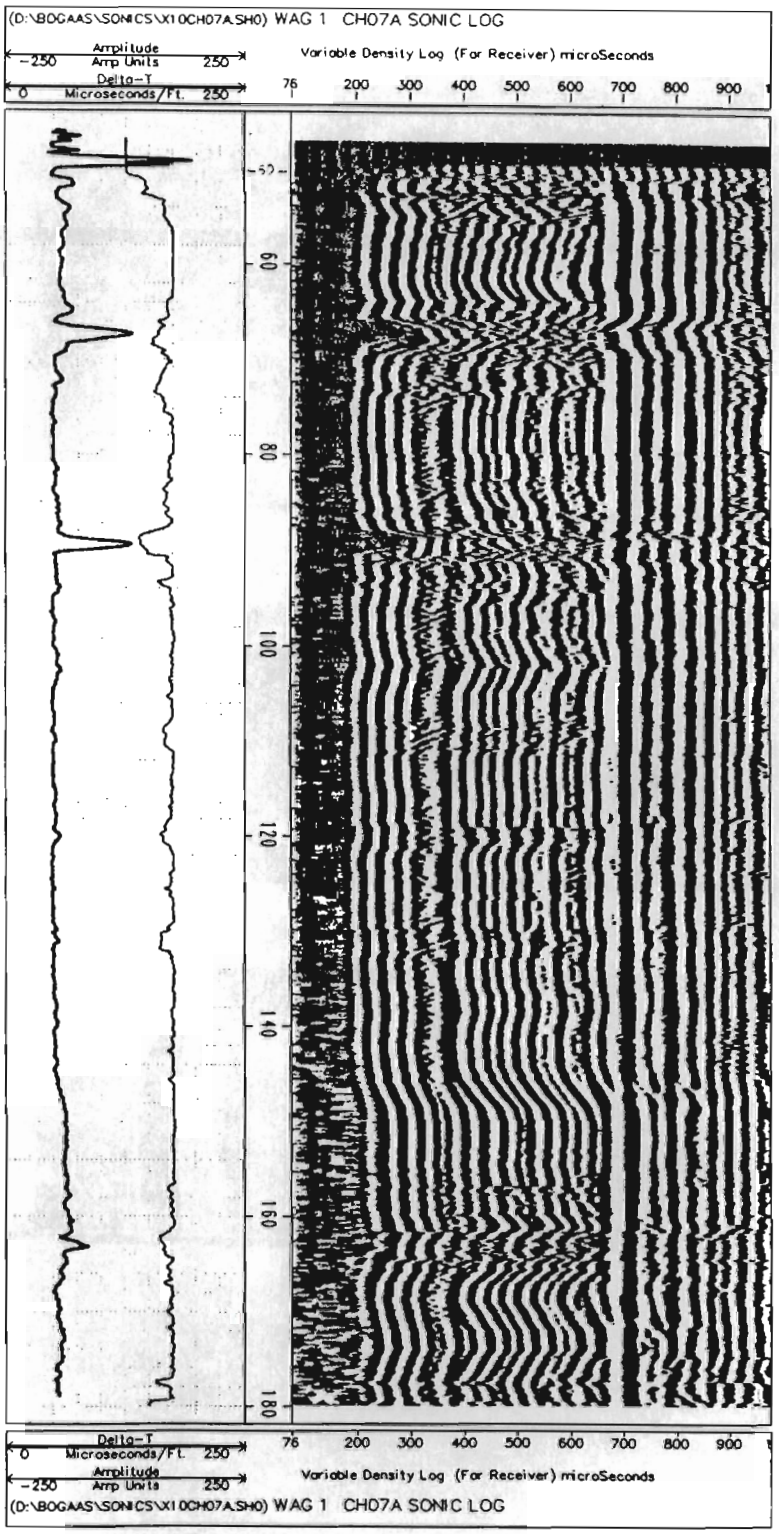


Fig. A2.2. CH07A variable density (acoustic) log.

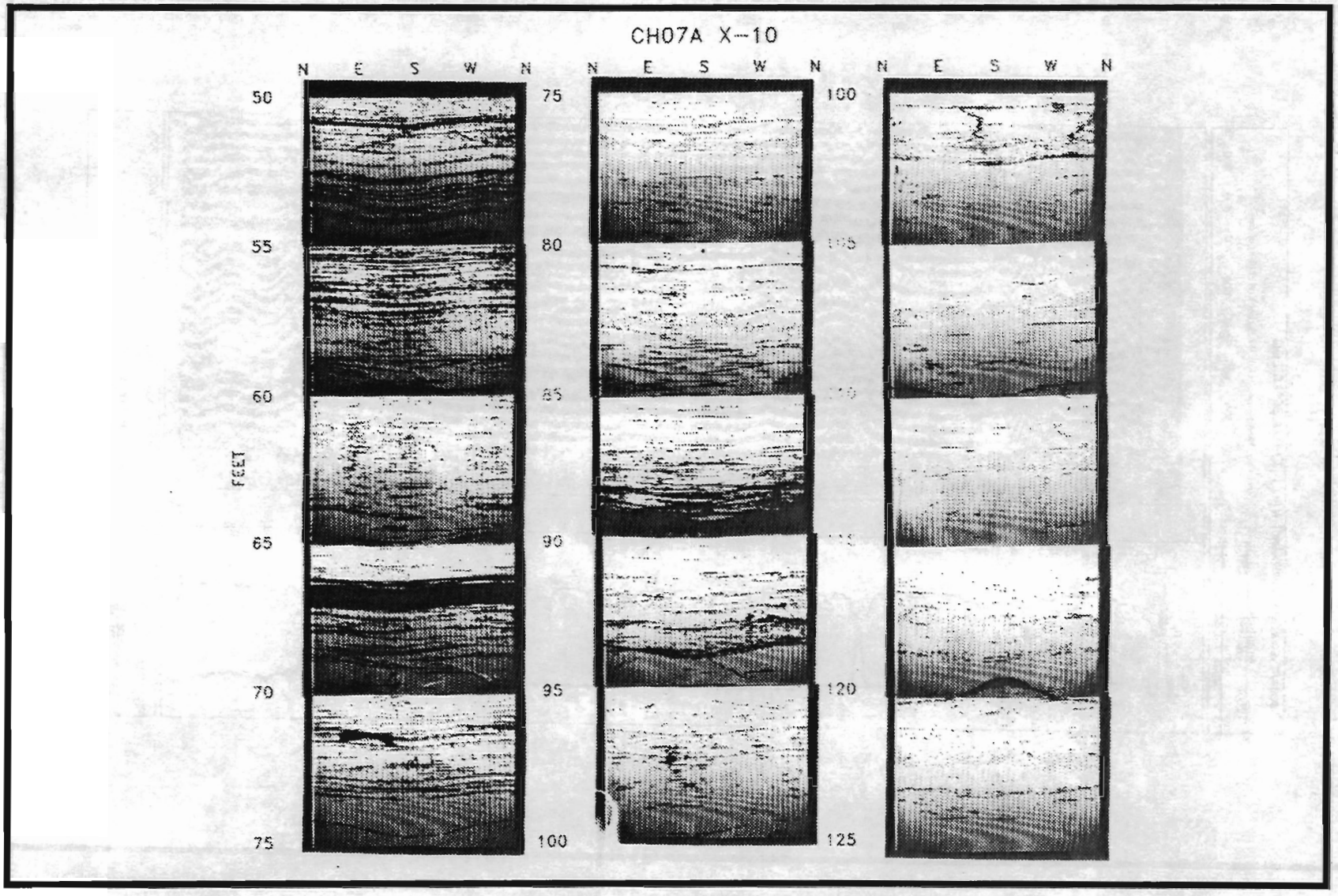


Fig. A2.3. CH07A borehole televiewer log.

5.27 5277.6

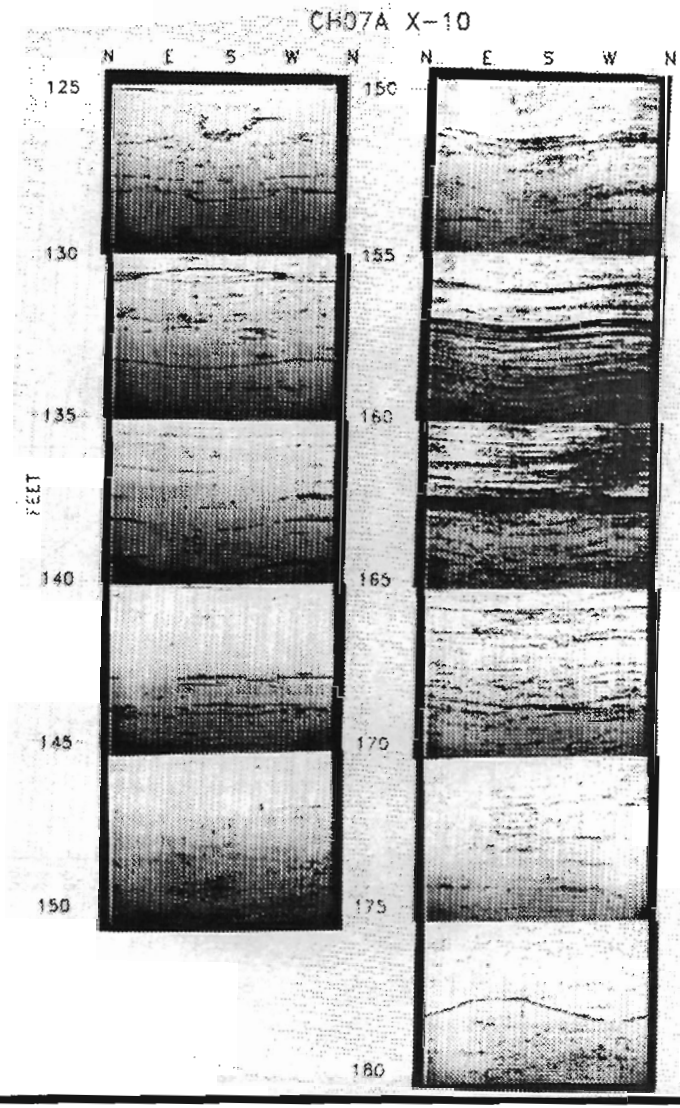
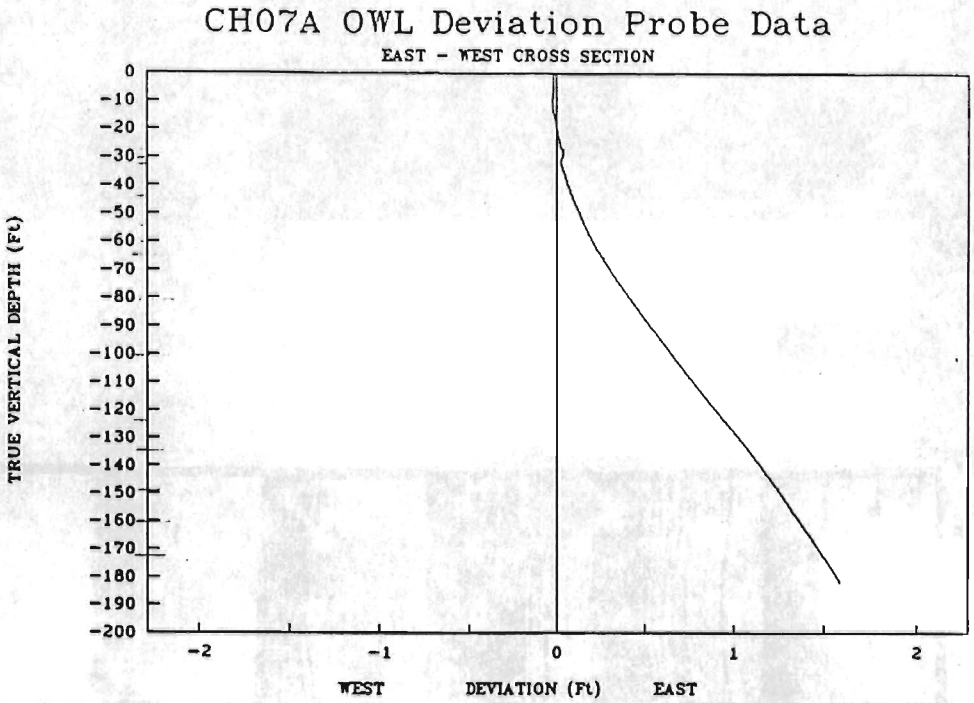


Fig. A2.3. (continued).



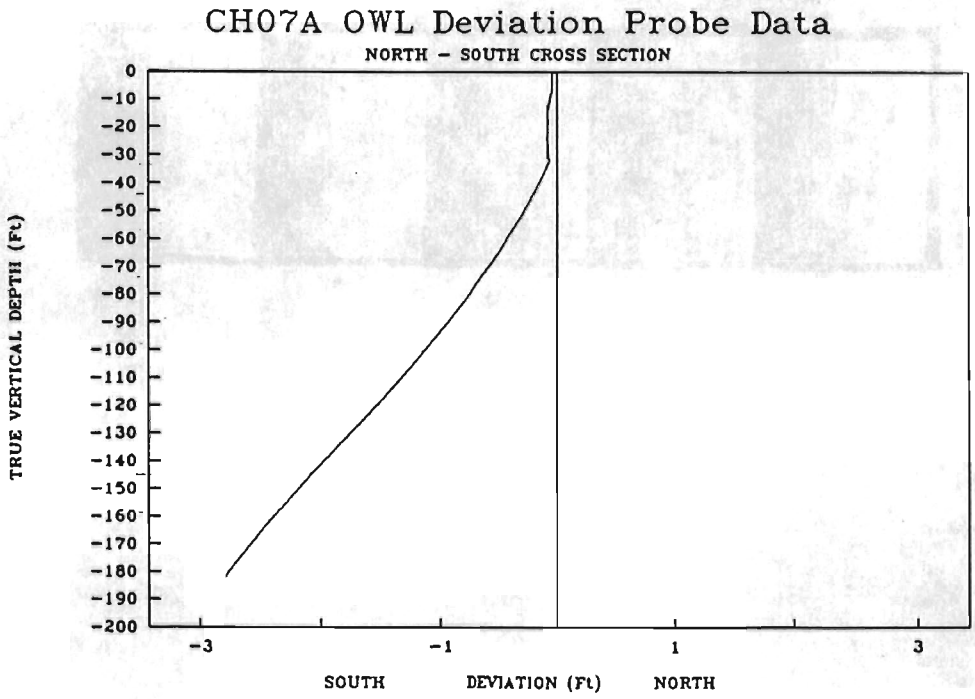
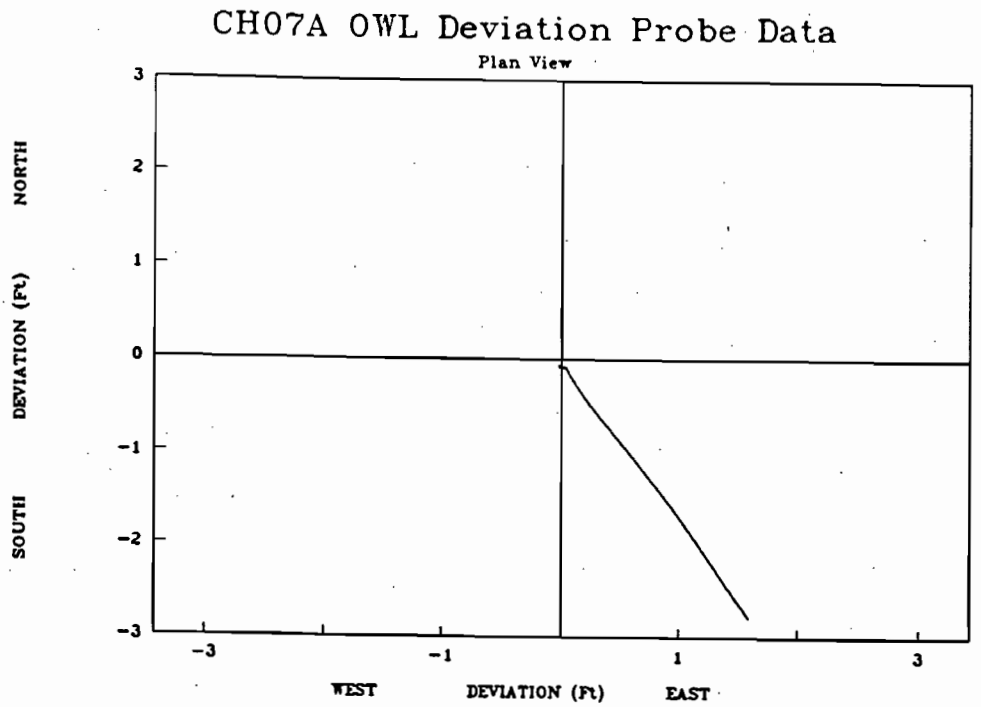


Fig. A2.4. CH007A OWL deviation probe data.



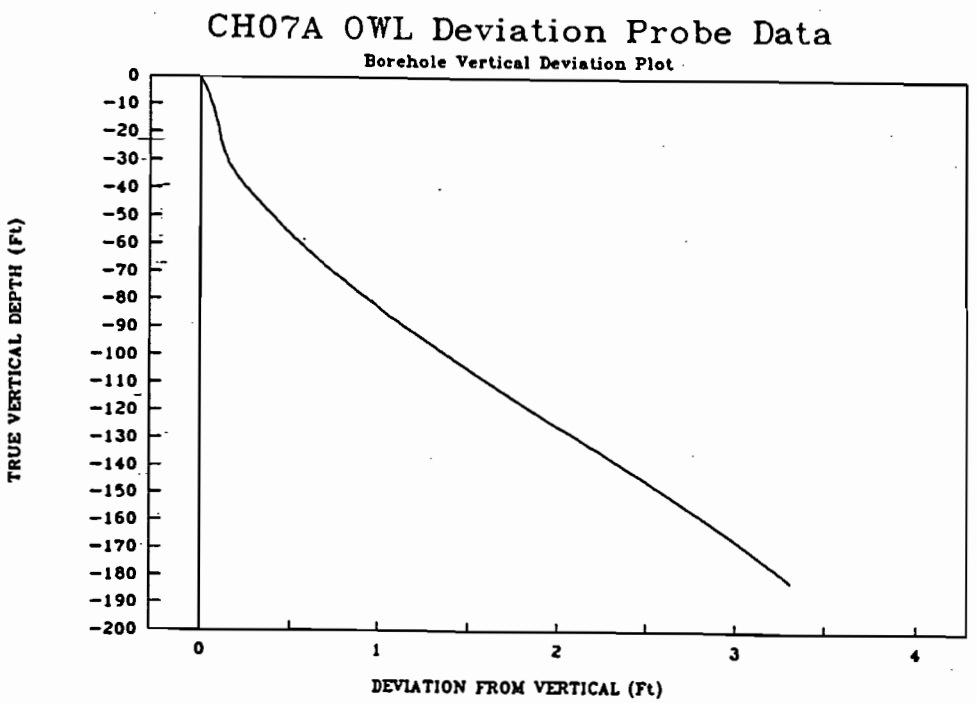


Fig. A2.4. (continued).

ATTACHMENT 3

CH009—GEOPHYSICAL AND GEOLOGIC DATA

Table A3.1. Summary of fractures identified in corehole CH009

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
			*** (15')							
33-34	G	4	X	X			X			30°, BP, open
34-35.1		3	X							20-30°, BP, open
35-36			X							
36-37		2	X				X			30°, open to tight
37-38		3								30°, open to tight
38-39		4	X	X						30°, open
39-40		8	X	X						30-35°, BP, open; ⊥ to BP, tight
40-41		5	X	X			X			25-30°, BP, open to tight
41-42		2	X							25°, BP
42-43		3	X	X						20-40°, BP, open to tight
43-44		3	X	X						30°, BP, open
44-45			X							
45-46		2	X	X			X			40°, BP, open
46-47		2	X	X						35°, BP, open to sl. open
47-48		2	X	X			X			30-40°, BP, open to tight
48-49		5	X	X						30-40°, BP, open
49-50		2	X				X			35°, BP, open
50-51		4	X	X			X	X		20-40°, BP, open
51-52		4	X	X			X			30-40°, BP, open
52-53		3	X	X						30-45°, BP, sl. open to open
53-54		3						X		35°, BP, sl. open to open
54-55			S				X			
56-57		3	X	X		X	X			25-35°, BP, tight to sl. open
57-58			X			X	X		X	
58-59		3	X							30-50°, BP, open
59-60			X				X			
60-61		8	X		X	X	X			20-30°, BP, open
62-63		4	X	X	X	X	X	X	X	20-30°, BP, open
63-64			X			B			X	
66-68						B	X	X		

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Table A3.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
70-72						X	X			
75-76						B	X			
78-79						B	X			
80-81			X		X	X	X	X		
85-86						B	X			
87-88			X	X		X			X	
88-89							X			
91-92					X	X	X			
94-95		2				X				35°, BP, tight
95-96		3		S				X		20-35°, BP, tight
96-97		4	X	X	X	X	X			40°, BP, tight
97-98			S							
98-99		5	X	X		B	X			BP, tight
99-100		3	X	X	X		X		X	20-40°, BP, tight
100-101		2								20°, BP, tight
101-102		2								15-30°, BP, tight
105-106		3	X		X					40°, BP, tight
118-119		2	X					X		
120-121			X			X				30°, BP, tight
123-125			X	X	X	X			X	
129-130		2				B				30°, BP, sl. open to open
131-132			X			B	X		X	
132-133		2	X	X		B	X		X	20-30°, BP, sl. open
134-135		2	X	X						30°, BP, sl. open to open
136-137		2	X	X						30°, BP, tight to sl. open
138-139		2		S						35°, BP, tight to sl. open
139-140			S							
143-144		3						X		35°, BP, sl. open
146-147			X		X	X				
147-148		2	X	X		B	X			30-40°, BP, sl. open to open
149-150		3	X							30°, BP, tight to sl. open

Table A3.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
150-151		2	X			X	X			30°, BP, sl. open
152-153			X		X		S			
153-154		2	X							40°, BP, tight to sl. open
155-156			X		X		X			
158-159			X				X			
159-160		2			X					20-25°, BP, sl. open to open
160-161			X				X			
170-171		2	X		X					30-40°, BP, tight to open
176-177		2						X		20°, BP, tight to open
179-180		2	X	X						30°, BP, tight
180-181		5	X	X					X	35°, BP, open
181-182		2		X						30°, BP, tight
182-183		3					X	X		30°, BP, open
184-185			X		X					
185-186		3								30-40°, BP, tight
187-188			X							
190-191						B			X	
195-196			X		X		X			
197-198		2	X	S			X	X		30°, BP, sl. open to open
207-208			X		X		X			
211-212		2		S		B	X	X	X	35°, BP, tight and open
212-213				X	X					
213-214			X							
218-219		2	X	X	X					30°, BP, tight and open
219-220		3	X	X	X					20-30°, BP, tight to open
220-221		2								30°, BP, open
221-222		2	X							25-30°, BP, sl. open to open
222-223		3	X							30°, BP, open to tight
223-224		3	X			X			X	30°, BP, open; 60°, ⊥ to bedding, tight
224-225		5	X	X				X		30°, BP, open
225-226			X							

Table A3.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
226-227		4	X	X						20-30°, BP, open
227-228			X							
229-230			X							
230-231		2	X	S						5-25°, BP, tight
231-232		2	X							30-40°, BP, open
232-233		5	X							20-25°, BP, 4 open, 1 tight
233-234		2	X	X	X					10-40°, BP, tight and open
234-235		2	X							30-60°, BP, tight and open
237-238		2	X			X		X		30°, BP, sl. open to open
239-240		2	X							25°, BP, tight to sl. open
246-247			X							
248-249		2		S						25-30°, BP, tight to sl. open
249-250			S							
251-252		3	X					X		25-30°, BP, open
253-254				X						
258-259		2	X							30°, BP, tight and open
259-260		2	X	X				X		25-30°, BP, sl. open to open
260-261			X							
262-263			X							
270-271		4	X							25-30°, BP, tight to open
275-276		2	X							20-25°, BP, tight
277-278			S							
282-283				S		B		X	X	
289-290			X	X				X		
295-296	F			X				X		
307-308			X							
311-312				X				X		
315-316		2			X					30°, BP, tight
317-318		3		X						20-30°, BP, tight
318-319		2		X						25-30°, BP, tight to open
319-320		2								25-40°, BP, tight to open

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Table A3.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
320-321		2						X		20°, BP, tight
321-322		2								25-40°, BP, tight
322-323			X	X	X					
325-326		2	X	X				X		25-40°, BP, open
329-330	E	3		X				X		30°, BP, tight
332-333		2								30°, BP, sl. open
333-334				X	X	B			X	
336-337		6	X	X						30-45°, BP, open; 1 ⊥ to bedding, tight
337-338		3	X	X						25-35°, BP, tight to open
338-339		2								25-30°, BP, fairly tight to sl. open
339-340		3	X					X		25-30°, BP, open and sl. open; 1 ⊥ to bedding, tight
341-342				S						
343-344			X	X						
345-346		2	X	X						30°, BP, open
346-347		2	X	X						30-35°, BP, open
347-348			X							
348-349		2	X							20-25°, BP, almost tight
349-350		2	X	X						15+30°, BP, tight, open
350-351			X	S						
351-352		2		X						30°, BP, open
352-353		3		X						20-30°, BP, open
353-354		2	X	X	X			X		25-30°, BP, open
354-355			X							
355-356		3		X						30°, BP, sl. open to open
356-357		2								20-25°, BP, open
357-358		2		X						30-35°, BP, open
359-360		2	X	X						25-30°, BP, open
360-361		3		X						20-35°, BP, open to tight
365-366			S							
366-367				X						

Table A3.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per foot	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
369-370				X						
383-384				X	X			X		
389-390		2	X			B	X			⊥ to bedding; 30°, BP, open
394-395				X						
395-396		3	+++	X						⊥ to bedding; partially healed; 30°, BP, open

[a]Only those depth intervals obtained from the geologist's logs have an accuracy of 0.1 ft. Depth intervals from other logs were not as accurate.
[b]From geologist's log.
[c]The general format for the fracture description is: fracture angle relative to horizontal, type of fracture, and degree of fracture openness. Fracture descriptions are separated by semicolons.

LEGEND

X	=	Log response
S	=	Slight log response
?	=	Questionable due to log quality
***	=	Denotes top of log
+++	=	Denotes end of log
B	=	Baseline shift in log curve

1. BP – Bedding plane fracture; a fracture that occurs along the plane of bedding, which typically ranged from 25–40° as measured perpendicular to the long axis of the core.
2. Dip-normal fracture – Any fracture that is perpendicular to bedding; typically either parallel or perpendicular to strike.
3. Dip-parallel fracture – Any fracture that is parallel to bedding.
4. Low angle fracture – As measured perpendicular to the long axis of the core, a low angle fracture is generally at an angle less than bedding.
5. High angle fracture – As measured perpendicular to the long axis of the core, a high angle fracture is generally at an angle greater than bedding.
6. ⊥ – A dip-normal fracture; perpendicular to bedding.

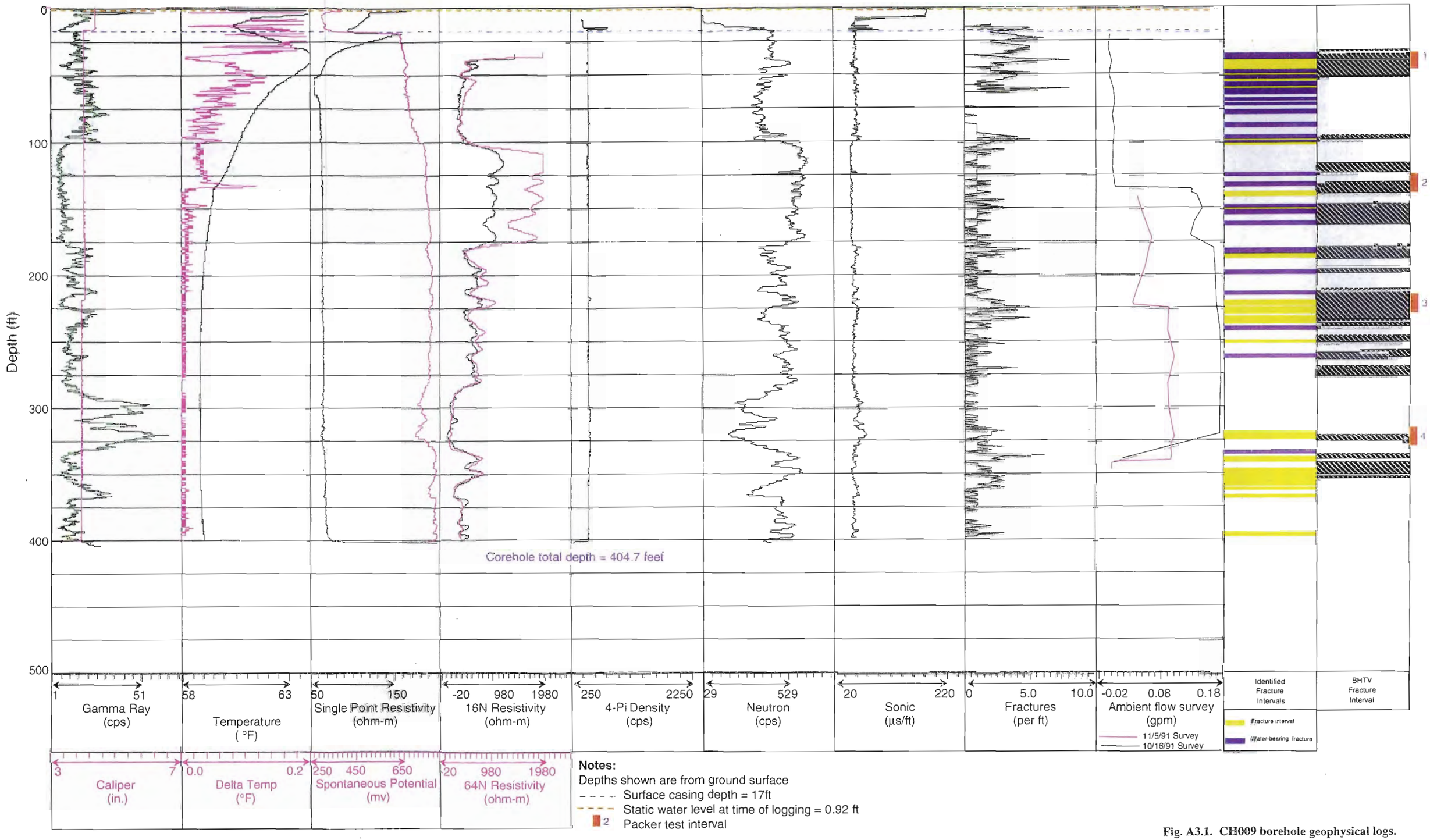


Fig. A3.1. CH009 borehole geophysical logs.

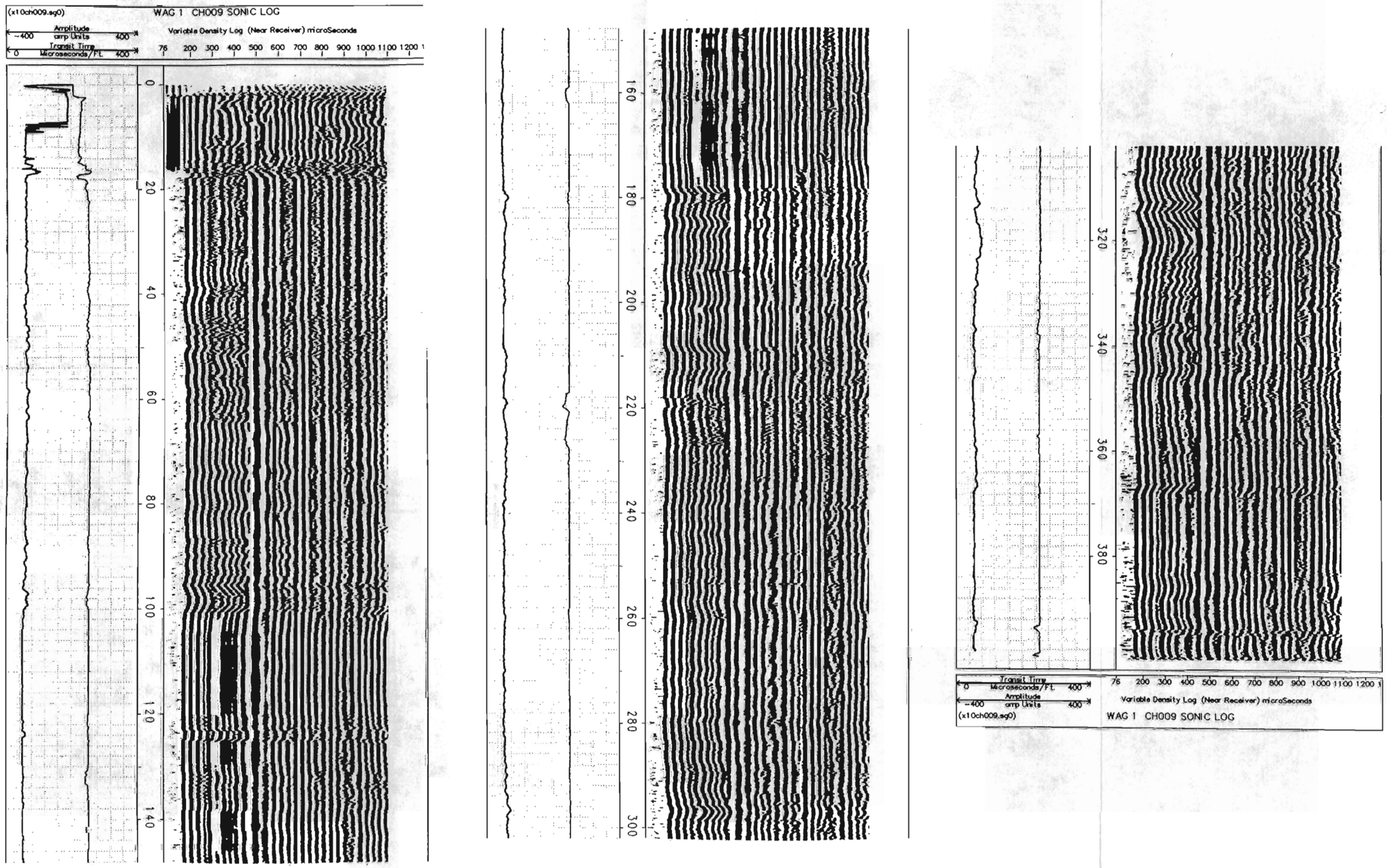


Fig. A3.2. CH009 variable density (acoustic) log.

ORNL DWG 91 7389

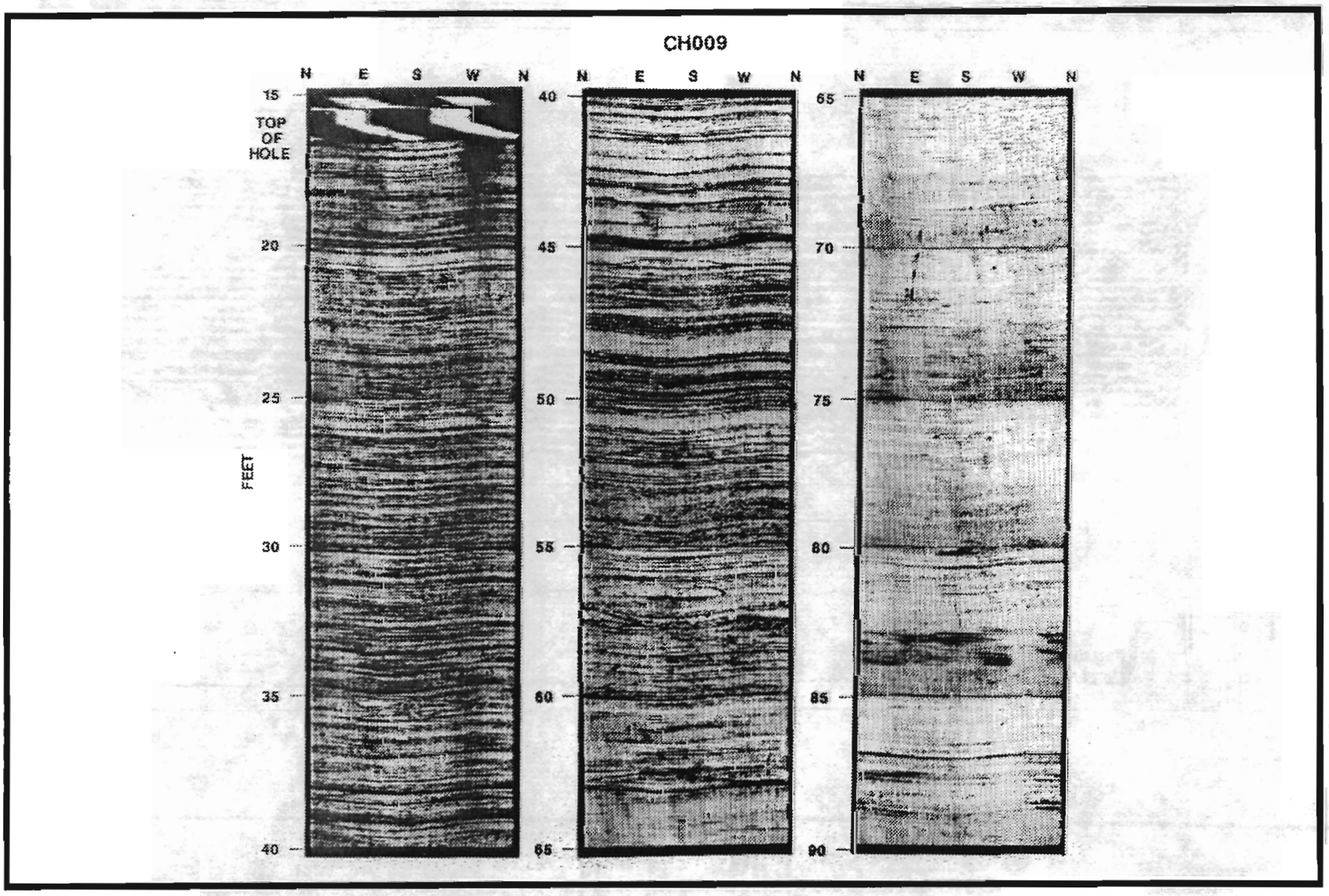


Fig. A3.3. CH009 borehole televiewer log.

5.27 5277.8

ORNL DWG 91 7390

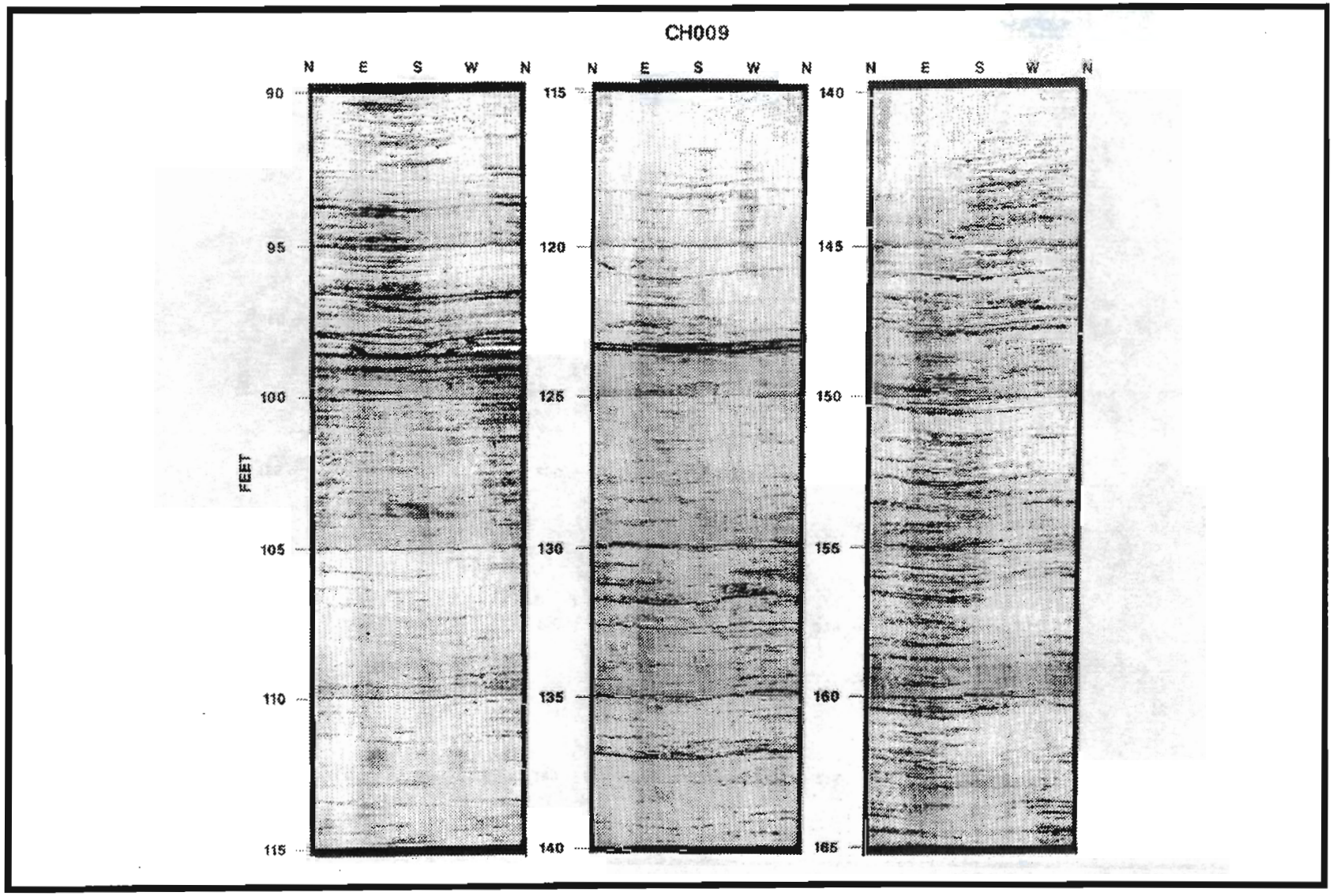
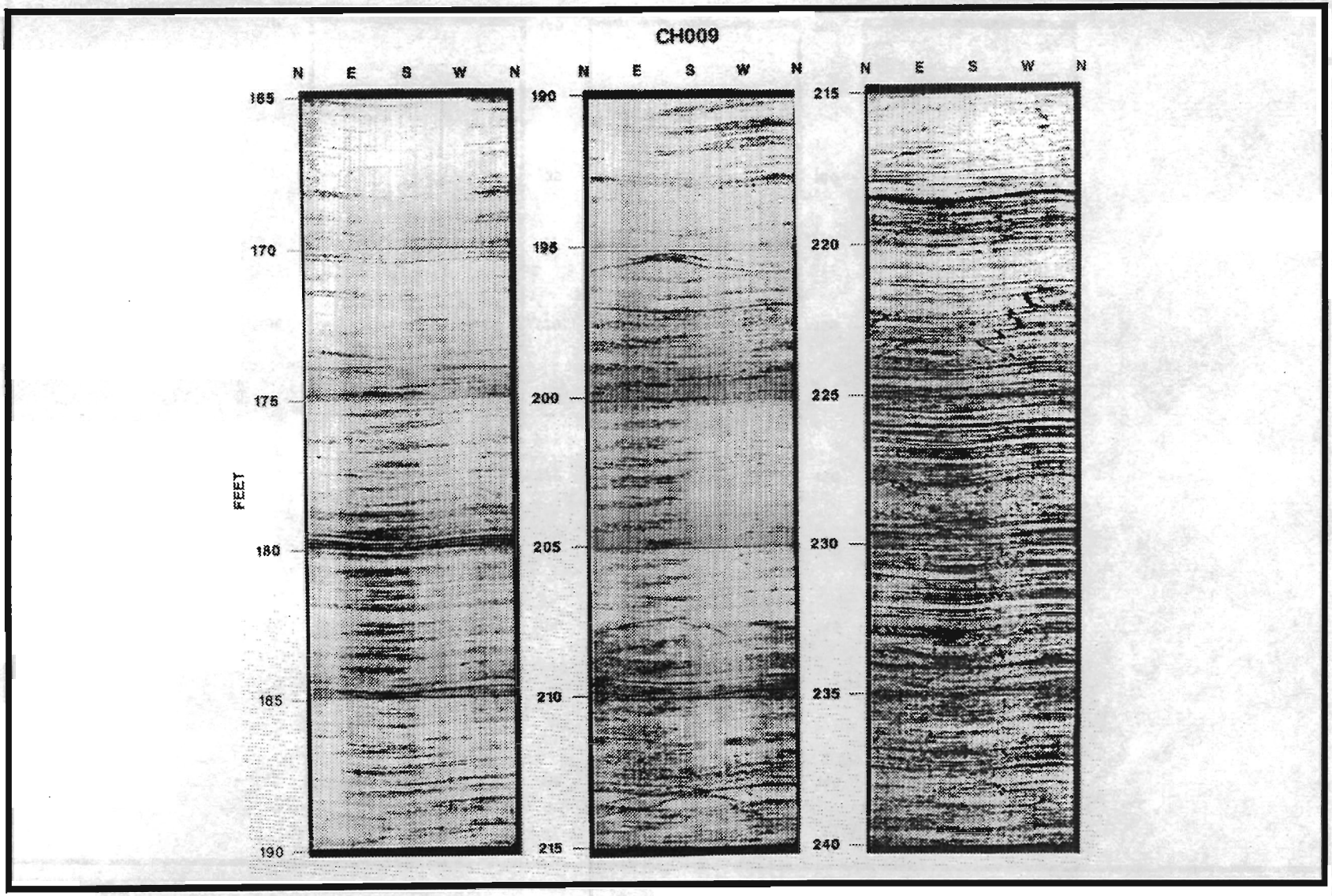


Fig. A3.3. (continued).

5.27 5277.9

ORNL DWG 91 7391



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5.27 5277.10

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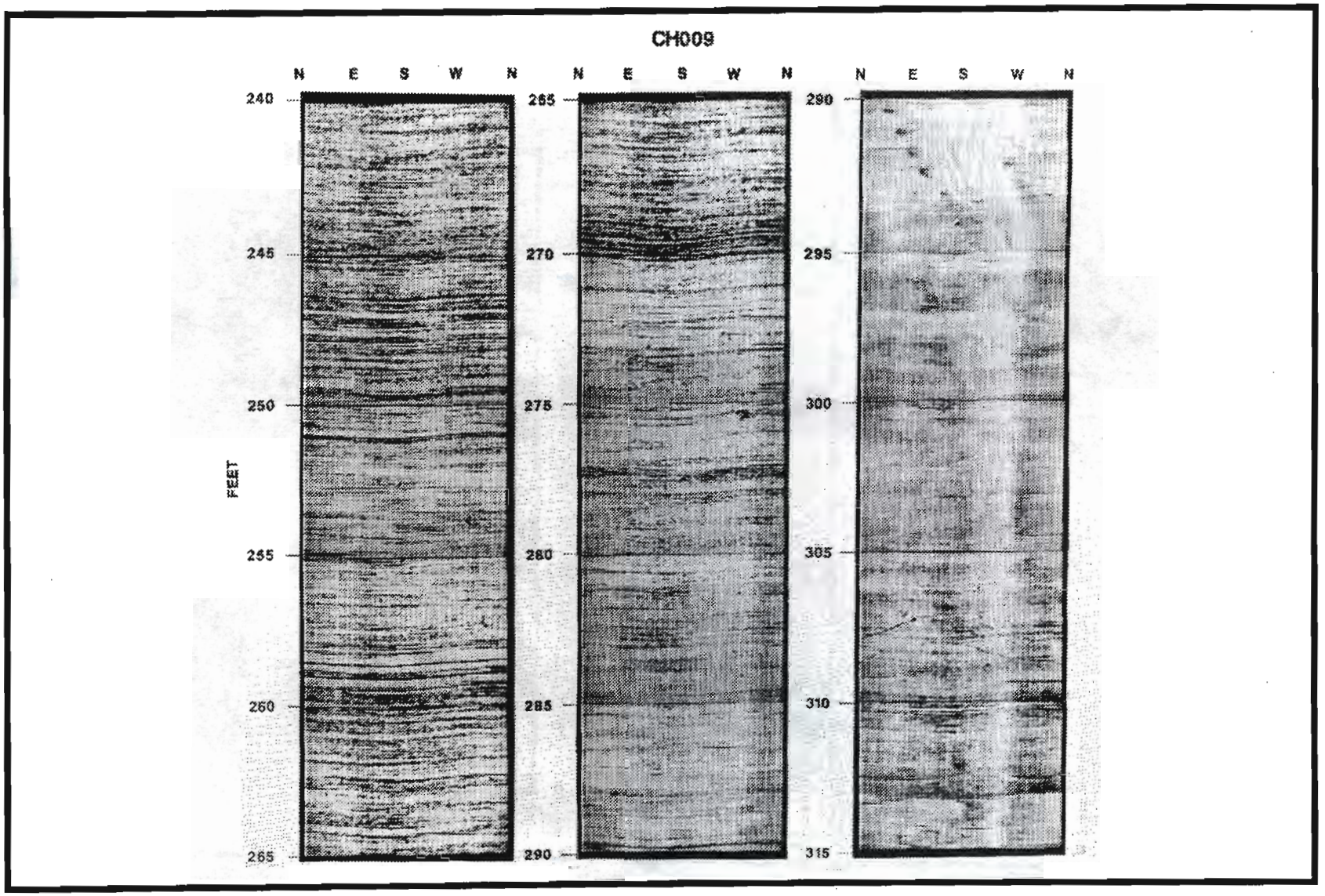


Fig. A3.3. (continued).

5.27 5277.11

ORNL DWG 91 7393

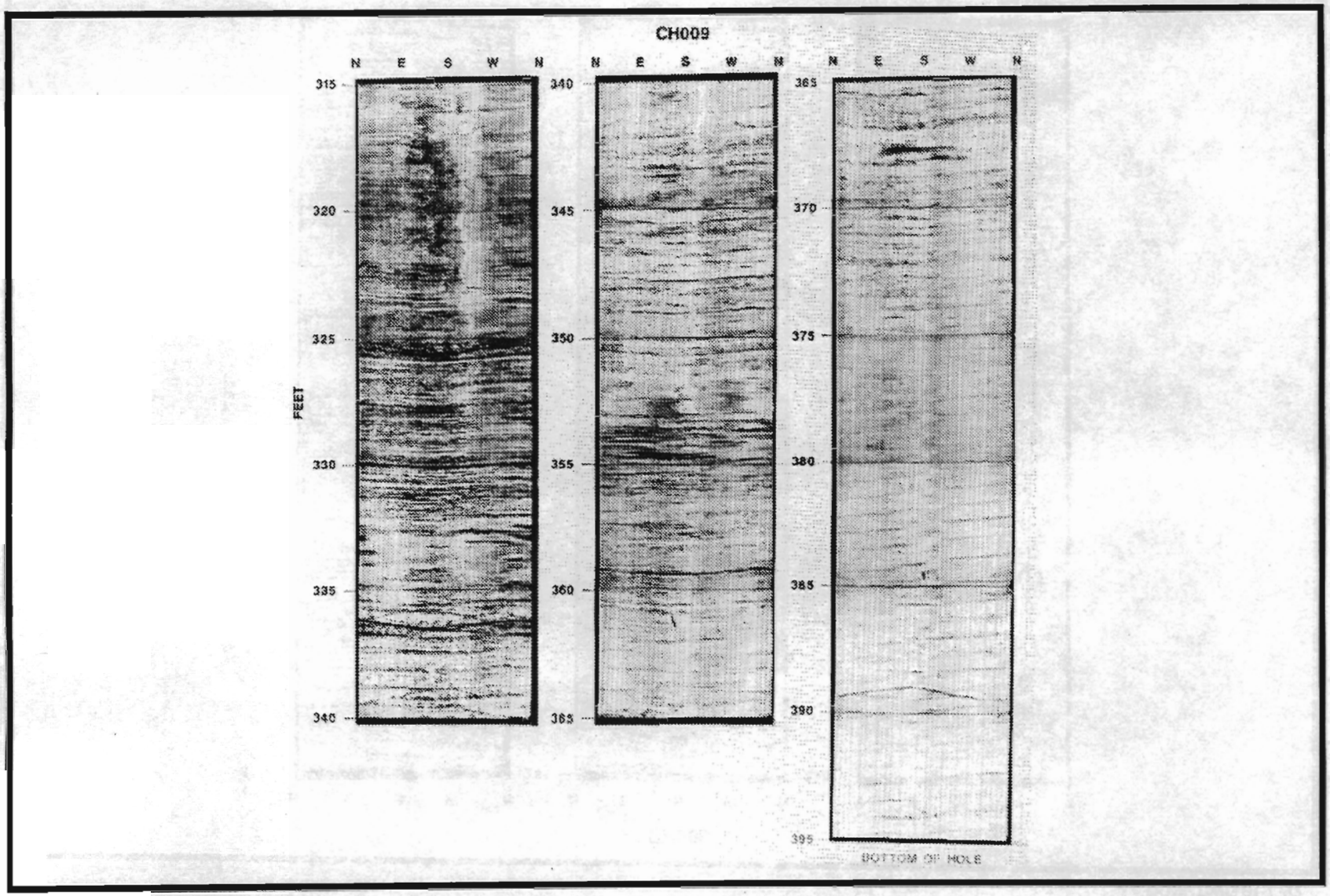
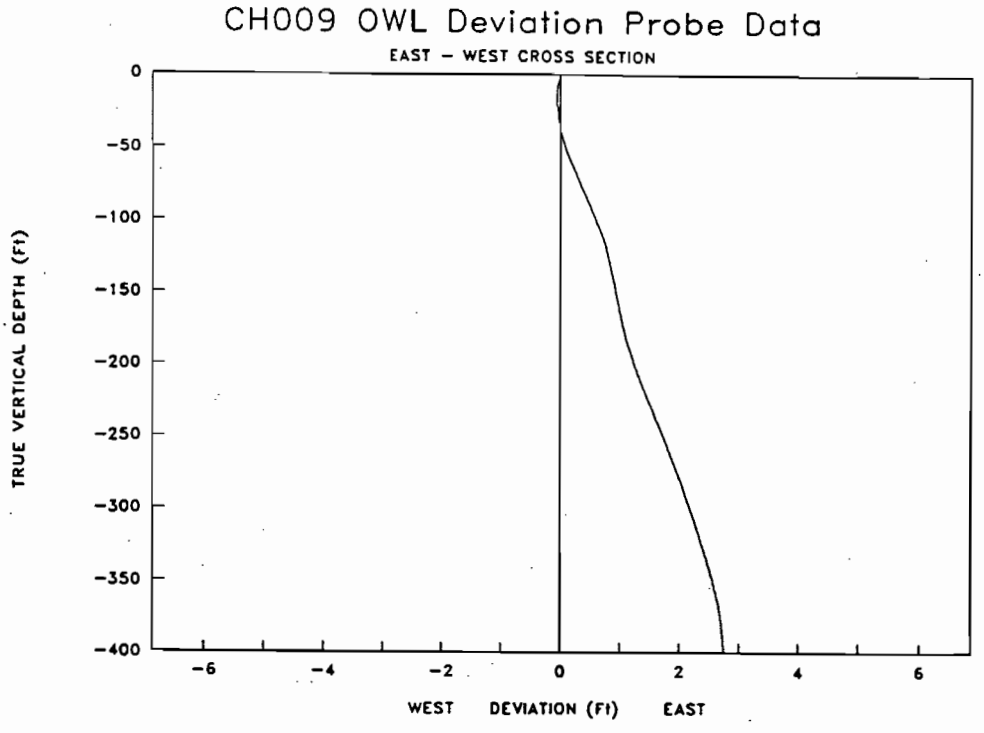


Fig. A3.3. (continued).

5.27 5277.12



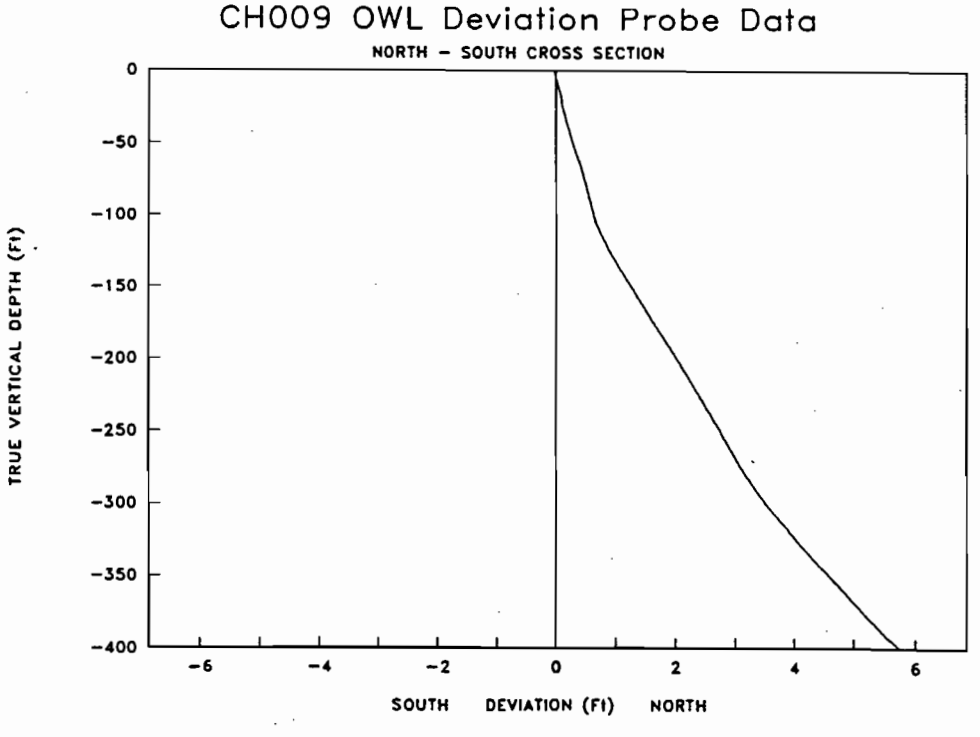
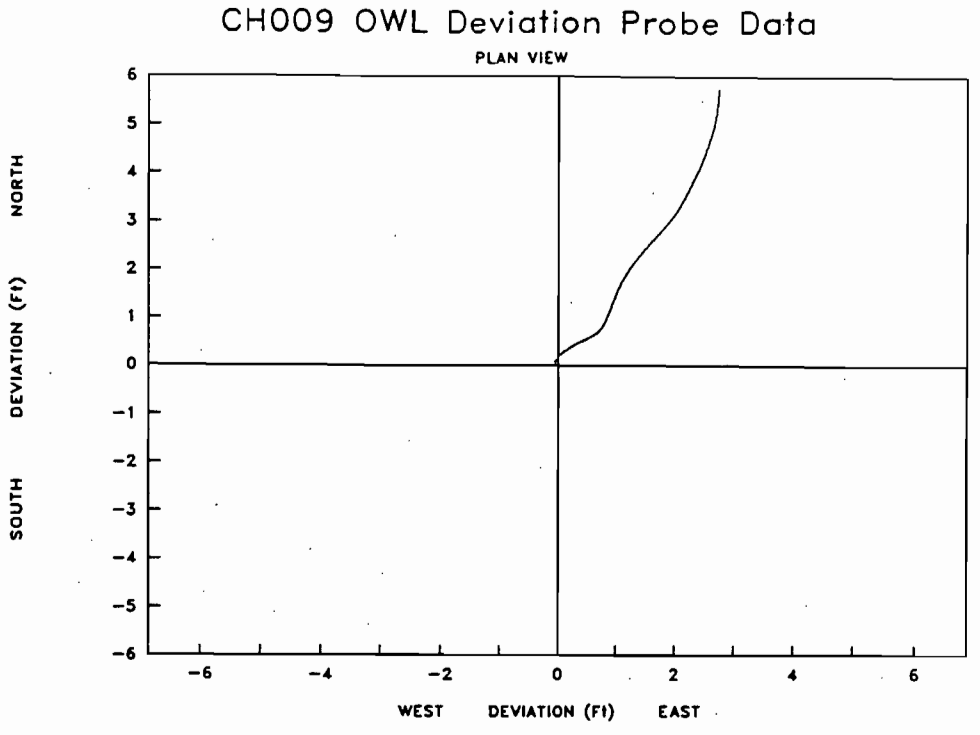


Fig. A3.4. CH009 OWL deviation probe data.



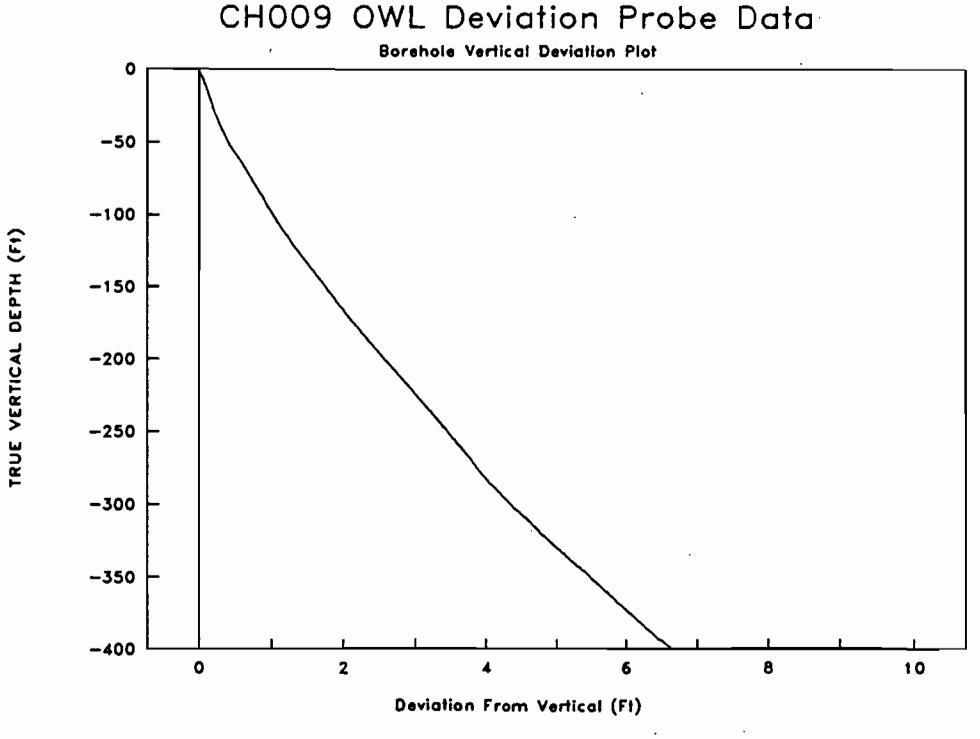


Fig. A3.4. (continued).

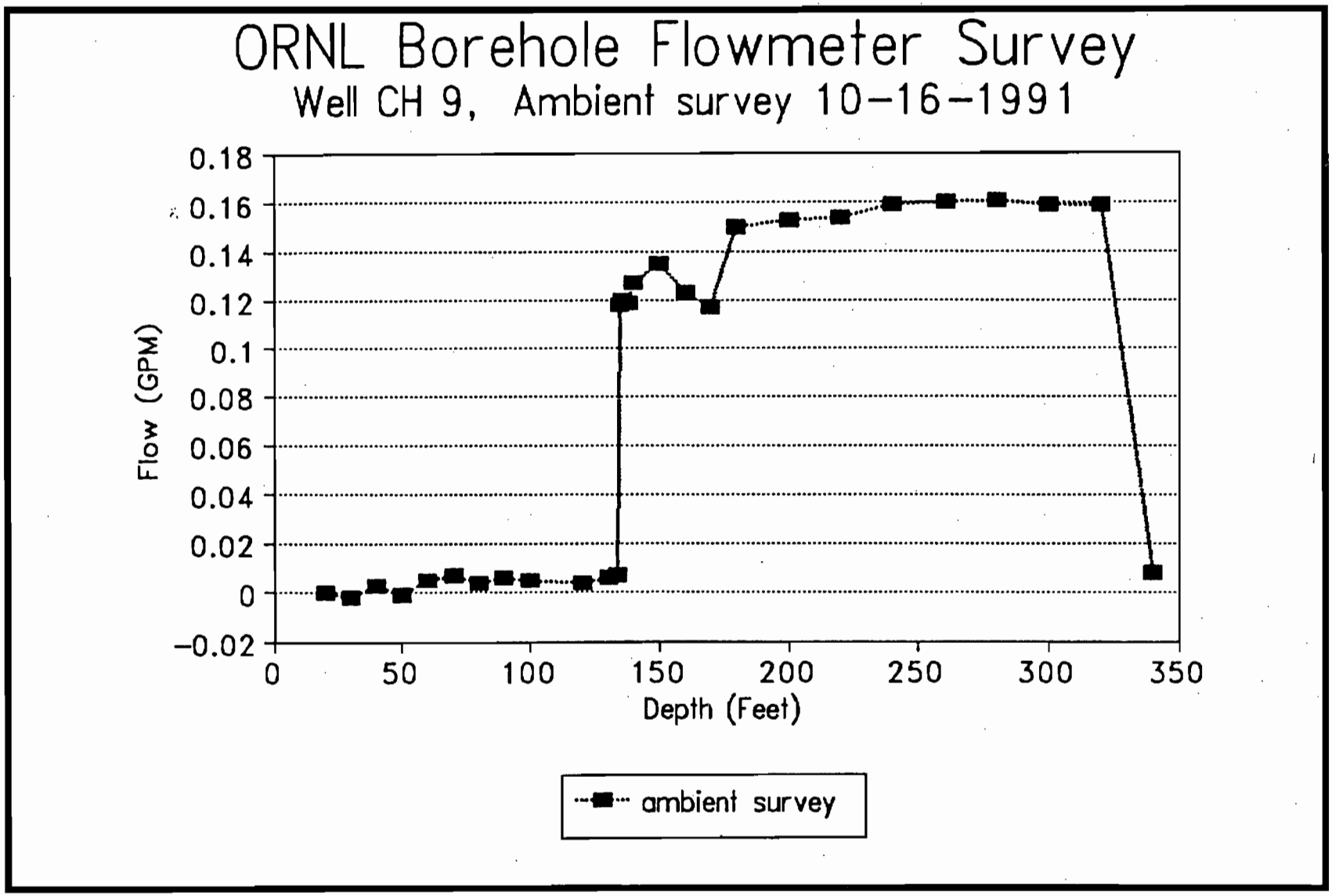


Fig. A3.5. CH009 ORNL borehole flowmeter survey.

ORNL Borehole flowmeter survey CH009, ambient survey October 16, 1991

ORNL Wells
10-16-1991 10:25:59
Well No. CH 9
CalFactor 0.47 Zero 0.02
Pump Rate 0
Ambient flow survey

Time	Flow[a] Volts	STD[b]	Flow[c] GPM	Depth[d] Feet
08:04:51	0.019	0.002	0.000	20
08:13:37	0.017	0.000	-0.002	30
08:20:23	0.027	0.016	0.003	40
08:28:51	0.018	0.001	-0.001	50
08:38:33	0.031	0.005	0.005	60
08:44:55	0.034	0.001	0.007	70
08:53:36	0.029	0.001	0.004	80
09:04:43	0.032	0.007	0.006	90
09:17:18	0.030	0.001	0.005	100
09:28:51	0.029	0.003	0.004	120
09:49:46	0.033	0.003	0.006	130
10:05:04	0.035	0.002	0.007	134
09:57:01	0.270	0.002	0.118	135
10:12:20	0.276	0.001	0.120	136
10:17:50	0.273	0.005	0.119	138
09:38:43	0.289	0.002	0.127	140
10:25:28	0.308	0.006	0.135	150
11:37:28	0.283	0.004	0.123	160
11:53:24	0.268	0.002	0.117	170
11:45:42	0.338	0.003	0.150	180
12:03:07	0.346	0.003	0.153	200
12:11:20	0.349	0.001	0.154	220
12:20:07	0.359	0.002	0.159	240
12:28:46	0.361	0.001	0.160	260
12:37:17	0.363	0.001	0.161	280
12:46:57	0.359	0.001	0.159	300
12:57:25	0.358	0.000	0.159	320
13:06:30	0.038	0.008	0.008	340

[a]Volts column is analog signal from the flowmeter.
[b]STD column is standard deviation of the analog signal.
[c]Ambient surveys measure natural flow (no injection) in the corehole. A plus sign means flow up the hole. Flow rate is gallons per minute.
[d]Depths are measured from top of inner casing.

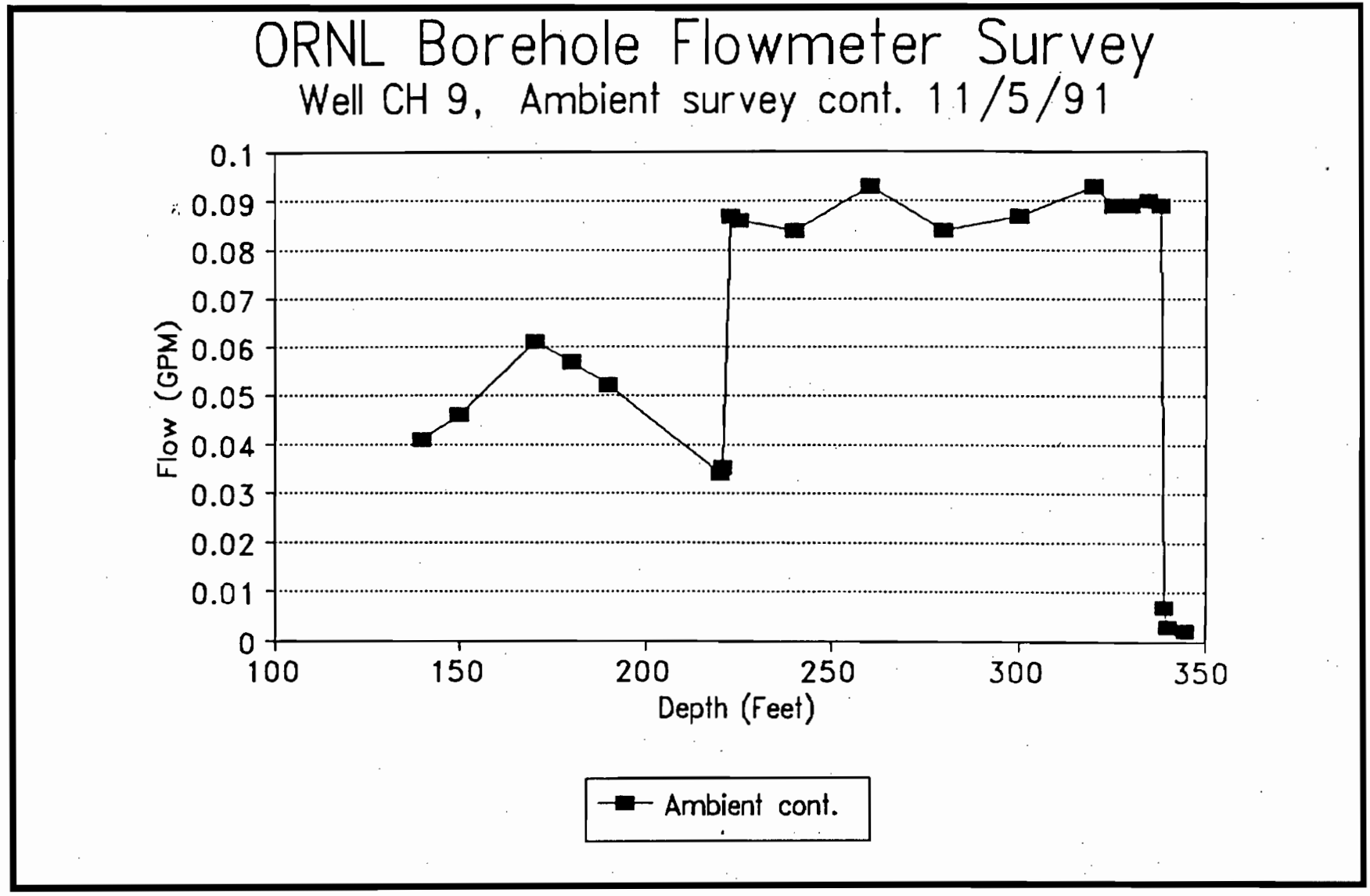


Fig. A3.5. (continued).

ORNL Borehole flowmeter survey CH009, ambient survey November 6, 1991

CH 9X2 Ambient flow Filenmae: CH9X2.PRN
11-05-1991 11:28:03
Well No. CH 9
K= 0.47 Z= 0.02
Pump Rate 0
Ambient flow cont.

TIME	VOLTS[a]	STD[b]	FLOW[c] GPM	DEPTH[d] FEET
09:30:19	0.107	0.002	0.041	140
09:39:35	0.117	0.003	0.046	150
09:48:35	0.150	0.003	0.061	170
09:56:03	0.141	0.005	0.057	180
10:05:52	0.130	0.001	0.052	190
13:13:32	0.093	0.002	0.034	220
13:40	0.095		0.035	221
13:25:53	0.205	0.002	0.087	223
13:20:14	0.202	0.003	0.086	225
13:06:02	0.198	0.002	0.084	240
12:29:41	0.217	0.001	0.093	260
11:19:35	0.199	0.002	0.084	280
11:12:14	0.206	0.001	0.087	300
10:19:13	0.217	0.001	0.093	320
10:25:36	0.210	0.002	0.089	325
10:31:41	0.210	0.001	0.089	330
10:37:49	0.212	0.001	0.090	335
10:57:01	0.208	0.001	0.089	338
11:04:13	0.035	0.001	0.007	339
10:44:04	0.027	0.002	0.003	340
10:51:07	0.024	0.001	0.002	345

[a]Volts column is analog signal from the flowmeter.
[b]STD column is standard deviation of the analog signal.
[c]Ambient surveys measure natural flow (no injection) in the corehole. A plus sign means flow up the hole. Flow rate is gallons per minute.
[d]Depths are measured from top of inner casing.

ATTACHMENT 4

CH11A—GEOPHYSICAL AND GEOLOGIC DATA

Table A4.1. Summary of fractures identified in corehole CH11A

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
			*** (13)							
19-20	G	5	X	X						25-40°, BP, open to sl. open
20-21		3	X							35°, BP, open
21-22		5	X	X						20-40°, BP, open
22-23		2	X							30°, BP, tight and open
23-24		4	X	X	X	B				30-40°, BP, open to tight; ⊥ to bedding, slightly open
24-25			X	X		B				
25-26		2	X	X						25-50°, BP, open
26-27		3	X			B	X			30-40°, BP, open
28-29		3	X	X			X			30-35°, BP, sl. open
29-30		2					X			30°, BP, sl. open to open
30-31		3	X	X	X	B	X			35°, BP, open; ⊥ to bedding
31-32		3	X	X						30°, BP, calcite mineralization, sl. open to open
32-33		3	X	X						20-30°, BP, open
33-34		2					X			35-40°, BP, tight and open
34-35			X			B				
36-37		3	X							30-35°, BP open
37-38		2	X							25-30°, BP, open
39-40		3								35-40°, BP, sl. open to open
40-41		3	X	X		B				35°, BP, open
41-42		2	X	X						30-35°, BP, open
43-44		3				B				30-35°, BP, open
44-45		2	X				X			30-40°, BP sl. open to open
45-46		3			X		X			30-40°, BP sl. open to open, some calcite mineralization
47-48						S				
48-49		2				X				35°, BP, sl. open to open
49-50			X	X			X			
50-51		3		X	X	X				30-50°, BP, sl. open to open, some calcite mineralization
53-54			X		X	X		X		

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Table A4.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
55-56							X			
63-64		4	X	X	X	X	X			30°, BP, open - thick calcite layer on bottom of fracture; ⊥ to bedding, tight; 20-30°, BP, open
66-67			X		X	X				
67-68	F	2	X	X						30-35°, BP, sl. open to open
68-69		4	X		X					28-37°, BP, sl. open to open; ⊥ to bedding plane, tight
70-71		5	X	X						35°, BP, sl. open to tight
71-72		6	X	X	X					35°, BP, sl. open to tight
72-73		3								30-37°, BP, tight
73-74				X	X	X			X	
75-76			X	X				X		
76-77				S						
79-80		2								30°, BP, tight to sl. open
80-81		2								30°, BP, open
81-82		2		X						30°, BP, sl. open; ⊥ to bedding, open
83-84		3	X	X		B				30°, BP, open
85-86				X		X	X			
86-87		3	X	X	X					25-35°, BP, sl. open to open; ⊥ to bedding, sl. open
89-90					?	B				
91-92				X						
92-93		4	?							30-50°, BP, sl. open to open
93-94		4	X		X					30°, BP, sl. open to open
94-95		6	X			X	X			30-35°, BP, sl. open to tight
95-96		3	X	X						25-40°, BP, open
96-97		4	?	X						26-30°, BP, open
97-98		4	?	X			X			28-32°, BP, open
98-99	E	2	X							30°, BP, tight
100-101		3	X	X						30°, BP, sl. open to open; ⊥ to bedding, open
101-102		2	X	X			X			30-35°, BP, sl. open to open

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Table A4.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
102-103		3	?			X	X			28-31°, BP, sl. open to open
103-104		3	X			B	X	X		30-35°, BP, open
106-107			?						S	
108-109						X	X		X	
112-113		2			X	X	X		X	30°, BP, open; ⊥ to bedding, open
114-115					?	X	X	X		
120-121		2	X			B		X	X	25-30°, BP, open; calcite mineralization
121-122		2		X						30°, BP, open; calcite mineralization
122-123		2	X		X				X	34-35°, BP, open
124-125			X			X			X	
125-126			X	s						
126-127		3	X				X			30-37°, BP, sl. open to tight
127-128		3	?		X					22-32°, BP, open
129-130					X		X	X		
132-133		2			X		X			30-32°, BP, open
133-134							X			
134-135			?					X		
136-137			+++		X	X				
141-142		2		X			X			30-34°, BP, open
142-143				X		X				
146-147		2				B		X	X	35°, BP, sl. open to open
153-154		2						X		35°, BP, open
155-156					X					
158-159				S			X		X	
162-163						B	S	X	X	
165-166					S			X		
170-171		2						X	X	35-37°, BP, open, calcite mineralization
173-174						B			X	
179-180						X	X	X		
182-183					S			X		

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Table A4.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
184-185					S					
186-187									X	
187-188		0						X		Healed fracture (calcite filled), 35°
189-190				S	S		X	X		
192-193							X		X	
197-198				S	X					
203-204					X			X	X	
211-212							X			
213-214		2			X					35-39°, BP, sl. open to open
214-215					S			X		
216-217						B				
222-223					X					
223-224		2								30°, BP, open
225-226		3		X	X					30-35°, BP, sl. open to open
226-227		4		X		X				30-35°, BP, sl. open to open
227-228		3		X						22-32°, BP, sl. open to open
228-229		3		X	X			X		30-32°, BP, sl. open to open
231-232		2						X		30°, BP, sl. open to open
232-233		2								25°, BP, open
233-234						B	S	X		
237-238		2		S	X		S	X		25-30°, BP, open, calcite mineralization
245-246				S	X	X		X		
247-248					X					
252-253					X			X		
256-257				S	X			X	X	
258-259				S			S		X	
262-263				S						
263-264					X					
266-267					X	B				
271-272									S	

Table A4.1 (continued)

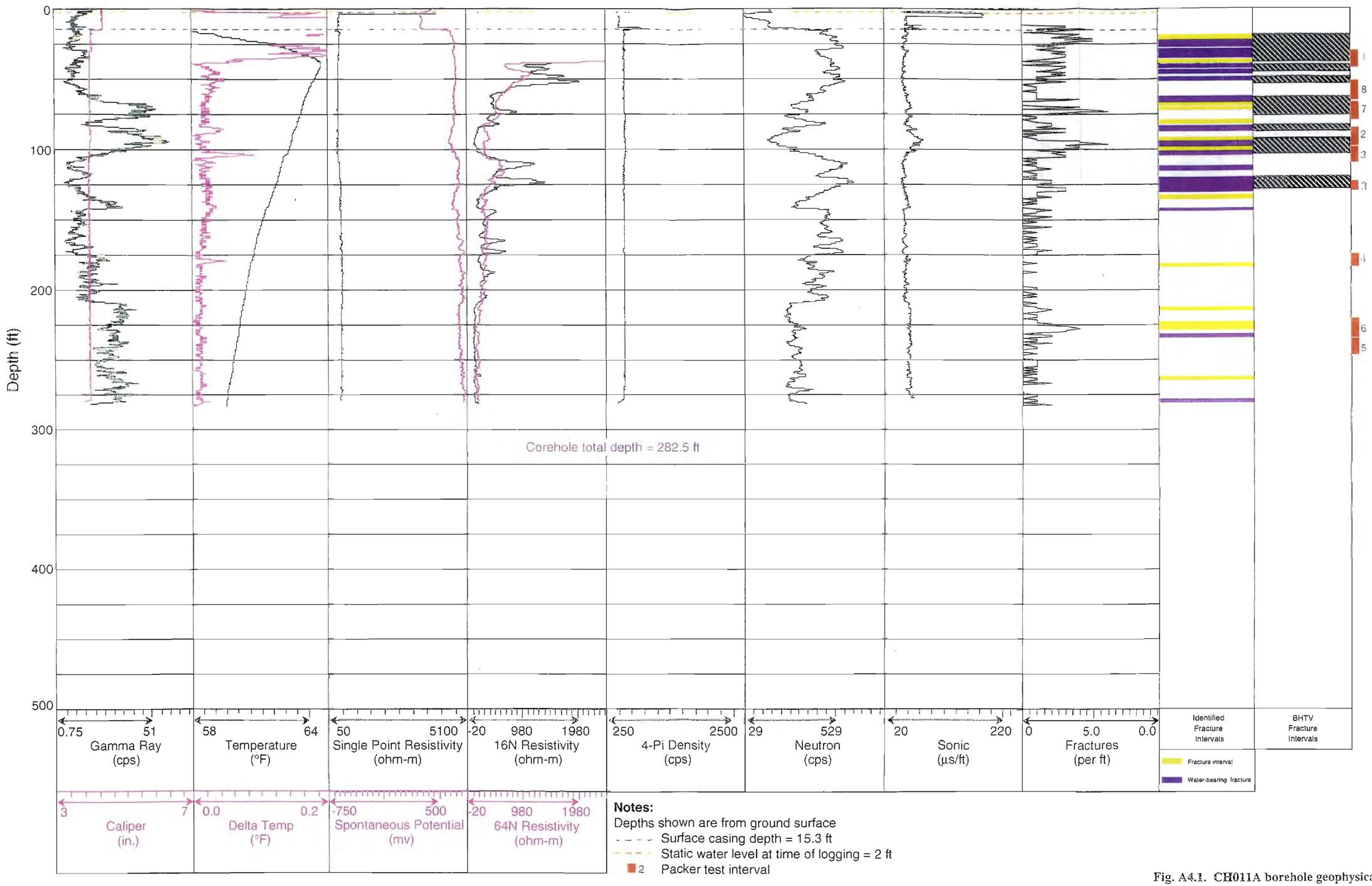
Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	Deviation survey	SP	Comments
275-276				S						
278-279						X				
279-280							S			
281-282		2								30-34°, BP, open

[a]Only those depth intervals obtained from the geologist's logs have an accuracy of 0.1 ft. Depth intervals from other logs were not as accurate.
[b]From geologist's log.
[c]The general format for the fracture description is: fracture angle relative to horizontal, type of fracture, and degree of fracture openness. Fracture descriptions are separated by semicolons.

LEGEND

X	=	Log response
S	=	Slight log response
?	=	Questionable due to log quality
+++	=	Denotes end of log
***	=	Denotes top of log
B	=	Baseline shift in log curve

1. BP – Bedding plane fracture; a fracture that occurs along the plane of bedding, which typically ranged from 25–40° as measured perpendicular to the long axis of the core.
2. Dip-normal fracture – Any fracture that is perpendicular to bedding; typically either parallel or perpendicular to strike.
3. Dip-parallel fracture – Any fracture that is parallel to bedding.
4. Low angle fracture – As measured perpendicular to the long axis of the core, a low angle fracture is generally at an angle less than bedding.
5. High angle fracture – As measured perpendicular to the long axis of the core, a high angle fracture is generally at an angle greater than bedding.
6. ⊥ – A dip-normal fracture; perpendicular to bedding.



Notes:
Depths shown are from ground surface
Surface casing depth = 15.3 ft
Static water level at time of logging = 2 ft
2 Packer test interval

Fig. A4.1. CH011A borehole geophysical logs.

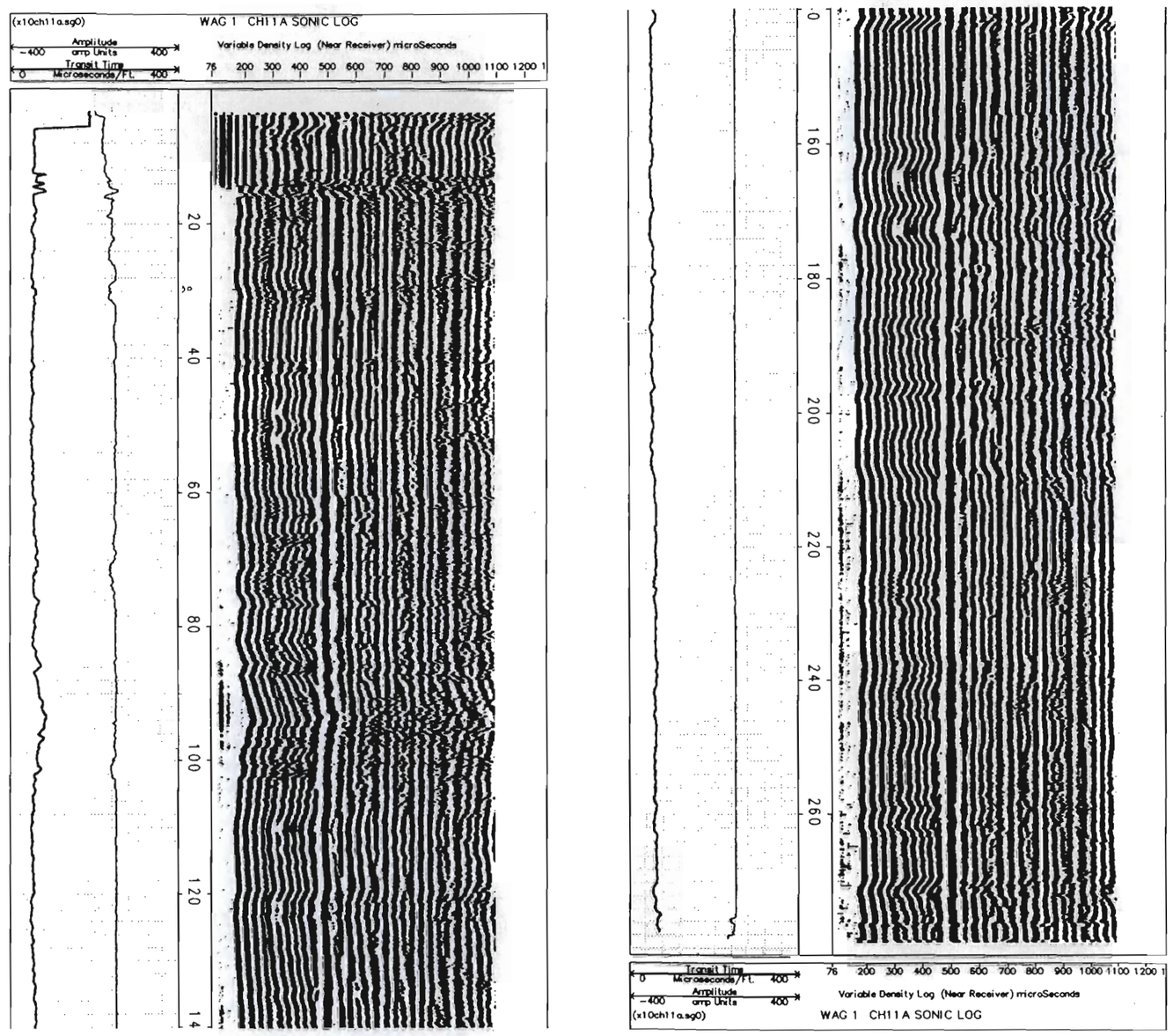


Fig. A4.2. CH011A variable density (acoustic) log.

ORNL DWG 91 7386

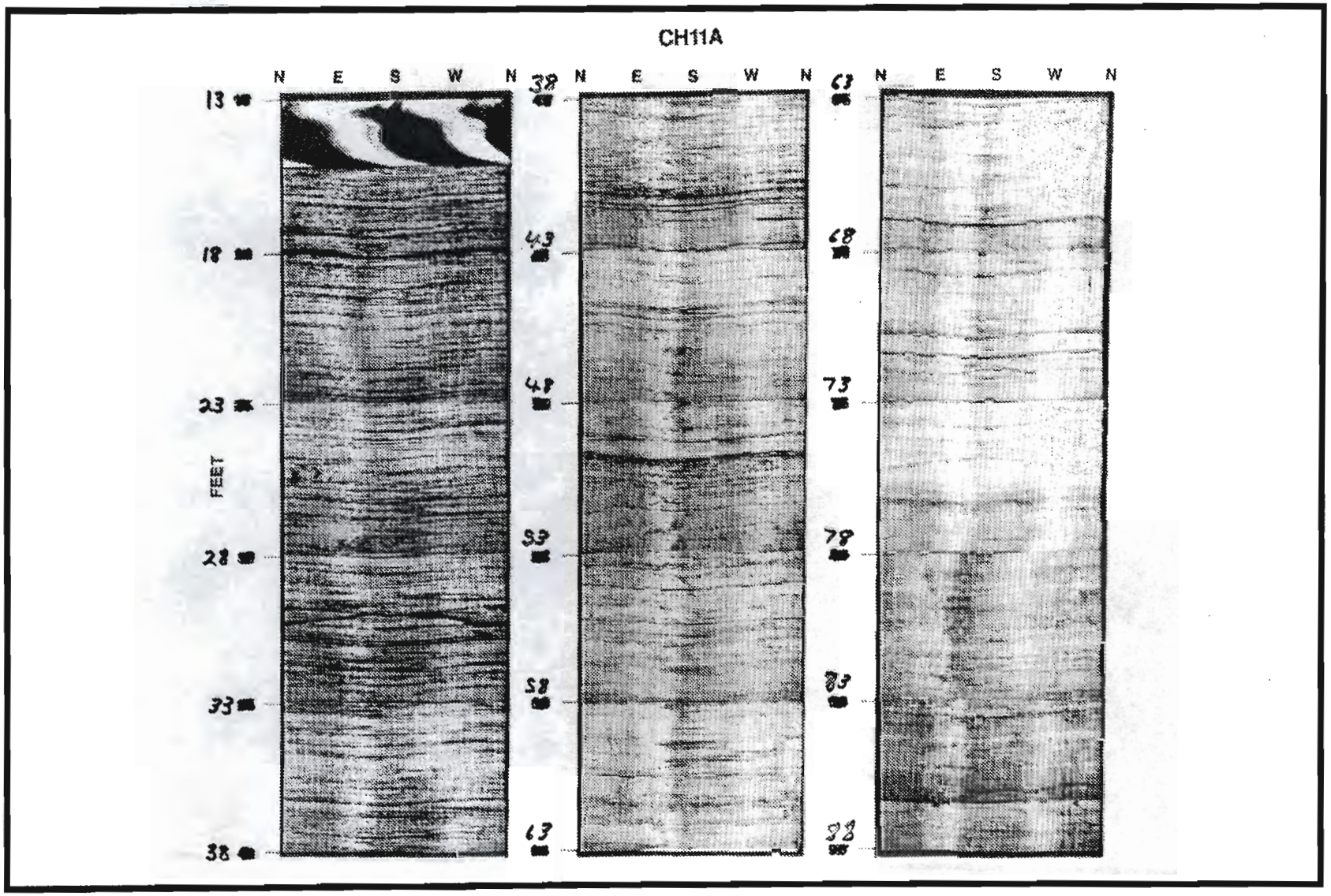


Fig. A4.3. CH11A borehole televiewer log.

5.27 5277.13

ORNL DWG 91 7385

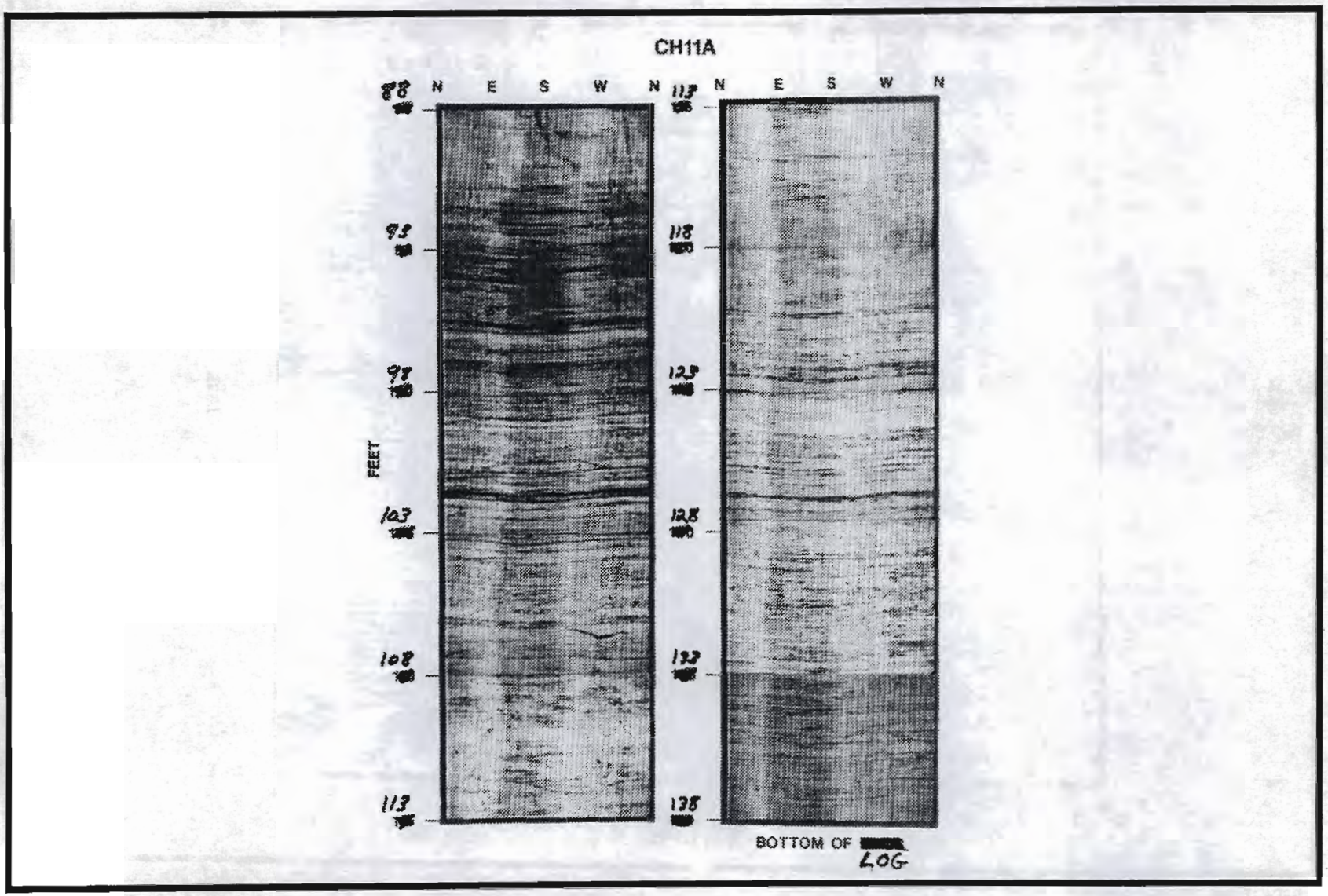
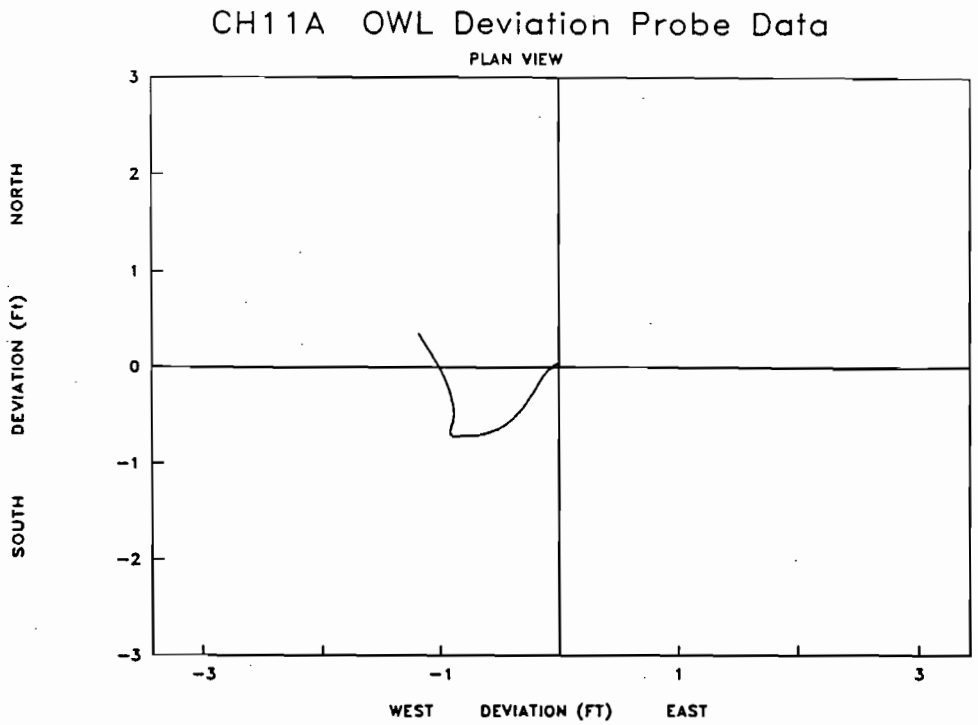


Fig. A4.3. (continued).

5.27 5277.14



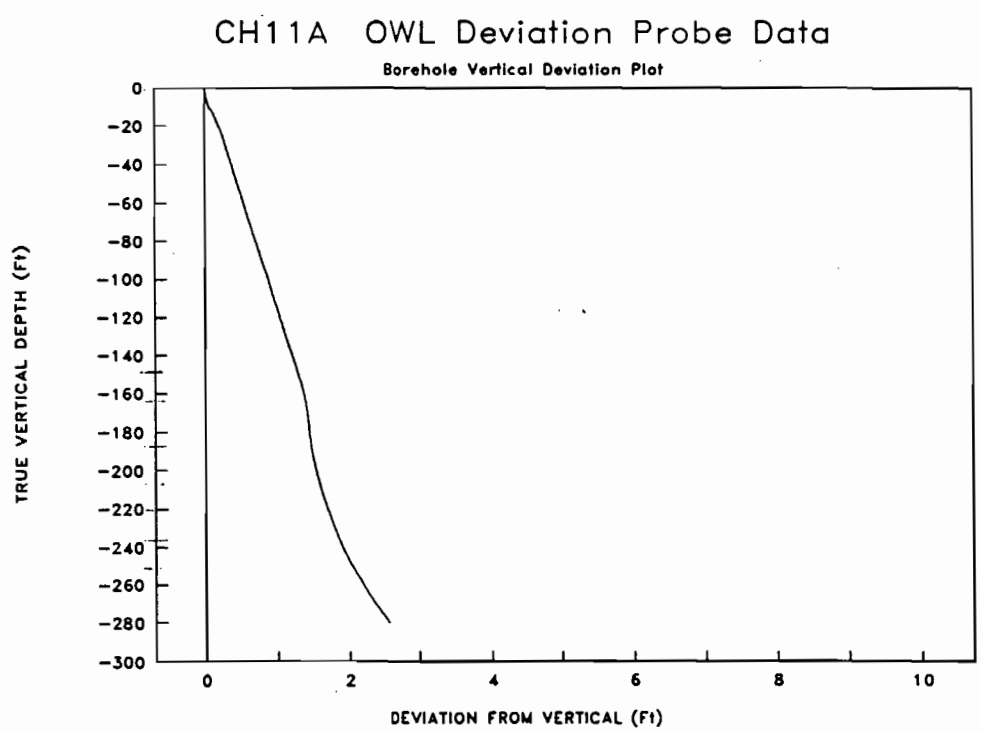
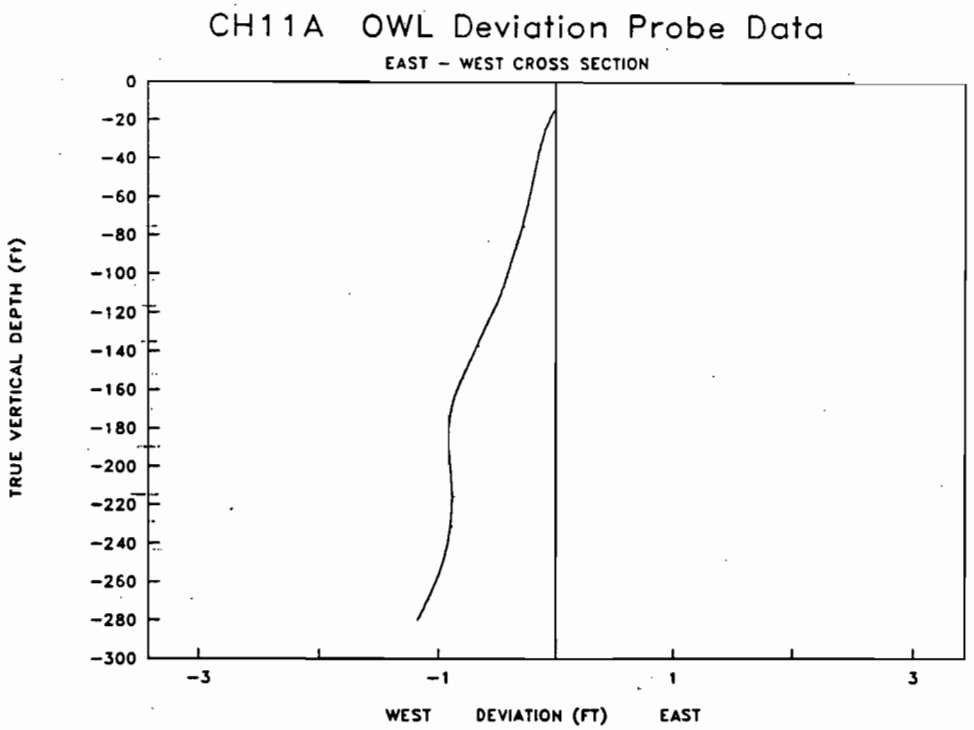


Fig. A4.4. CH011A OWL deviation probe data.



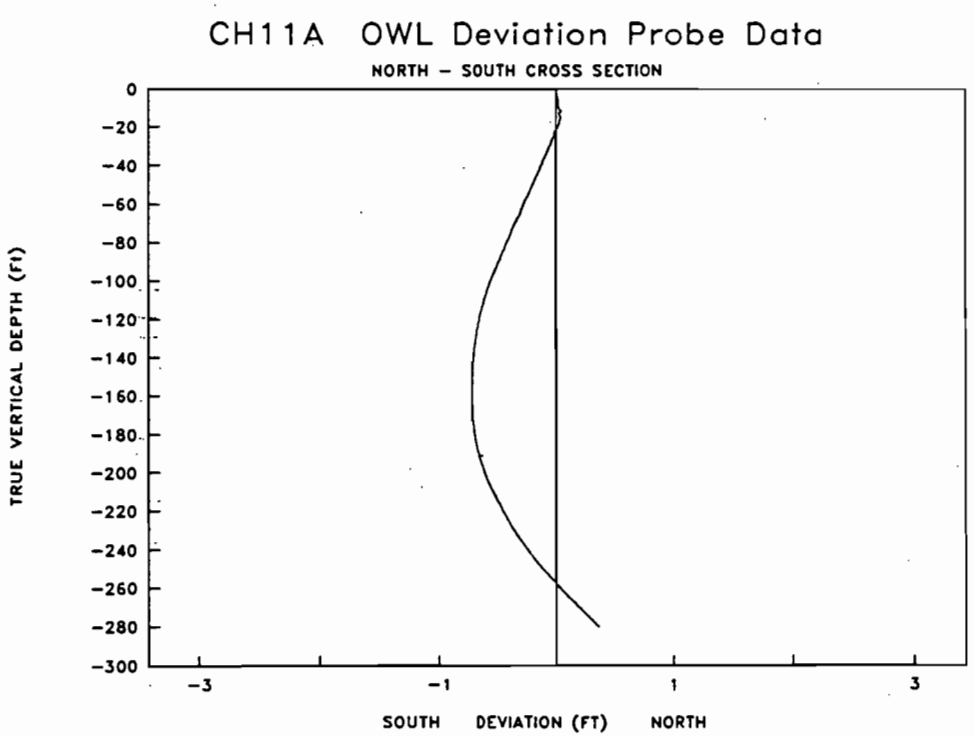


Fig. A4.4. (continued).

ATTACHMENT 5

CH012—GEOPHYSICAL AND GEOLOGIC DATA

Table A5.1. Summary of fractures identified in corehole CH012

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Comments[c,d]
			*** (15)						Dip-normal, dip-parallel fracture set is high
19.1-20.1	H	2							angle, strike is tight, dip is open
23.1-24.1		3	X	X					28°, BP, open; ⊥ to core axis, tight and open, calcite crystals
24-25			?						
25-27			X	X	X				
28.1-29.1		5	X						22-33°, BP, open to tight; 0°, fracture surface, tight
29.1-30.1		2	X						30°, BP, open; 43°, high angle fracture, sl. open
30.4-31.4		3	?	X		B			28-30°, BP, open, calcite mineralization
32.4-33.4		3	?	X		X			28-30°, BP, sl. open, calcite mineralization
34.4-35.4		4	?	X		X		S	30°, BP, fairly tight, calcite fill; open fractures
35.4-36.4		2	X						28-30°, BP, open
36.4-37.4		4	?			B	X		28-30°, BP, sl. open to tight; small ⊥ to bedding open fracture
38.4-39.4		2	X	X			X		30°, BP, calcite mineralization
39.4-40.4		3	X	X					10-20°, low angle fracture, sl. open to tight; 30°, BP
40.4-41.4		2							28°, BP, sl. open
44.4-45.4		2					X		30°, BP; ⊥ to bedding sl. open fracture
45.4-46.4		2	?		X				30°, BP, tight; large subvertical open fracture
48.4-49.4		3	X			X	X		30°, BP, sl. open
61-63			X	X					
63.4-64.4		2	?				X		35°, BP, sl. open; 30° fracture ⊥ to bedding, open
65-66			X			X	X		
67.4-68.4		2				X			High angle (40°) ⊥ to bedding fracture; high angle (50°) parallel bedding fracture, ⊥ to previous fracture
70.4-71.4		3	X	X			X		30°, BP, open and tight
74-76							?		
79-80			X	X		B		S	
82.4-83.4		2	X		X		X		26°, BP, tight
86-87			X	X					
87.4-88.4		2		X		X	X		28°, BP, tight

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Table A5.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Comments[c,d]
92-93			X	?			X		
95-97			X	X		B	X		
101-102			?						
102-103			X	X		X	X		
111.4-112.4		2	?						29-32°, BP, tight
113.4-114.4		2							20-22°, BP, tight
126-127			X		X				
127-128				X		X			
128.2-129.2		2		X			X		25°, BP, sl. open to tight
130.2-131.2		2	X	X					23°, BP, sl. open to open
131-132				X					
132-133			X				X		
136-137							X		
141-143			X	X	X	B		S	
143-145				X		B			
151-152			X	X			X		
152.2-153.2	?	3	?	X			X		47°, high angle fracture, open; low angle fracture surface, open
153-154.2	G		X	X	X	X	X		
156.2-157.2	?	3	X	X		X			33-40°, BP, sl. open to tight
157.2-158.2		3	X	X					35°, BP, sl. open
159.2-160.2		4	?				X		30°, BP, sl. open to tight
165.2-166.2		2	X			B			26°, BP, tight
168-169			X			B	X		
174.2-175.2		2							24-28°, BP, tight
175-176				S	X		X		
176.2-177.2		2	X						28-34°, BP, sl. open to tight
179-180						X			
181-182			X						
182-183			X		X	X			
184.2-185.2		2							40-43°, BP, tight
187-188			?						
188.2-189.2		2	X						33-35°, BP, tight
192-193			X						
193-195				S					

Table A5.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Comments[c,d]
198.2-199.2		2	X						30°, BP, tight
199.2-200.2		3	X	X		B			27-32°, BP, sl. open to tight
200.2-201.2		2	X	X	X				27-29°, BP, tight
202.2-203.2		3	?						25-30°, BP, tight; 18°, low angle fracture, sl. open
203-204			?						
204.2-205.2		2							23-24°, BP, tight
205-206			X						
206-207			?	X					
207.2-208.2		2	X	X	X				27°, BP, tight; 39°, high angle fracture, tight
210.2-211.2		>10	?						>10 fracture surfaces, predominantly BP that average 30°
212-213			?		X				
215-216			?						
216-217			X	X					
217-218			?		X				
218-219			?						
219-220				S					
221-222			X						
222-223			X	S					
223.1-224.1		4	?	X	X				22-25°, BP, tight
225-226			X	X					
226.1-227.1		2		X					20°, BP, open and tight
228.1-229.1		4	X		X	X			20-25°, BP, open to tight
229.1-230.1		3		X		X			23-28°, BP, sl. open to open
231.1-232.1		5	X	X					20-25°, BP, sl. open to tight
232.1-233.1		5	?	S					Low angle fracture, sl. open; 20-23°, BP, sl. open to tight
233-234			X	X	X				
234.1-235.1		2		X					25-27°, BP, tight
235.1-236.1		3	X	X					20°, BP, open and tight
239-240				S		X			
249-251			X	X		X			
257.0-258.0		2		S	X			S	21°, BP, tight; 40°, high angle fracture, tight
259-260				X					

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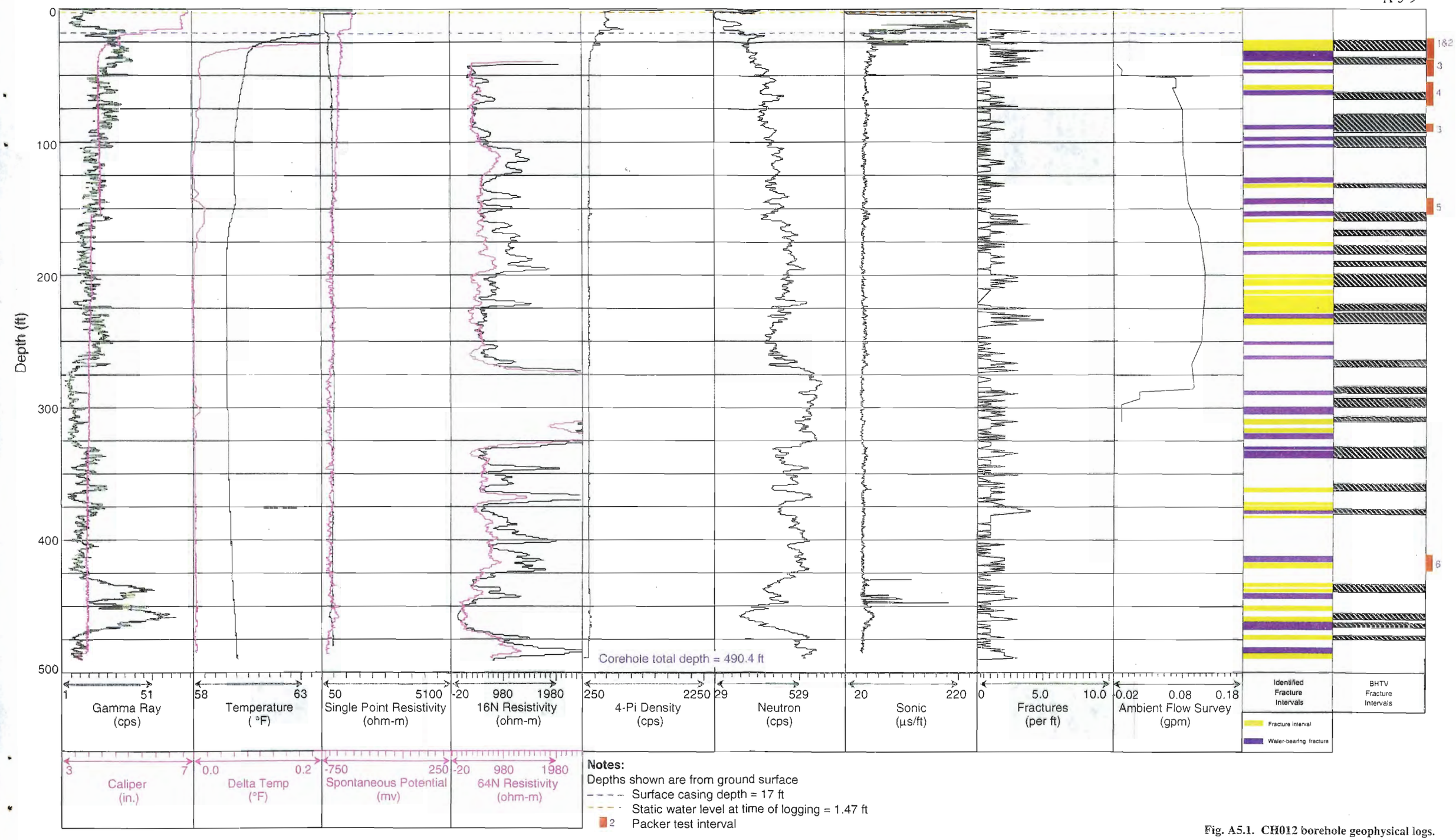
Table A5.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Comments[c,d]
260-262			?	X		B			
264.0-265.0		3	X						24-28°, BP, sl. open to open
267.0-268.0		2	X	X		X			16-20°, BP, open and tight
270.0-271.0		3	S						20-26°, BP, sl. open to tight
284-185			X						
286.0-287.0		2				X	X		19-22°, BP, sl. open to tight
287-288			X	X					
288.0-289.0		3+		X	X	X			Fragmented, a lot of rubble
293.0-294.0		2	S						24°, BP, tight
298-299			X	X					
299.0-300.0		2		X		B			26-34°, BP, sl. open
301.7-302.7		2				B	X		22-29°, BP, tight
303.7-304.7		2				B			23°, BP, sl. open; 15°, low angle fracture, sl. open
307-308			X			X			
308.7-309.7		3		X					8-12°, BP, tight, one fracture with heavy
309.7-310.7		2	X	X					20-30°, BP, open
311.7-312.7		2		X	X	X			22°, BP, tight
315-316				S					
316-317			X						
317-319				S					
319.7-320.7		2				X	X		25-26°, BP, tight
321.7-322.7		2	S		X		X		22-25°, BP, sl. open
323-324				S	X				
329-330.7			X	X	X				
330.7-331.7		2	X			X			26°, BP, tight
332.7-333.7		3	X						20-30°, BP, tight and open
333.7-334.7		2	?			X			23-24°, BP, sl. open to tight
334.7-335.7		2	X	X					21-35°, BP, tight
336-337			S	X	X				
342.7-343.7		2		X		X			27°, BP, tight; ⊥ to bedding (dip-normal), heated
346-348			X	X					
348-349			?	X					
351-352				S					

Table A5.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Comments[c,d]
355.7-356.7		2	X	X		B			15-27°, BP, tight
358.7-359.7		2	X	X					22-24°, BP, open and tight
360-361				X	X				
361-362			X						
362.7-363.7		2		X	X				20-22°, BP, tight
367.7-368.7		2		S		X			18-24°, BP, tight
371.7-372.7		2	?	X					20°, BP, sl. open to tight
372.7-373.7		2		X					22°, BP, tight
374.7-375.7		3		S					20°, BP, sl. open to tight
375.7-376.7		3	X	S					25-38°, BP, open and tight
376.7-377.7		4	X						30° (average), BP, sl. open to tight
377.7-378.7		4	X	X	X	X			34-36°, BP, tight and open
378.7-379.7		2	X	X					25°, BP, sl. open to open
381-382				X					
382-383			S						
402.7-403.7		2		X					27°, BP, tight and sl. open
412.7-413.7		2		X	X	X			26°, BP, sl. open
413.7-414.7		2		S					20-29°, BP, sl. open and tight
414.7-415.7		2		X					25°, BP, tight
416.7-4.7.7		2							16-25°, BP, tight
417.7-418.7			X						
418.7-419.7		2							21°, BP, open to tight
419.7-420.7		2		S					21-27°, BP, open to tight
421.7-422.7		2	?	X				S	Dip-normal, dip-parallel fracture set, strike is tight, dip is open
427-428				S	X	B			
429-430				X					
433.4-434.4		2	X	X					24°, BP, open
434-435				X					
437.4-438.4		2		S	X				25-30°, BP, tight
438.4-439.4	F	2	X	S	X				25°, BP, open and tight
440.4-441.4		2		X			X		18-20°, BP, sl. open to tight
441.4-442.4		2		X					20-21°, BP, sl. open to tight
442.4-443.4		2			X	X			19°, BP, sl. open to open
443.4-444.4		3	X	X					19-20°, BP, tight

TM-007



Notes:
Depths shown are from ground surface
Surface casing depth = 17 ft
Static water level at time of logging = 1.47 ft
2 Packer test interval

Fig. A5.1. CH012 borehole geophysical logs.

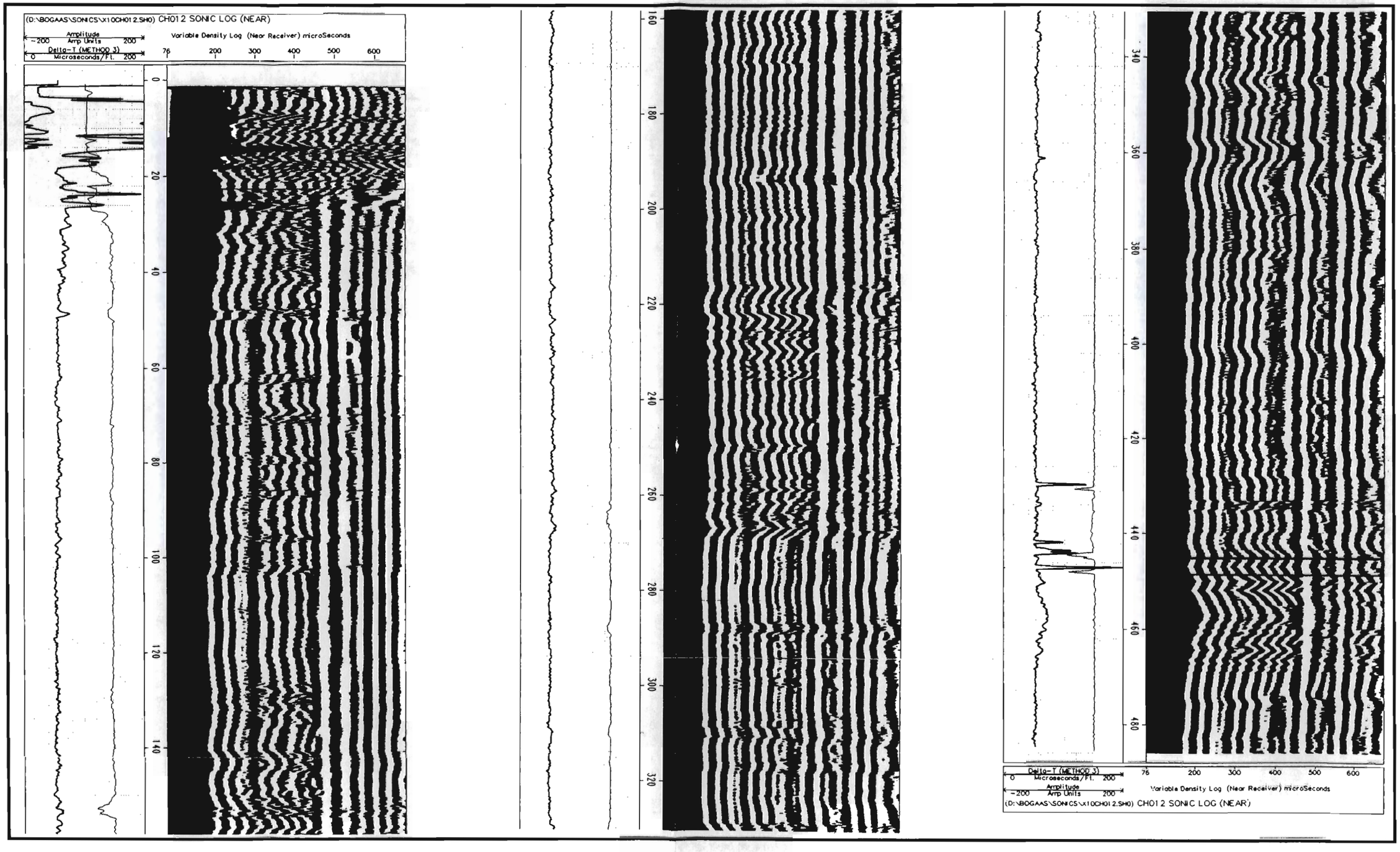


Fig. A5.2. CH012 variable density (acoustic) log.

Table A5.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Comments[c,d]
450-451			X	X					
451-452				X					
452.4-453.4		2	?		X		X		23-26°, BP, tight
455-456			X	X					
457.4-458.4		2	X	X					22°, BP, tight
458.4-459.4		3	X	X					22-30°, BP, tight
459.4-460.4		2	X	X				S	25°, BP, tight
461-462	E			X					
463-464			X			B	X		
464-465				X					
465-466			X				X		
466-467				X	X	X			
467-468				X					
472.4-473.4		2	X				X		20°, BP, sl. open to tight
474-475				X					
477-478			?		X				
481.4-482.4		2				B	X		23-40°, BP, sl. open to tight
483.4-484.4		2			X				Dip-normal, dip-parallel fracture set, strike is tight, dip is open
484.4-485.4		2	+++			B			30°, BP, tight
485.4-486.4		2							30-40°, BP, tight
486.4-487.4		2							35-40°, BP, tight
488.4-489.4		3							10-26°, BP, sl. open to tight

[a]Only those depth intervals obtained from the geologist's logs have an accuracy of 0.1 ft. Depth intervals from other logs were not as accurate.
[b]From geologist's log.
[c]The general format for the fracture description is: fracture angle relative to horizontal, type of fracture, and degree of fracture openness. Fracture descriptions are separated by semicolons.
[d]No deviation survey performed on this corehole due to equipment failure.

LEGEND

X	=	Log response
S	=	Slight log response
?	=	Questionable due to log quality
+++	=	Denotes end of log
***	=	Denotes top of log
B	=	Baseline shift in log curve

1. BP – Bedding plane fracture; a fracture that occurs along the plane of bedding, which typically ranged from 25–40° as measured perpendicular to the long axis of the core.

Table A5.1 (continued)

2. Dip-normal fracture – Any fracture that is perpendicular to bedding; typically either parallel or perpendicular to strike.
3. Dip-parallel fracture – Any fracture that is parallel to bedding.
4. Low angle fracture – As measured perpendicular to the long axis of the core, a low angle fracture is generally at an angle less than bedding.
5. High angle fracture – As measured perpendicular to the long axis of the core, a high angle fracture is generally at an angle greater than bedding.
6. ⊥ – A dip-normal fracture; perpendicular to bedding.

ORNL DWG 91 14424

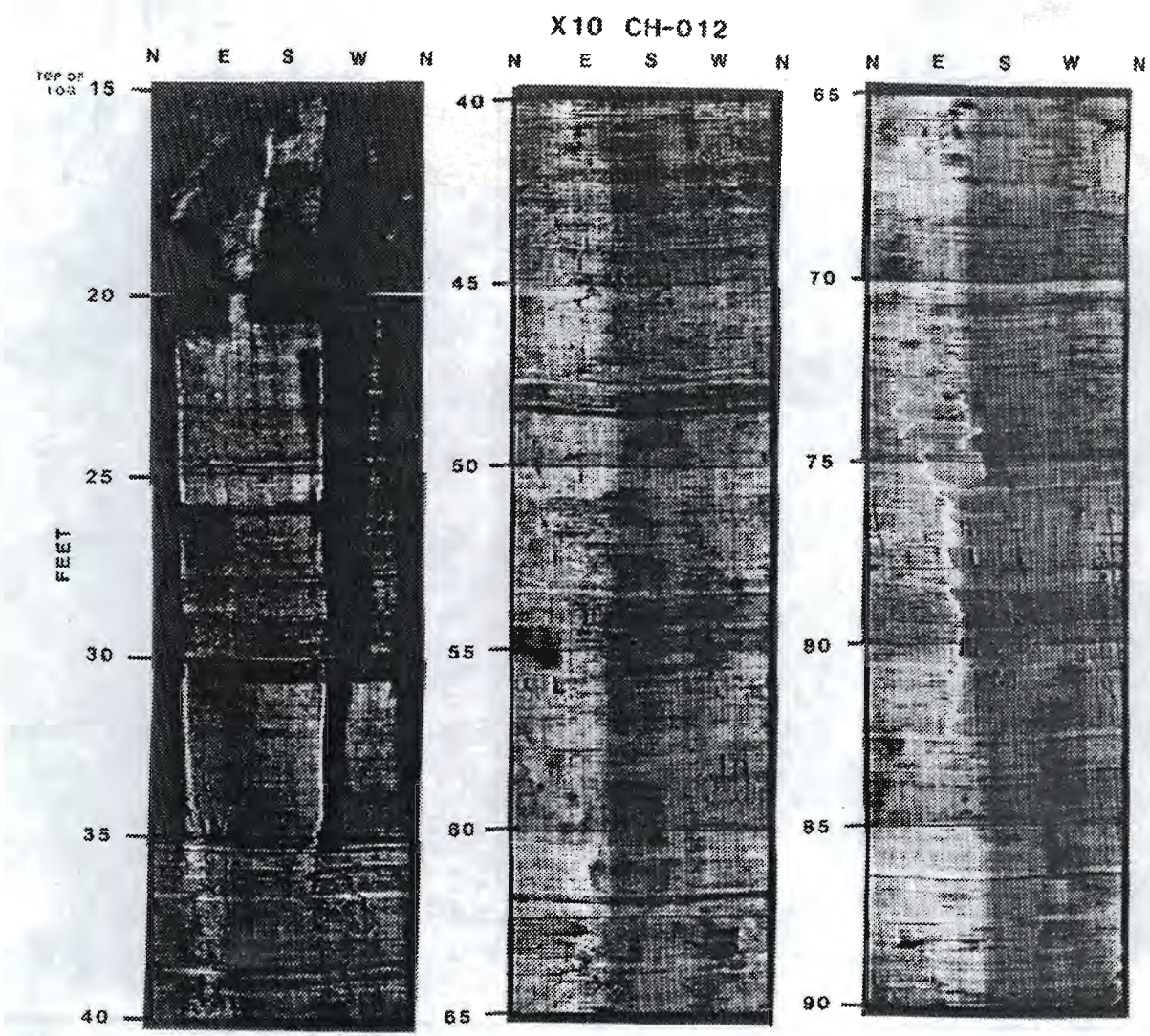


Fig. A5.3. CH012 borehole televiewer log.

5.27 5277.17

ORNL DWG 91 14425

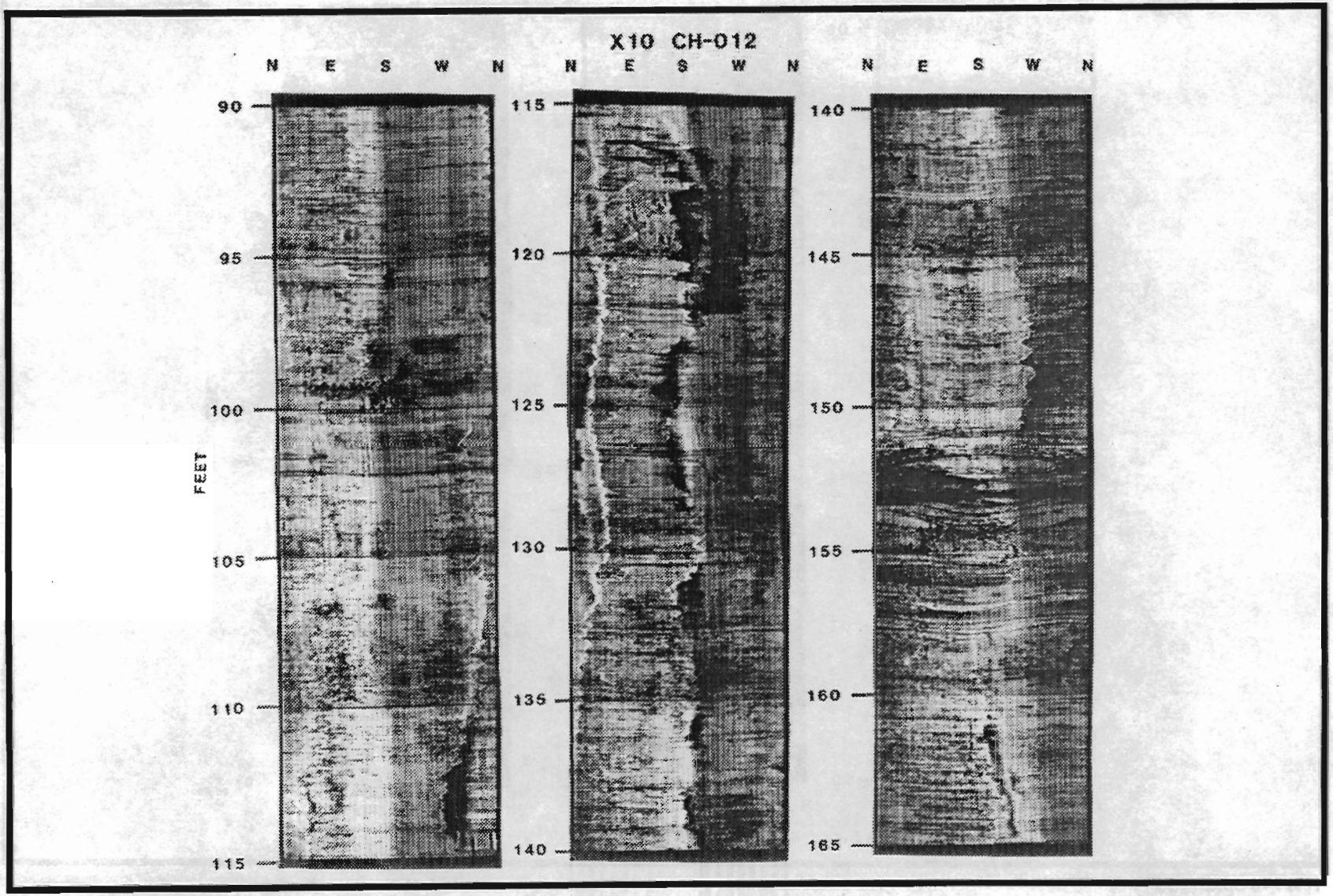


Fig. A5.3. (continued).

5.27 5277.18

ORNL DWG 91 14426

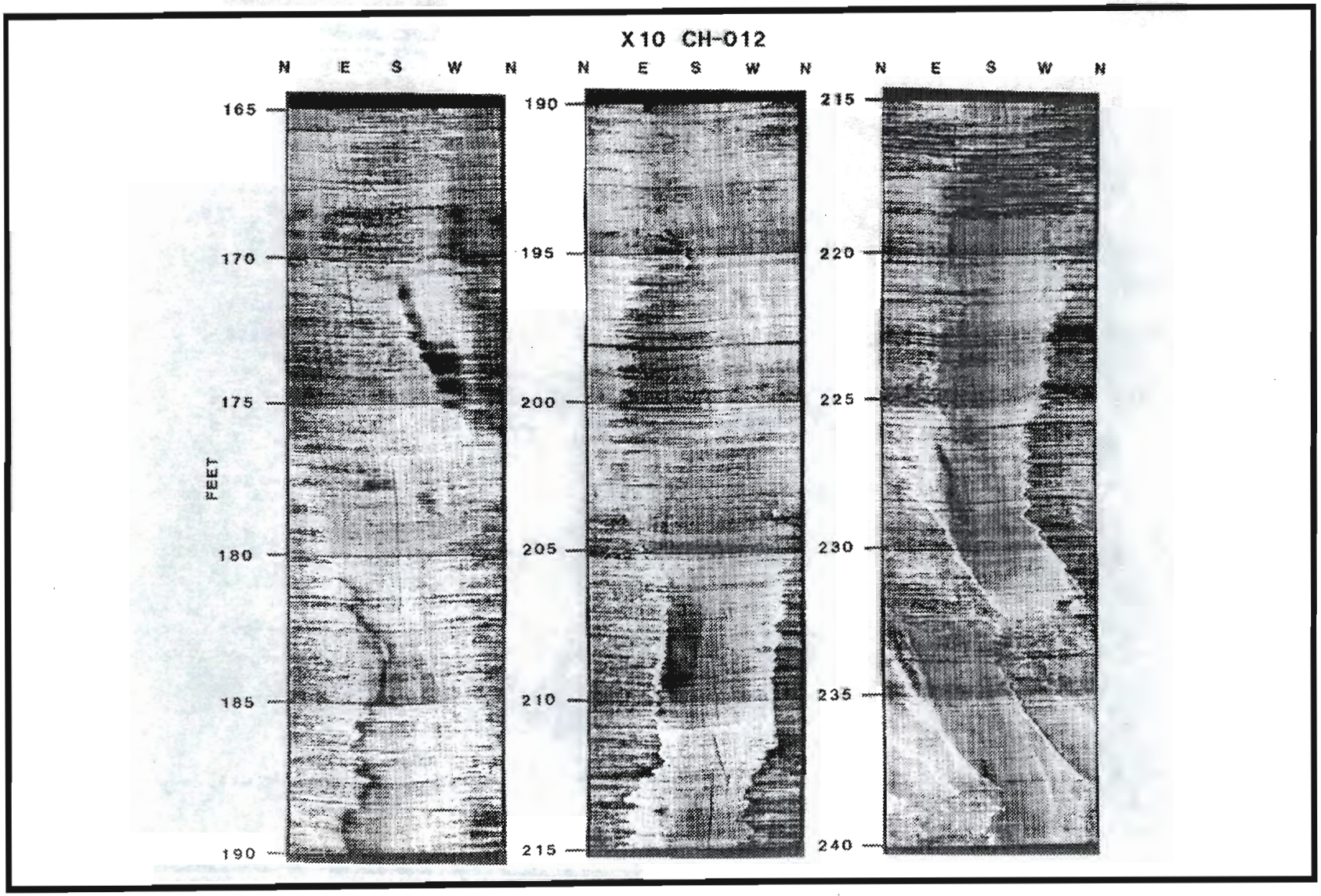


Fig. A5.3. (continued).

5.27 5277.19

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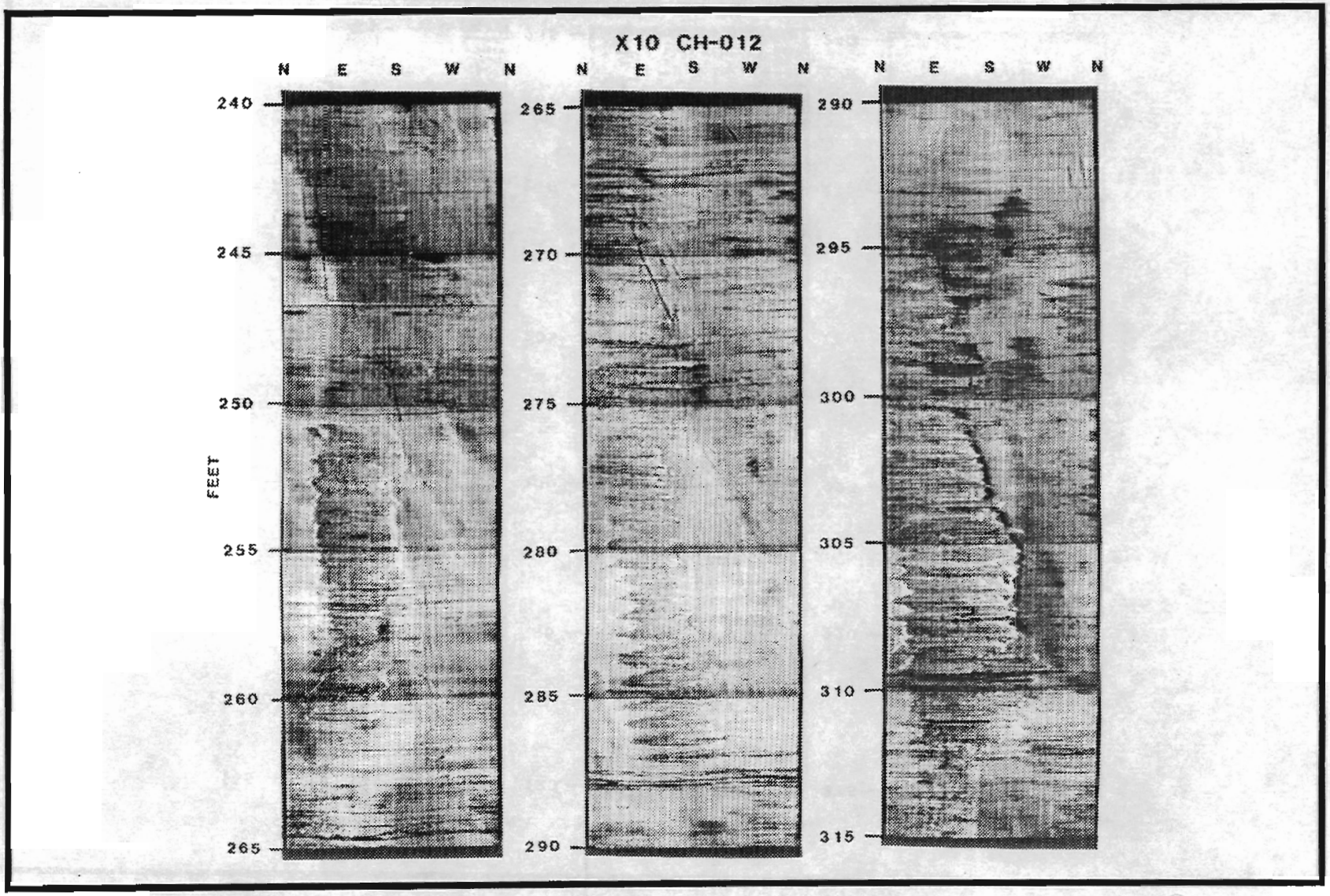

Fig. A5.3. (continued).

5.27 5277.20

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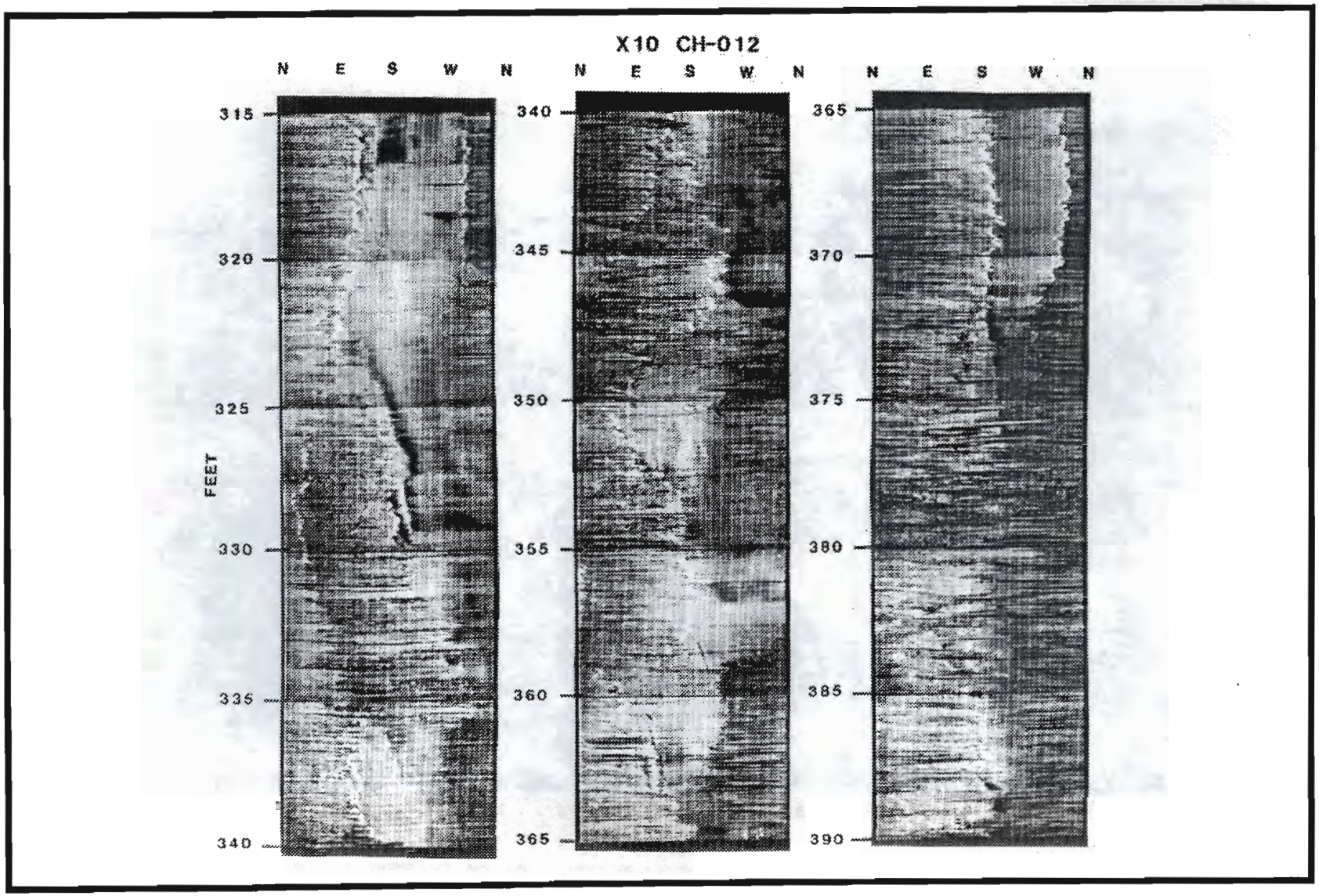


Fig. A5.3. (continued).

5.27 5277.21

ORNL DWG 91 14429

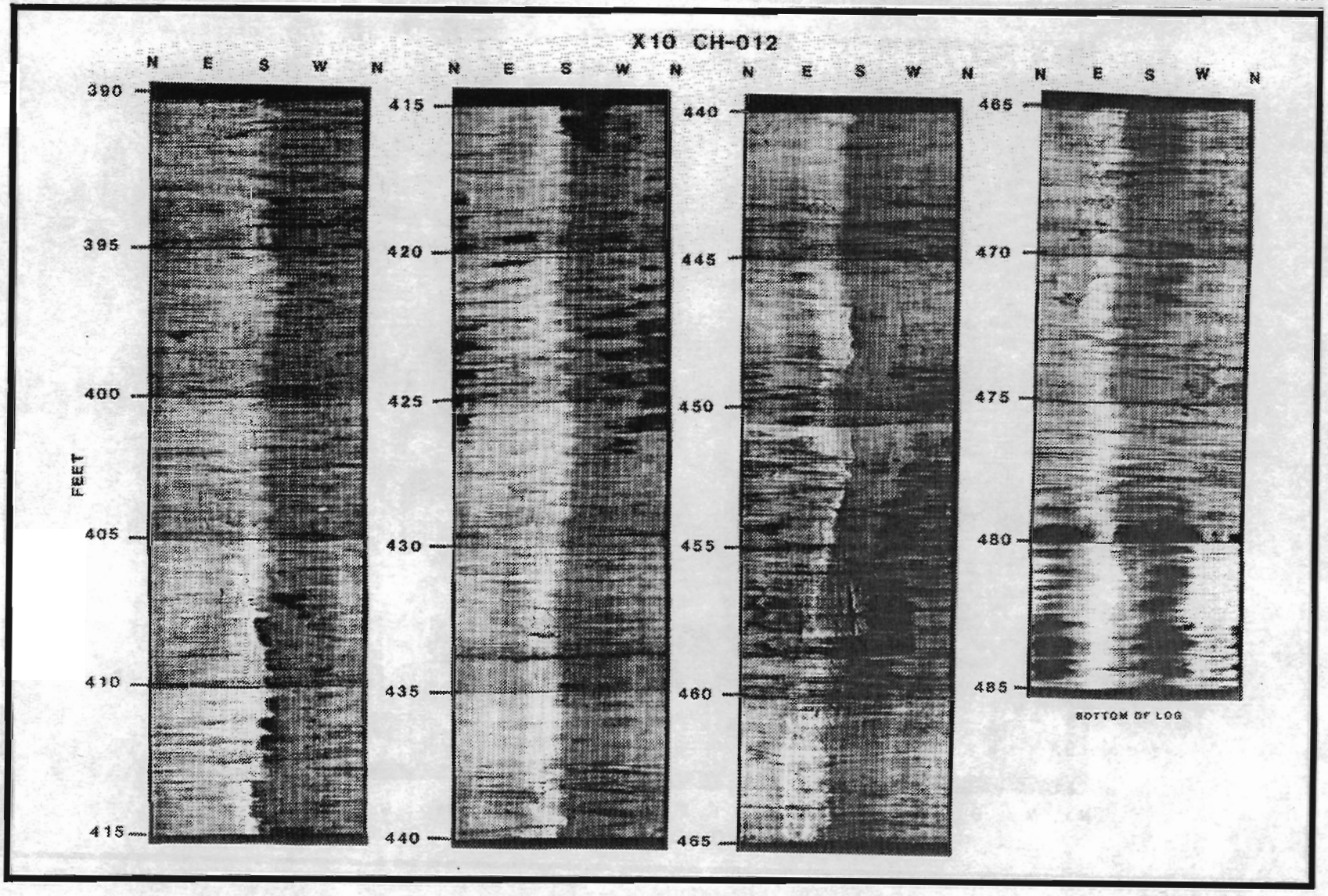


Fig. A5.3. (continued).

5.27 5277.22

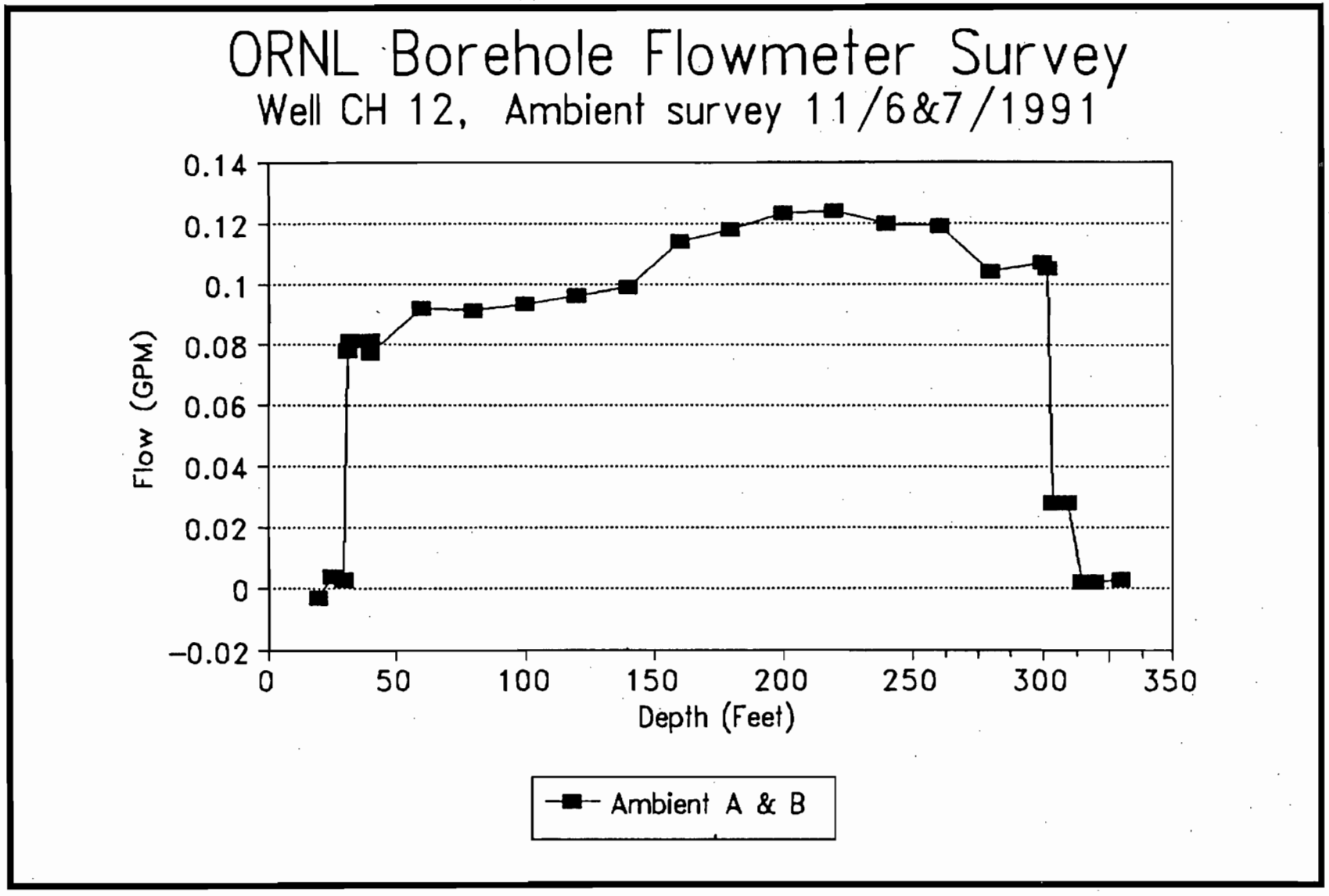


Fig. A5.4. CH012 ORNL borehole blowmeter survey.

ORNL Borehole flowmeter survey CH012, ambient survey November 6-7, 1991

CH 12 A Ambient survey Filename: CH12A.PRN
11-06-1991 15:26:33
Well No. 12
K= 0.47 Z= 0.02
Pump Rate 0
Ambient flow survey CH12B.PRN added 11/7/91

Time	Volts[a]	STD[b]	Flow[c] GPM	Depth[d] Feet
12:50:54	0.014	0.001	-0.003	20
09:36:23	0.028	0.006	0.004	25
09:18:39	0.026	0.005	0.003	30
09:30:55	0.187	0.005	0.078	31
09:26:42	0.192	0.006	0.081	32
13:03:11	0.193	0.001	0.081	40
09:12:17	0.183	0.002	0.077	40.1
13:11:39	0.216	0.002	0.092	60
13:18:56	0.215	0.001	0.091	80
13:27:01	0.217	0.001	0.093	100
13:35:07	0.223	0.000	0.096	120
13:42:47	0.230	0.002	0.099	140
13:51:31	0.262	0.002	0.114	160
14:00:13	0.271	0.001	0.118	180
14:07:38	0.282	0.001	0.123	200
14:14:33	0.284	0.000	0.124	220
14:23:53	0.275	0.003	0.120	240
14:33:14	0.274	0.002	0.119	260
14:40:27	0.242	0.006	0.104	280
14:47:57	0.248	0.002	0.107	300
15:24:49	0.242	0.003	0.105	302
15:21:14	0.079	0.000	0.028	304
15:17:34	0.079	0.002	0.028	306
15:14:05	0.079	0.001	0.028	308
15:09:49	0.079	0.002	0.028	310
15:05:17	0.025	0.000	0.002	315
14:55:41	0.025	0.001	0.002	320
15:00:45	0.026	0.001	0.003	330

[a]Volts column is analog signal from the flowmeter.
[b]STD column is standard deviation of the analog signal.
[c]Ambient surveys measure natural flow (no injection) in the corehole. A plus sign means flow up the hole. Flow rate is gallons per minute.
[d]Depths are measured from top of inner casing.

ATTACHMENT 6

FT10—GEOPHYSICAL AND GEOLOGIC DATA

Table A6.1. Summary of fractures identified in corehole FT10

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Deviation survey*	Comments
30-31	D					X				Geologist's log not available
33-34						X				
35-36						X				
40-41						X				
46-47						X				
50-51						X				
53-54							X			
67-68				***			S			
78-79				X						
79-80			***	X		X		X		
80-81			X							
81-82			S							
82-83			X							
83-84			X							
84-85			S							
85-86			S		X	B				
87-88	C		X							
88-89					X					
90-91			X	X						
91-92			X	X						
93-94					X		X			
94-95			X							
95-96			X	X		X				
99-100				X	X					
100-101			X	X	X					
102-103			X	X	X	B		X		
103-104				X						
104-105			X	X		X		X		
105-106			X	X		X				
106-107			X	X	X					
107-108			X	X						
108-109			X	X						

TM-011

Table A6.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Deviation survey*	Comments
109-110			X	X						
110-111			X	S						
111-112			X	X						
112-113			X	X						
113-114				X	X	X				
114-116				X	X					
117-118					X					
119-120								X		
120-121			X							
121-122			?	X			X			
123-124			X							
124-125			X	X						
125-126				X						
126-127				X	X					
127-128	B			X				X		
131-132				X						
133-134				X	X					
134-135				X						
136-137				X				X		
138-139					X					
139-140			S							
141-143					X	S		X		
145-146			X	X						
146-147				X						
147-148			?	X						
148-149				X						
150-151				X	X					
152-153			S	X						
154-155			S	X				X		
156-157			X	X						
157-158			X	X				X		
160-161				X	X	X	X	X		
162-163				X						

TM-011

Table A6.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Deviation survey*	Comments
163-164				X						
168-169				S						
169-170				X						
170-171			S	X	X	S		X		
171-172			S	X	X			X		
173-174			S	X				X		
174-175				X				X		
175-176			X	X				X		
176-177				X				X		
177-178				X	X			X		
178-179				X				X		
179-180			S	X				X		
180-181			?	X		X	X	X		
181-182			S	X				X		
182-183				X				X		
183-184			S	X	X			X		
184-185			S	X				X		
185-186				X				X		
186-187						X		X		
188-189				X				X		
189-190			S	X	X					
190-191				X						
191-192			X	X						
192-193			X				X			
194-195			S							
195-196			S	X	X					
200-201				X		X				
201-202				X						
202-203				X			X	X		
203-204				X						
204-205			?			X				
206-207					X			X		
211-212			X	X						

TM-011

Table A6.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Deviation survey*	Comments
212-213			X	X						
213-214				X						
214-215				X		X				
217-218			S			S				
222-223				X						
223-224			?	X						
226-227				X						
228-229			S							
230-231				X				X		
232-233					X					
236-237			S	X	X					
237-238				X						
238-239			S							
240-241				X	X	X	X			
245-246				X				X		
246-247					X					
249-250				X						
250-251				X						
251-252				X						
252-253				X	X	X				
259-260				X	X		X			
260-261				X						
261-262				X						
263-264				X	X					
264-265			X	X						
270-271			S	X						
271-272				X						
273-274				X	X					
276-277			S	X	X	B	X			
288-289				X						
289-290				X						
290-291				X			X			
293-294			X	X	X					

TM-011

Table A6.1 (continued)

Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Deviation survey*	Comments
295-296							S			
298-299			S	X			X			
302-303				X						
303-304				X						
306-307					X		X			
308-309				X		X				
309-310			X	X						
310-311			X	X						
311-312			X	X						
313-314					X			X		
317-318					X					
319-320				X			X	X		
320-321			S	X						
321-322				X						
323-324					X			X		
324-325				X						
327-328				X						
328-329				X						
329-330				X						
331-332			X	X				X		
332-333			S	X						
333-334					X					
337-338			S							
338-339				X						
339-340				X						
343-344					X					
344-345				X						
345-346			X	X		X		X		
346-347			X							
347-348						B				
349-350				X						
355-356					X			X		
360-361			S							

TM-011

Table A6.1 (continued)

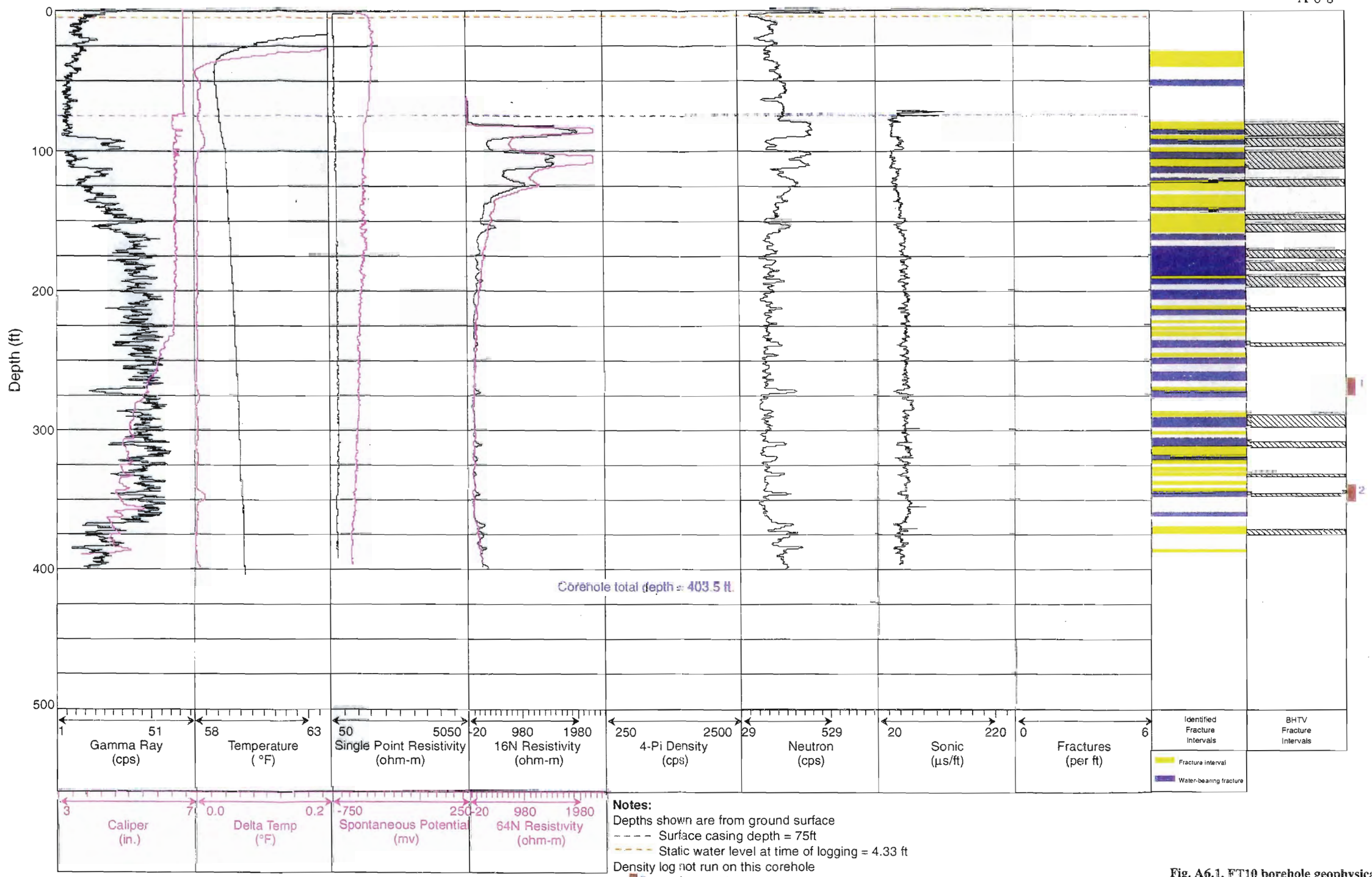
Depth BGS (ft)	Geologic unit	Fractures per ft	BHTV	VDL	Caliper	Temperature	Delta temperature	SP	Deviation survey*	Comments
361-362						S				
362-363				X	X		X			
367-368	A		S						S	
370-371				X						
371-372			S	X						
372-373			S							
373-374				X						
374-375			S		X					
376-377								S		
381-382				X	X					
383-384				X						
386-387					X					
387-388				X						
389-390				X						
395-396			+++	X						

[a]Only those depth intervals obtained from the geologist's logs have an accuracy of 0.1 ft. Depth intervals from other logs were not as accurate.
[b]From geologist's log.
[c]The general format for the fracture description is: fracture angle relative to horizontal, type of fracture, and degree of fracture openness. Fracture descriptions are separated by semicolons.

LEGEND

X	=	Log response
S	=	Slight log response
?	=	Questionable due to log quality
***	=	Denotes top of log
+++	=	Denotes end of log
B	=	Baseline shift in log curve
*	=	Not available for this corehole

TM-011



Notes:
Depths shown are from ground surface
- - - - Surface casing depth = 75ft
- - - - Static water level at time of logging = 4.33 ft
Density log not run on this corehole
2 Packer test interval

Fig. A6.1. FT10 borehole geophysical logs.

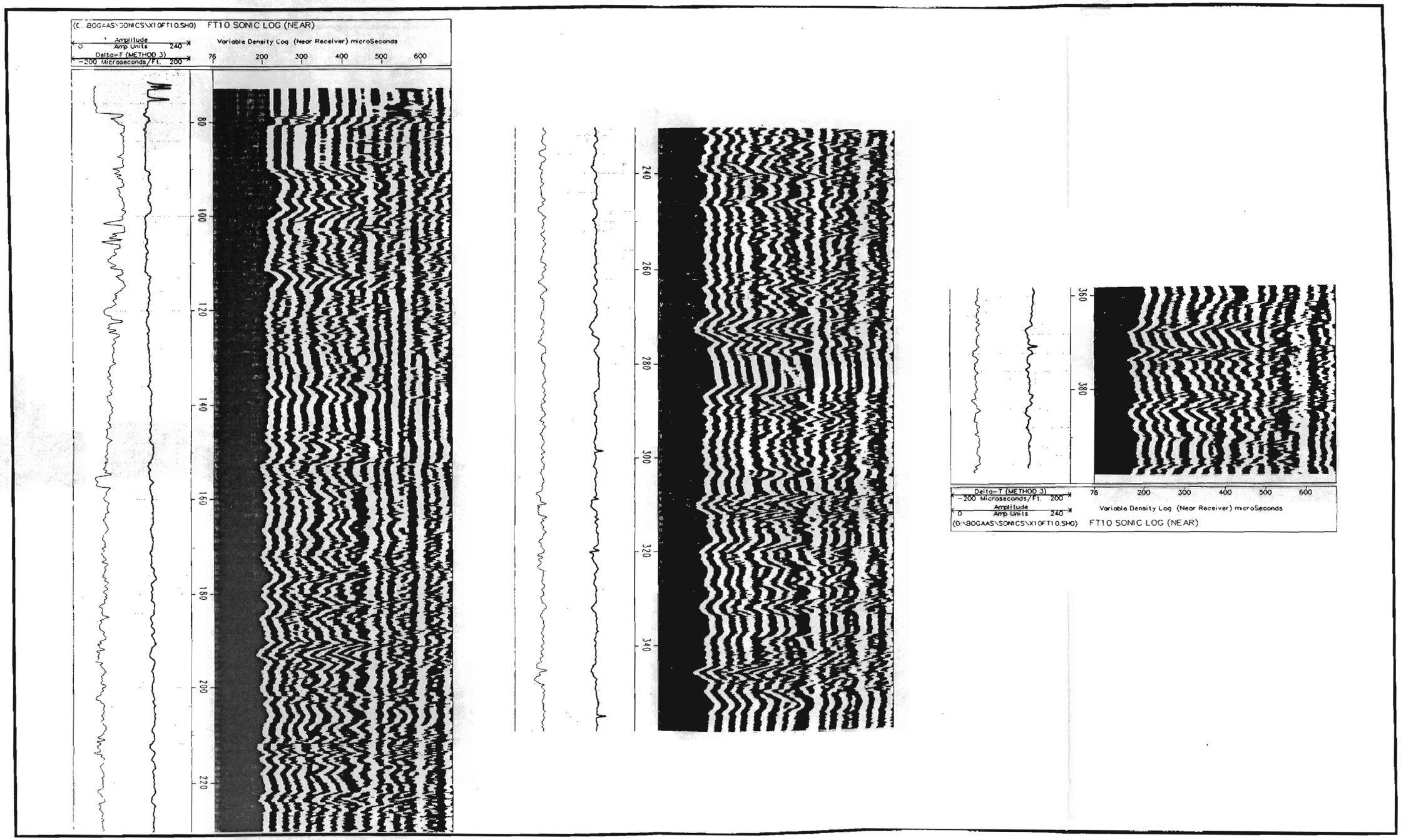


Fig. A6.2. FT10 variable density (acoustic) log.

ORNL DWG 91 7371

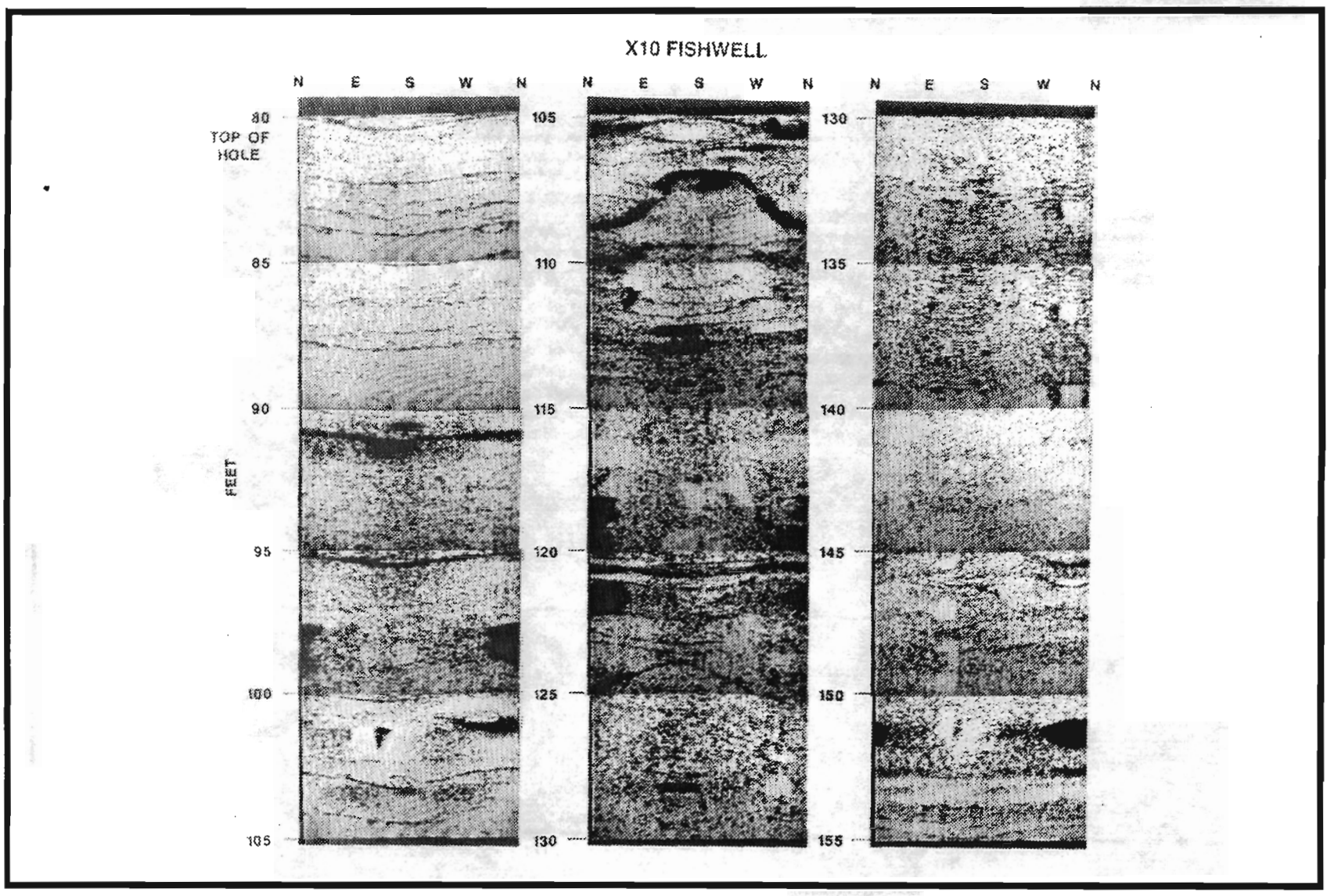


Fig. A6.3. FT10 borehole televiewer log.

5.27 5277.23

ORNL DWG 91 7372

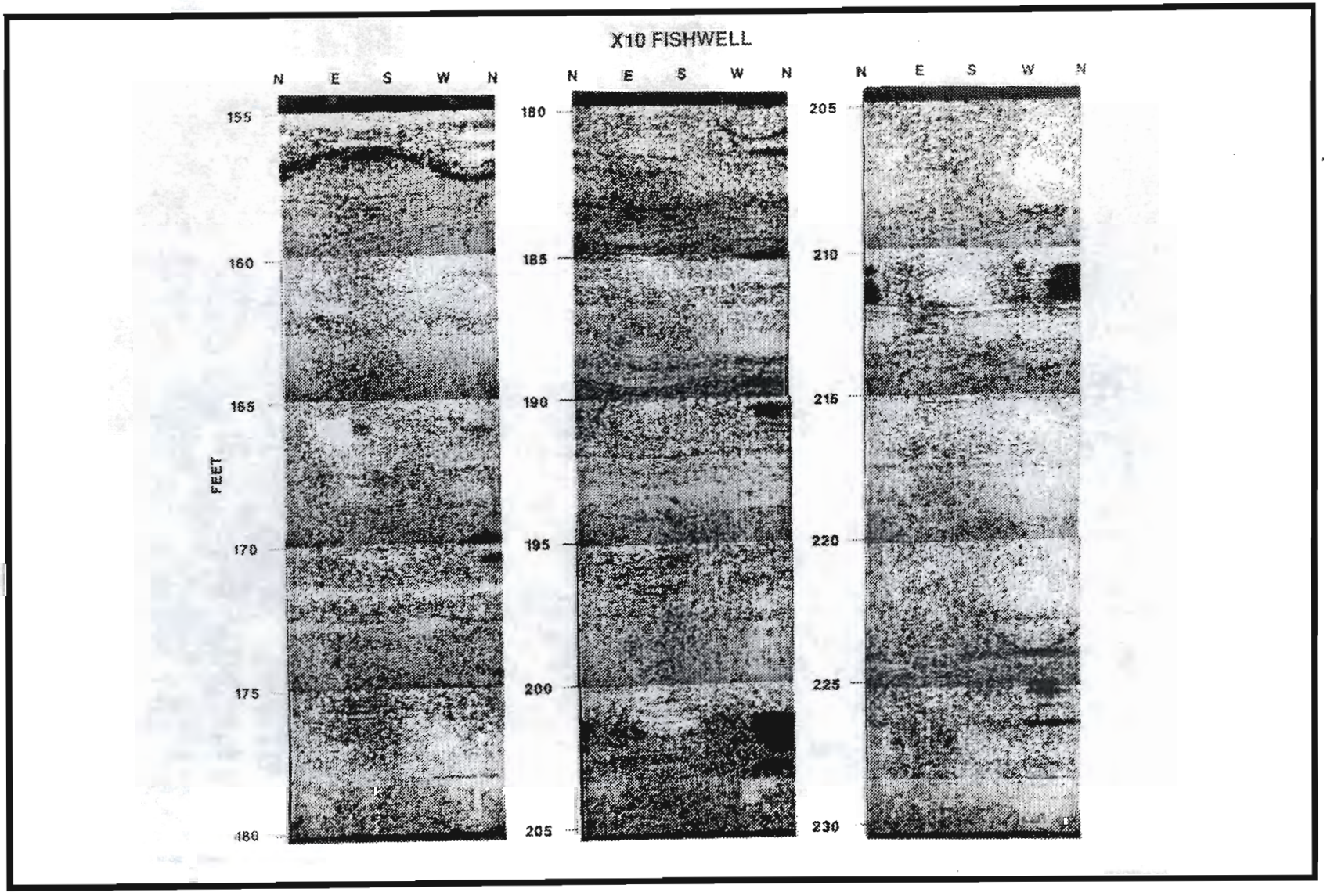


Fig. A6.3. (continued).

5.27 5277.24

ORNL DWG 91 15779

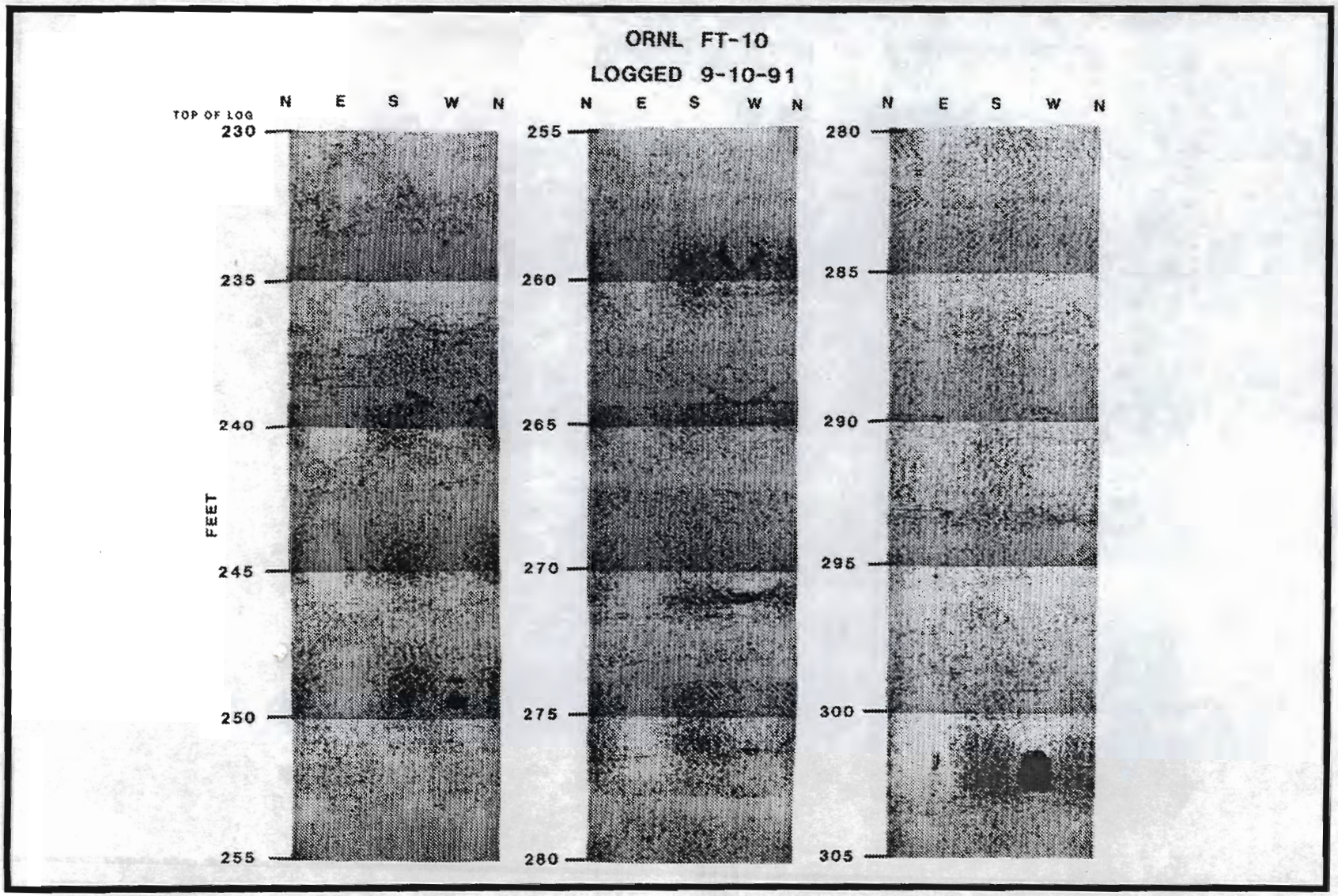


Fig. A6.3. (continued).

5.27 5277.15

ORNL DWG 91 15780

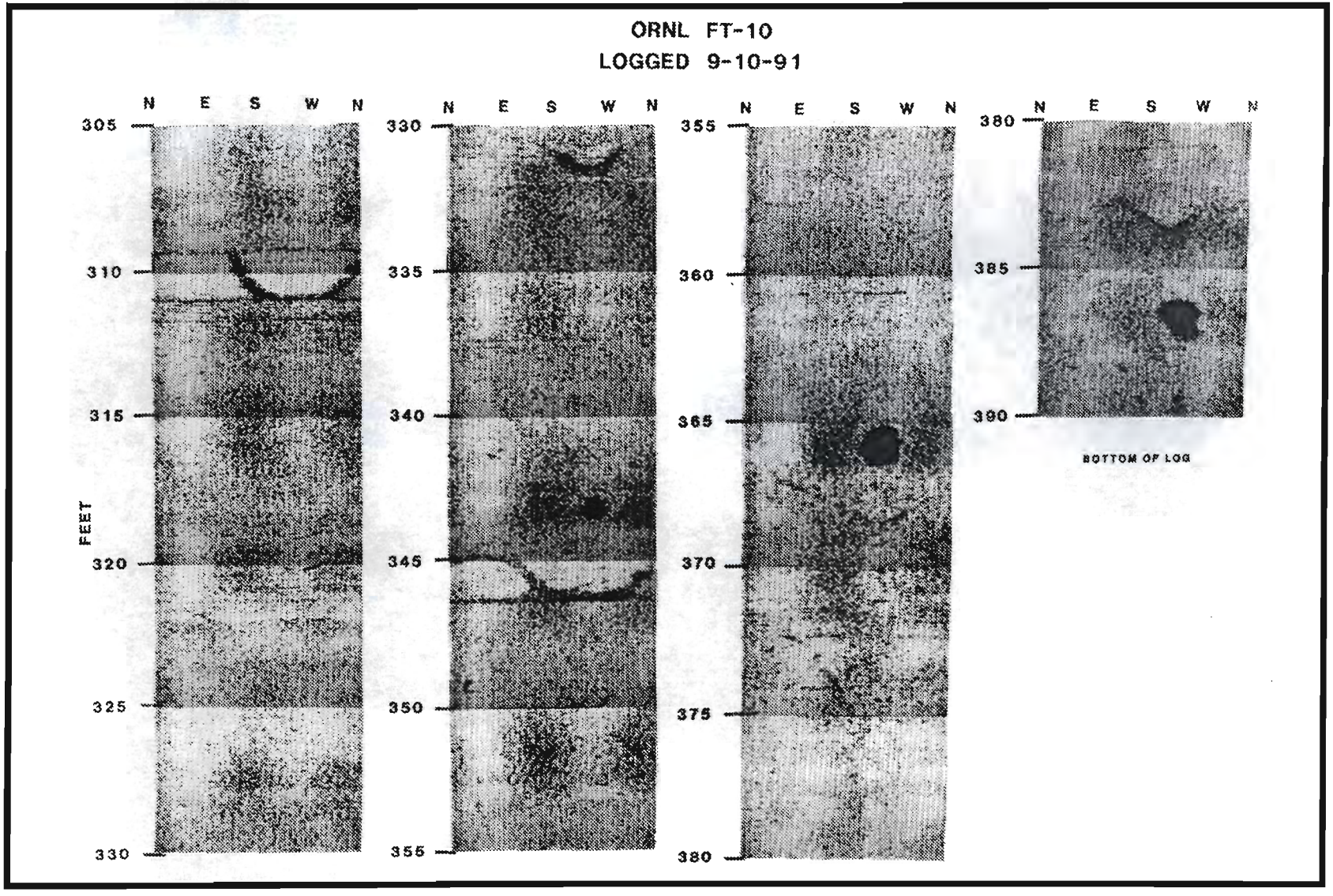


Fig. A6.3. (continued).

5.27 5277.16

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