

Use of Advanced Borehole Geophysical Techniques to Delineate Fractured-Rock Ground-Water Flow, Faults, Foliation, and Fractures along the Western Part of Manhattan, New York

By Frederick Stumm, Anthony Chu, and Andrew D. Lange

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For additional information
write to:

U.S. Geological Survey
2045 Route 112, Bldg. 4
Coram, NY 11727

Copies of this report may be
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U.S. Geological Survey
Branch of Information Services
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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

	Multiply By	To Obtain
Length		
inch (in.)	25.4	millimeter
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi ²)	2.590	square kilometer
Flow		
gallons per minute (gal/min)	0.06309	liters per second
Transmissivity		
square foot per day (ft ² /d)	0.0929	square meter per day
Volume		
gallon per minute (gal/min)	3.785	liter per minute
Specific capacity		
gallon per minute per foot (gal/min)/ft	12.418	liter per minute per meter

Other abbreviations used in this report

greater than (>)
 hour (h)
 megahertz (MHz)
 microsiemens per centimeter ($\mu\text{S}/\text{cm}$)
 millisiemens per meter (mS/m)
 minute (min)

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Use of Advanced Borehole-Geophysical Techniques to Delineate Fractured-Rock Ground-Water Flow, Faults, Foliation, and Fractures along the Western Part of Manhattan, New York

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Abstract

Advanced borehole-geophysical methods were used by the U.S. Geological Survey in cooperation with the New York City Department of Environmental Protection (NYCDEP) to assess the geohydrology of crystalline bedrock at three test boreholes (W34ST-B, W37ST-A, and W55ST-A) on the western side of Manhattan Island, N.Y., in preparation for construction of a third water tunnel for New York City by the NYCDEP. The borehole-logging methods included natural gamma, single-point resistance, mechanical and acoustic caliper, focused electromagnetic induction, magnetic susceptibility, borehole-fluid temperature and resistivity, heat-pulse and EM (electromagnetic) flowmeter, borehole deviation, acoustic and optical televiewer, and borehole radar. The boreholes penetrated gneiss and other crystalline bedrock with an overall southwest-to-northwest dipping foliation. Most of the fractures encountered are either nearly horizontal or have moderate to high-angle northwest dip azimuths. Foliation within the tunnel-construction zone is southwest-to-northwest dipping, with fractures that average a northwest dip azimuth. EM and heat-pulse flowmeter logs obtained under pumping and ambient conditions, together with other geophysical logs, indicate transmissive fracture-flow zones in each borehole. The 60-megahertz directional borehole radar logs delineated the location and orientation of radar

reflectors that would intersect the projection of the borehole above or below the drilled depth. Borehole data and interpretations may not reflect the exact location of the proposed tunnel-construction zone because of borehole deviation and constraints on borehole placement.

Fracture indexes range from 0.25 to 0.44 fracture per foot of borehole. The three-dimensional orientation of the fractures indicates a highly transmissive fracture zone at 328 to 330 feet below land surface (BLS) (-287.73 to -289.73 feet elevation) in W34ST-B that may intersect the proposed tunnel-construction zone to about 220 feet northwest of the borehole. Analysis of pumping tests of each borehole indicates that their total transmissivity ranges from 11 to 360 feet squared per day; the highest transmissivity is at the middle borehole (W37ST-A).

INTRODUCTION

In 1970, the New York City Department of Environmental Protection (NYCDEP) began construction of a third tunnel to supply water to New York City in the event that one of the two present water tunnels should require repair. Manhattan Island is about 12.5 mi long and 2 mi wide (fig. 1) and consists of unconsolidated deposits ranging from less than 1 ft thick to more than 200 ft thick overlying metamorphic bedrock. Manhattan Island is bounded on the west by the Hudson River, on the east by the East River, and on the south by New York Harbor.

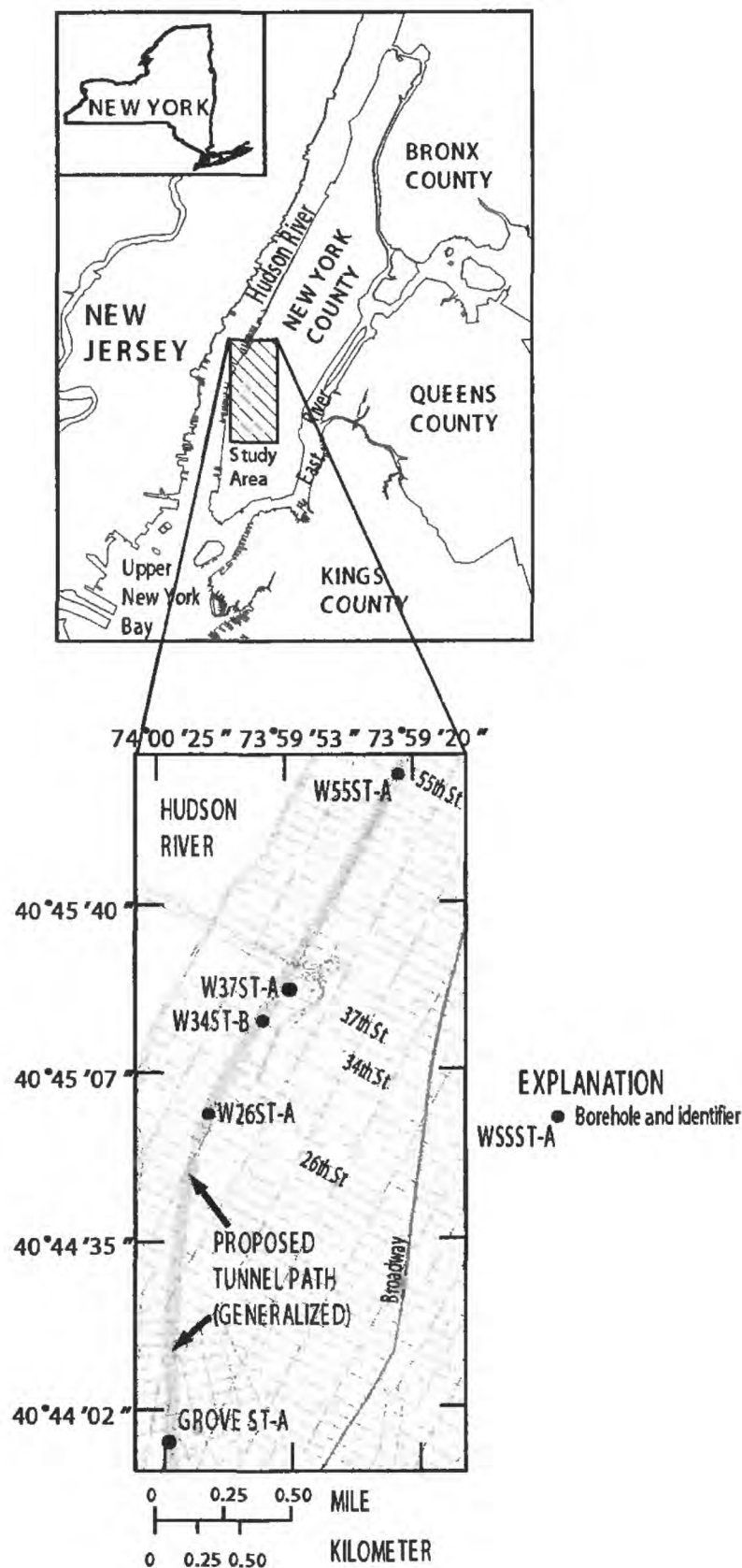


Figure 1. Locations of boreholes W34ST-B, W37ST-A, W55ST-A, W26ST-A, GroveST-A, Manhattan island, N.Y.

Three test boreholes were drilled in 1998-99 to identify the type of rock and its degree of fracturing at the proposed tunnel depths, but the resulting information was insufficient in that (1) cores were not oriented, and (2) neither the hydraulic characteristics of fractures, nor the vertical deviation of the boreholes,

can be determined from cores. Two additional boreholes were drilled, and only fracture and foliation orientations measured.

In 1998, the U.S. Geological Survey (USGS), in cooperation with the NYCDEP, began a study to apply advanced borehole-geophysical methods to provide a comprehensive geologic and hydrologic assessment of the crystalline bedrock in southeastern New York. These techniques were applied at the three boreholes on western Manhattan Island, N.Y., to identify (1) the bedrock lithology and major contacts, (2) the location and orientation (true strike and dip) of fractures and the foliation of the rock intersected by the boreholes, (3) the hydraulic characteristics of transmissive fracture-flow zones, and (4) major fractures or faults that lie as much as 100 ft beyond the borehole.

Purpose and Scope

This report (1) describes the geophysical methods used; (2) describes the geology at the three sites; (3) presents geophysical logs, equal-area plots of total-borehole and tunnel-zone fractures and foliation, and summarizes the geophysical interpretations of fractures, faults, and foliation in each borehole; (4) presents ground-water levels, water-temperature and resistance logs, and drawdown data; and (5) summarizes the transmissivity and locations of transmissive fractures in the boreholes, and relative hydraulic head. Borehole data and interpretations may not reflect the exact location of the proposed tunnel-construction zone because of borehole deviation and constraints on borehole placement.

Borehole-Geophysical Logging Methods

Borehole-geophysical logs collected in this investigation included natural gamma, single-point-resistance, mechanical and acoustic caliper, focused electromagnetic induction, magnetic susceptibility, borehole-fluid temperature and resistance, heat-pulse and EM flowmeter, borehole deviation, acoustic and optical televiewer, and borehole radar. The logging methods are briefly described below.

Natural-gamma (gamma) logs are a record of the total gamma radiation detected in a borehole (Keys, 1990) and are most commonly used for lithologic and stratigraphic correlation. Radioiso-

topes in bedrock minerals such as feldspar and mica are instrumental in correlating lithology. Clay minerals within fractures may be detected as elevated gamma responses in comparison with those of surrounding rock.

Spontaneous-potential (SP) logs provide a record of the naturally occurring potential difference along the borehole and can be used to identify changes in lithology, bed thickness, and salinity of formation water under some geologic conditions (Keys, 1990).

Single-point resistance (SPR) logs provide a measure of the electrical resistance of the rock or formation, in ohms, and are used to obtain qualitative lithologic information with a depth resolution approximately equal to borehole diameter (Keys, 1990).

Caliper logs provide information on lithology and the location of major fractures or faults. Mechanical calipers use spring-loaded arms to profile the surface of the borehole wall. Acoustic calipers calculate the distance to the borehole wall from the traveltime of the acoustic signal emitted from an acoustic televiewer (ATV) to provide high-resolution, compass-oriented logs (Keys, 1990).

Focused electromagnetic induction (EM) logs provide a profile of the electrical conductivity of the rock around the borehole with respect to depth, which can be interpreted in terms of formation water conductivity. This technique uses an electromagnetic emitter coil to induce electrical eddy currents within a specified volume of the surrounding formation to generate a secondary electromagnetic field. The intensity of the secondary field received by the receiver coil is proportional to the formation's conductivity (Keys, 1990; Serra, 1984; Keys and MacCary, 1971).

Magnetic-susceptibility (MAG) logs provide a record of the variations in magnetic minerals within the surrounding rock. Magnetite is the most common magnetic mineral, and local variations in its abundance may indicate lithologic contacts (McNeill and others, 1996).

Temperature logs measure the temperature of the fluid column as a function of depth and can provide information on the movement of ground water through the borehole and the location of areas that produce or accept water (Keys, 1990).

Borehole fluid resistivity logs of ground water in a borehole provide a record of the capacity of the fluid to conduct electricity and provide an indication of salinity (Keys, 1990).

Heat-pulse/EM flowmeter logs measure vertical flow in boreholes and can indicate which fractures are producing or accepting water in a borehole under pumping and static conditions (Keys, 1990). Cross-borehole flowmeter tests can be used to identify connections between fractures (Paillet, 1998).

Acoustic televiewer (ATV) uses a rotating transducer that transmits and receives high-frequency acoustic pulses to produce an image of the intensity of acoustic energy reflection. The ATV provides high-resolution information on the location and strike and dip of fractures or faults within a borehole (Keys, 1990; Williams and Johnson, 2000).

Borehole-deviation logs provide information on the borehole's angle and direction of deviation from vertical. All deep boreholes deviate from vertical; therefore, deviation logs must be obtained before three-dimensional information on fractures and faults is interpreted (Keys, 1990). After processing, the resulting log indicates the true depth of the borehole, its distance from vertical, and the direction or azimuth of deviation.

Optical televiewer (OTV) digitally records a high-resolution optical scan of the borehole wall that can be used to produce a virtual core. The virtual core is oriented to allow for visualization of major faults and fractures as they were imaged within the borehole. Faults and fractures, both opened and sealed, can be viewed in three-dimensional orientations. This system also allows measurement of true strike-and-dip orientation and fracture spacing (Stumm and others, 2000; Williams and Johnson, 2000).

Borehole radar uses a single-hole, 60-MHz directional radar unit (transmitter/receiver) that can detect fracture zones and other structural features at distances to as much as 100 ft from the borehole in electrically resistive rocks. The data logs can be used to calculate the orientation of fractures (Singha and others, 2000).

Borehole Network

Five NX-sized (3-in diameter) boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A) were drilled by the diamond-core method to obtain continuous rock core samples from the west side of Manhattan (fig. 1), the proposed area of the new tunnel. All boreholes were cased with steel from land surface through the unconsolidated overburden to the top of bedrock, and were uncased or open from the bedrock surface to the bottom of the drilled depth. The full suite of geophysical logs was not completed at boreholes W26ST-A or GroveST-A; fracture and foliation data were collected from W26ST-A and GroveST-A, but no other analyses were completed (see appendix). Boreholes W34ST-B, W37ST-A, and W55ST-A were drilled to depths of 625.7, 651.4, and 619.4 ft below land surface (BLS), respectively (-585.43, -610.09 and -579.99 ft elevation).

Acknowledgments

The authors thank the USGS Office of Ground Water and Branch of Geophysical Applications and Support for technical assistance and cooperation, the USGS Borehole Geophysics Research Project for technical assistance, and members of the Geotech Unit of the NYCDEP Waterworks Construction Section for technical assistance.

GEOHYDROLOGY

Manhattan's west side is underlain by high-grade metamorphic bedrock consisting of a sequence of gneiss and schistose-gneiss interlayered with granite (Baskerville, 1992). The bedrock contains many fractures, some of which are transmissive. Depth to bedrock ranges from 8 to 34 ft BLS (32.27 to 5.41 ft elevation).

The ATV, OTV, and borehole-radar data indicate that all boreholes penetrate moderately fractured rock that contains highly fractured zones. Every borehole contains medium and large open fractures that were transmissive. Structural trends of these geologic units imply that all fractures and faults detected in each borehole extend beyond each borehole. The gamma, SPR, EM-conductivity, resistivity, fluid-temperature, and resistance logs detected some of the fracture zones.

Methods of Geologic-Structure Analysis

Foliation and fractures encountered in each borehole were delineated from the OTV and ATV geophysical data. Fractures were classified as small, medium, large, or very large, depending on the apparent aperture or width of the opening. Measured fracture apertures in the boreholes are considered apparent to account for alterations caused by the drilling process. Small fractures or microfractures have apertures of 0.04 in. (1 mm) or less; medium fractures have apertures of >0.04 to 0.39 in. (>1 to 10 mm); large fractures have apertures >0.39 to 9.8 in. (>10 to 25 cm); and very large fractures have apertures >9.8 in. (>25 cm). Borehole-radar data were used to (1) verify the assumption that most fractures extend beyond the borehole, (2) detect major fractures or faults as far as 100 ft from the borehole that may not intersect any borehole in the area and would otherwise had been missed, and (3) delineate the orientation (strike and dip) of these distant fractures or faults.

Orientations of each fracture in each borehole was calculated from the ATV and OTV data through standard computer programs. Deviation from vertical and magnetic declination of each borehole was included in the final orientation calculation. Final corrected orientation of fractures and foliation was listed as dip azimuth and dip angle (dip). Orientation of all fractures is listed in the appendix.

The orientations were then converted through standard equal-area net projections as poles to planes, where dip azimuths have 180° added, and dip-plunge angles are subtracted from 90°. Computer-generated stereonet contours were used to identify fracture or foliation populations and their mean orientations. The mean fracture or foliation orientation (strike and dip) is the average for the entire cluster of features plotted.

The tunnel-construction zone (TCZ) was defined as a horizon ranging from 50 ft above the roof of the proposed tunnel to 50 ft below the tunnel floor; this zone represents the interval from 540 to 625.7 ft BLS (-499.73 to -585.43 ft elevation) at W34ST-B, 530 to 651.4 ft BLS (-488.68 to -610.09 elevation) at W37ST-A, and from 462 to 619.4 ft BLS (-422.59 to -579.99 elevation) at W55ST-A. Most boreholes are deeper than the bottom of the TCZ. High-angle large fractures above the TCZ at each of the boreholes, if continuous, could intersect the TCZ at a distance and were considered to be critical features. For this reason, fracture analysis of the entire borehole is most useful

in terms of potential intersections with the tunnel away from the borehole. Within the TCZ, fracture and foliation data are useful for the borehole location only.

Structure orientations for fractures or foliation are displayed further on as “tadpoles,” which are circles with “tails” plotted with respect to a horizontal scale to indicate the degree of dip-plunge angle of the structures from 0 to 90°. The tail of each tadpole points to the dip azimuth of the structure. The tadpole plots of foliation and fractures are included with the geophysical logs for each borehole to illustrate the variation in dip azimuth and dip with depth.

Analysis of the fractures within each borehole included the fracture index. The total number of fractures detected in each borehole was divided by the thickness of bedrock encountered to provide a fracture index indicating the average number of fractures per foot of bedrock. Average fracture indexes at W34ST-B, W37ST-A, and W55ST-A were 0.44, 0.40, and 0.25 fracture per foot of bedrock, respectively.

Foliation

Foliation analyses, grouped by depth, indicate populations with similar dip azimuths and dip angles. Total borehole-foliation dip azimuths are southwestward at W34ST-B, and northwestward at W37ST-A and W55ST-A. Total borehole foliation at W34ST-B, W37ST-A, and W55ST-A is N09°W57°SW, N06°E55°NW, and N16°E60°NW, respectively.

Foliation data from within the TCZ indicate a change from a 65° southwest dip at W34ST-B to a 58° northwest dip at W37ST-A, and a 61° northwest dip at W55ST-A. This variation in dip angle and azimuth if present at the proposed tunnel-construction zone could create block- or wedge-failure during tunnel construction.

Fractures

Fracture analysis identifies populations with similar dip azimuths and dip angles. No general correlation between fracture orientation and depth is evident in the study area. Overall total borehole fracture-population orientations are (1) nearly horizontal, and (2) moderate to high-angle dip with a northwest dip azimuth. The intersection of these fracture populations, coupled with the spatial variation in foliation dip azimuth, could create block- or wedge-failure during tunnel construction. Fracture means have dips of 17° to

the northwest at W34ST-B, an 8° dip to the northwest at W37ST-A, and a 44° dip to the northwest at W55ST-A. Many fractures were detected throughout the study area with dip angles in excess of 70°. The appendix lists fracture depth, dip azimuth, and dip angle of all fractures observed by OTV within the three boreholes. Analysis of the 60-MHz directional radar indicates strong radar reflectors that are probably fractures that, if transmissive, could produce appreciable quantities of ground-water to flow into the tunnel.

Methods of Ground-Water Flow Analysis

Ground-water levels were measured at three (W34ST-B, W37ST-A, W55ST-A) boreholes during field visits from November 1998 through April 1999. Fluid-temperature, resistance, and flowmeter logs were collected at each borehole (except W55ST-A) during pumping and ambient conditions (fig. 2). Measurements of the drawdown, pumping rate, and total pumping time at each borehole during test pumping were applied to a computer program (Bradbury and Rothschild, 1985) to calculate specific capacity and transmissivity of the entire borehole.

Fluid-temperature and resistance logs were used to help delineate transmissive fractures within the boreholes. Erratic and abnormal temperature gradients can be caused by ground-water flow into or out of fractures intersected by the boreholes (Keys, 1990; Williams and Conger, 1990). Changes in fluid resistance also may occur at transmissive fractures.

Transmissivity

Calculated transmissivity values for boreholes W34ST-B, W37ST-A, and W55ST-A were 75, 362, and 11 ft²/d, respectively. Clearly, the transmissive fracture network is a discrete system not correlated specifically with the fracture index. Several fractures were found to be highly transmissive and could produce appreciable quantities of ground water to flow into the tunnel during construction.

The flowmeter logs were analyzed through techniques of Paillet (1998, 2000), whereby differences between flow values at adjacent fracture zones within each borehole are attributed to measurement scatter and a possible net difference in borehole flow. Therefore, flow-log interpretation involves identification of the relative amounts of inflow or outflow occurring at

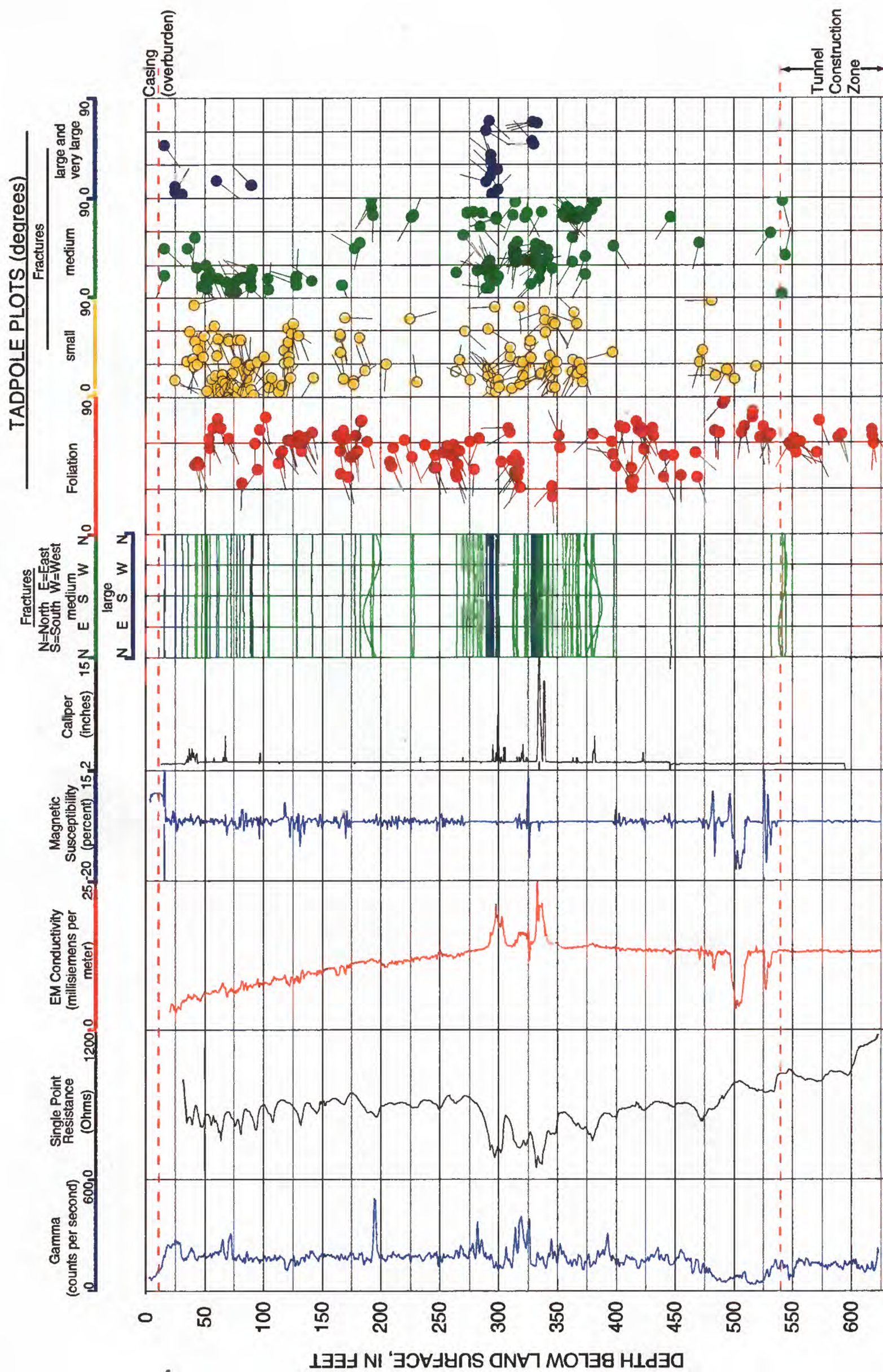


Figure 2. Suite of borehole-geophysical logs from borehole W34ST-B, Manhattan Island, N.Y., 1998. (Borehole location is shown in fig. 1.)

specific depth intervals. Inflow or outflow at several depth intervals at each borehole was measured; each of these intervals coincides with a fracture, or sets of fractures. The effects of hydraulic-head differences between zones can be eliminated by analyzing flow under ambient and pumping conditions in accordance with the techniques of Molz and others (1989) and Paillet (2000).

Ground-Water Levels in Fall 1999 and Summer 2000

Water levels in the fractured bedrock averaged 29.1 ft elevation in the northern part of the study area at W55ST-A, 13.5 ft elevation at W37ST-A, and 10.5 ft elevation in the southern part at W34ST-B. The hydraulic head in fractured bedrock wells represents the transmissivity-weighted average of the heads in all transmissive fractures in the borehole, rather than head in specific fractures.

DELINEATION OF FAULTS, FRACTURES, FOLIATION, AND GROUND-WATER FLOW

Faults, fractures, and foliation were interpreted from OTV, ATV, borehole-radar, gamma, SP, SPR, EM, MAG and caliper logs, which are reproduced in the individual borehole summaries that follow. The SP log yielded no significant results as a result of the conditions of the borehole and therefore is not discussed further. The hydraulic characteristics of the bedrock at each borehole are described in the summaries. OTV data (borehole depth, fracture orientation, and foliation orientation) for all fractures and faults in all five boreholes are listed in the appendix.

The following borehole summaries describe results of the fault, fracture, and foliation data analysis and the ground-water flow zones for boreholes W34ST-B, W37ST-A, and W55ST-A. Gamma, SPR, EM, MAG, and caliper logs with tadpole plots of the foliation and fractures from OTV data for each borehole are depicted in figures 2, 7, and 11; equal-area plots of total borehole and TCZ fractures and foliation are depicted in figures 3, 8, and 12; deviation plots for each borehole are depicted in figures 4, 9, and 13; and an example of a directional radar log showing a major reflector is presented in figure 5.

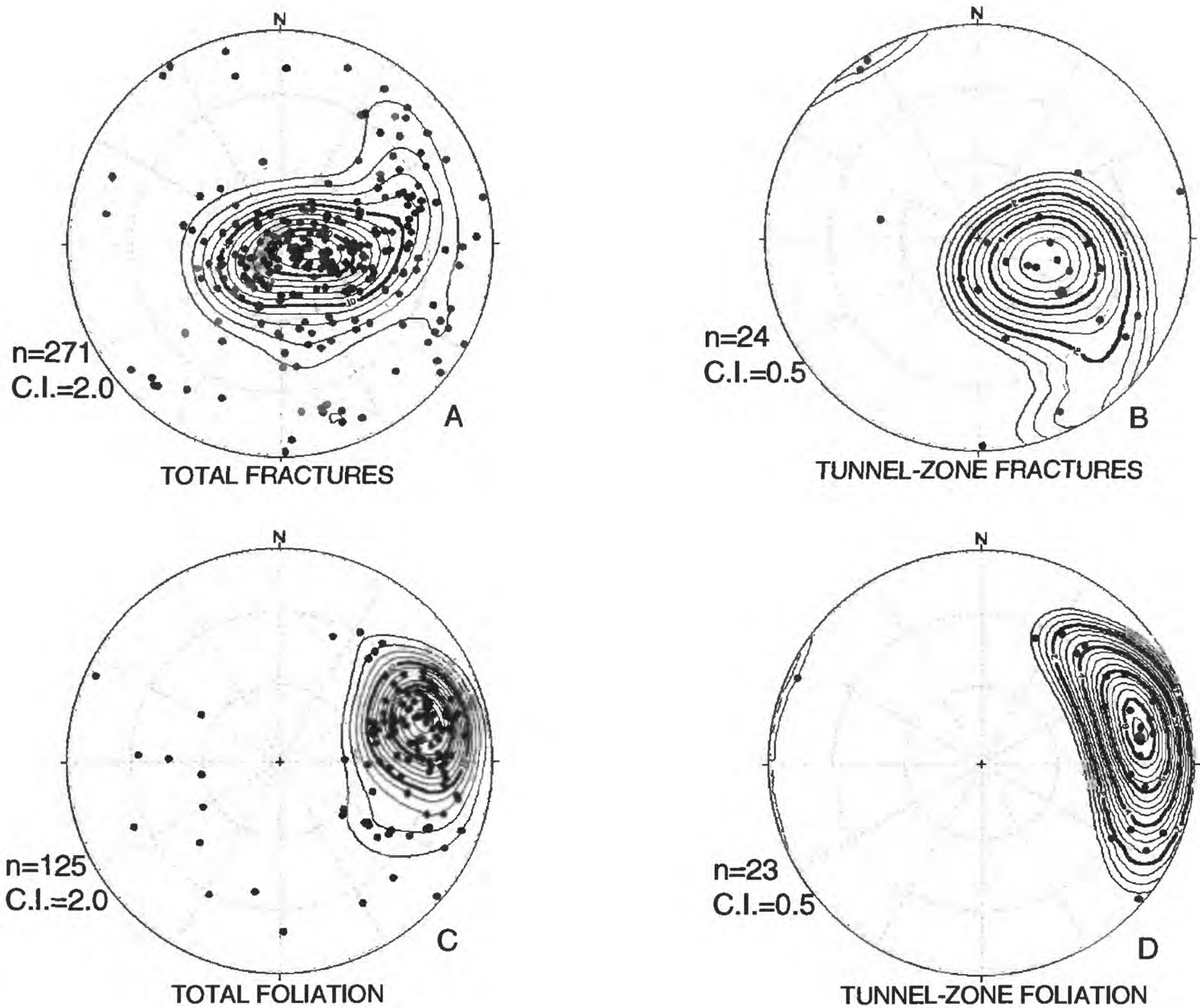
Borehole W34ST-B

W34ST-B is the first of five boreholes geophysically logged within the proposed westside tunnel (fig. 1). The borehole was drilled to a depth of 625.7 ft BLS (-585.43 ft elevation), with steel casing extending from land surface (40.27 ft elevation) to 8.0 ft BLS (32.27 ft elevation) in the unconsolidated deposits (overburden). The bedrock penetrated by the borehole consists of a sequence of gneiss and schistose gneiss with granite.

Faults, Fractures, and Foliation

The ATV and OTV data indicate a total of 271 small, medium, and large fractures from below the casing to the bottom of the borehole (shown as fracture and foliation logs in fig. 2 and listed in appendix). Large open fractures were detected at 16, 25, 31, 60, 90, 289, 292, 299, 300, 329, 330 and 332 ft BLS (24.27, 15.27, 9.27, -19.73, -49.73, -248.73, -251.73, -258.73, -259.73, -288.73, -289.73 and -291.73 ft elevation). In addition, four very large open fractures represent a possible fault-gouge zone from 328 to 330 ft BLS (-287.73 to -289.73 ft elevation, fig. 2). This gouge zone is highly fractured and has a horizontal diameter of almost 30 in. The borehole has a fracture index of 0.44 fracture per foot of borehole. The tadpole plots of fractures (fig. 2) indicate a high fracture density at depths from 30 to 125 ft BLS (10.27 to -84.73 ft elevation) and from 275 to 375 ft BLS (-234.73 to -334.73 ft elevation). The majority of small and large fractures have dip angles less than 45°. No clear pattern of dip azimuth orientations with respect to depth is evident from in the tadpole plots of fractures. The mean fracture orientation for the 271 fractures is N20°E17°NW (fig. 3). About 12 high-angle fractures with dip angles greater than 70° were encountered throughout the length of the borehole. Fractures within the proposed TCZ, which extends from 540 ft BLS (-499.73 ft elevation) to the bottom of the borehole (fig. 3), were analyzed. All fractures from 370 ft BLS (-329.73 ft elevation) to the bottom of the borehole were included to provide a statistically significant sample. In all, 24 fractures were detected, 14 of which are medium size. The mean fracture orientation for the TCZ is N34°E39°NW (fig. 3).

The tadpole plots of foliation (fig. 2) indicate correlations between foliation, azimuth, dip angle, and depth. The foliation dip azimuth in most of the bore-



EXPLANATION

- SMALL FRACTURES (1 millimeter or less)
 - MEDIUM FRACTURES (> 1 millimeter to 10 millimeters)
 - LARGE AND VERY LARGE FRACTURES (> 10 millimeters)
 - STATISTICAL MEAN ORIENTATION
- C.I. CONTOUR INTERVAL (point density contouring)

Figure 3. Stereonet plots of borehole W34ST-B, Manhattan Island, N.Y., 1998: A. Total fractures. B. Tunnel-zone fractures. C. Total foliation. D. Tunnel-zone foliation. (Borehole location is shown in fig. 1.)

hole is southwestward, except in a zone from 350 to 420 ft BLS (-309.73 to -379.73 ft elevation), where it is northeastward. The foliation dip angle increases slightly with depth. The mean orientation of foliation for the entire borehole is N09°W57°SW (fig. 3). The TCZ foliation was analyzed from 50 ft above the projected tunnel ceiling (invert) to the bottom of the borehole. The mean TCZ foliation is N09°W65°SW (fig. 3).

The gamma-log analysis (fig. 2) indicates fairly uniform gamma counts in the bedrock, except for a few spikes that reflect possible changes in mineralogy. The SPR log (fig. 2) has conductive spikes at locations that correlate with large fractures; the spikes may indicate chemically weathered zones (clays) and also ground-water in some fractures. The SPR and EM log data indicate the upper 300 ft of the rock to be more conductive than the rest. Two zones at 290 to 300 ft BLS (-249.73 to -259.73 ft elevation) and 328 to 335 ft BLS (-287.73 to -294.73 ft elevation) have the lowest resistance and the highest EM conductivity in the borehole (fig. 2) and correlate with two highly fractured transmissive zones. The magnetic-susceptibility log (fig. 2) shows areas of low response that indicate granitic zones or other areas containing low concentrations of magnetite. The lowest 85 ft of the borehole is mostly granitic.

Borehole-deviation analysis of W34ST-B indicates the bottom of the borehole to be a horizontal distance of 79.6 ft from its surface starting point at an azimuth of 84° (fig. 4). The true vertical depth of the borehole is calculated to be 618.2 ft BLS (-577.93 ft elevation).

Borehole radar data indicate six reflectors (possibly fractures) beyond the borehole, with orientations of N156°E85°NE, N143°W80°SE, N77°E53°NW, N77°E54°NW, N23°W75°SW, and N23°W88°SW (fig. 5).

Ground-Water Flow Zones

The lowest hydraulic heads of all three boreholes were in W34ST-B, probably as a result of proximity to the Hudson River (about 2,500 ft), and the relatively long distance from Manhattan Island's topographic high to the northeast. Water-level fluctuations of about 4 ft during successive field visits over 2 months indicate a possible tidal (Hudson River), pumping, or natural recharge effect.

EM-flowmeter, fluid-temperature, fluid-resistance logs from borehole W34ST-B (fig. 6) indicate several depth intervals at which a deflection or change in slope corresponds to transmissive fractures. Slope changes in these logs are seen at 72, 299, 328 to 330, 355 to 363, and 470 ft BLS (-31.73, -258.73, -287.73 to -289.73, -314.73 to -322.73, and -429.73 ft elevation, fig. 6). OTV images of two medium fractures at 72 ft BLS (-31.73 ft elevation) show mineral streaking that suggests ground-water outflow. Small deflections in the fluid-temperature and resistance logs are seen at 72 ft BLS (-31.73 ft elevation, fig. 6).

Pumping the borehole at a rate of 3 gal/min for 2.88 h produced a drawdown of 11.2 ft, or a specific capacity of 0.27 (gal/min)/ft. Total borehole transmissivity was calculated to be 75 ft²/d. EM flowmeter, fluid-temperature, and fluid-resistance logging detected five separate transmissive fracture zones within the borehole at 72, 299, 328 to 330, 355 to 363, and 470 ft BLS (-31.73, -258.73, -287.73 to -289.73, -314.73 to -322.73, and -429.73 ft elevation, fig. 6). Although somewhat ambiguous, the analysis of ambient ground-water conditions indicate a small amount of downflow between the 72-ft and 328 to 330 ft BLS (-31.73-ft and -287.73 to -289.73-ft elevation) fracture zones. Under pumping conditions, 75 percent of the borehole's transmissivity corresponds to the 299-ft BLS (-258.73 ft elevation) zone, and 25 percent to the 72-ft BLS (-31.73-ft elevation) zone. Fluid-log analysis of ambient and pumping conditions also indicates upward ambient flow from the 299-ft BLS (-258.73-ft elevation) zone to the 72-ft BLS (-31.73-ft elevation) zone, and downward flow from the 300-ft BLS (-259.73-ft elevation) zone to the 328- to 330-ft BLS (-287.73- to -289.73-ft elevation) zone. Transmissivity values for the 72-ft and 299-ft BLS (-31.73-ft and -258.73-ft elevation) fracture zones were 19 and 56 ft²/d, respectively.

If intersected, the 328- to 330-ft BLS (-287.73- to -289.73-ft elevation) fracture zone may result in appreciable quantities of ground water to flow into the tunnel because of high transmissivity and large open fractures. This zone had a reported low Rock Quality Designation (RQD) during drilling (NYCDEP, oral commun., 1998). RQD is a percentage value obtained by dividing the summed lengths of all core pieces equal to or greater than 4 in. long by the cored interval length. Trigonometric analysis of the dip angles and

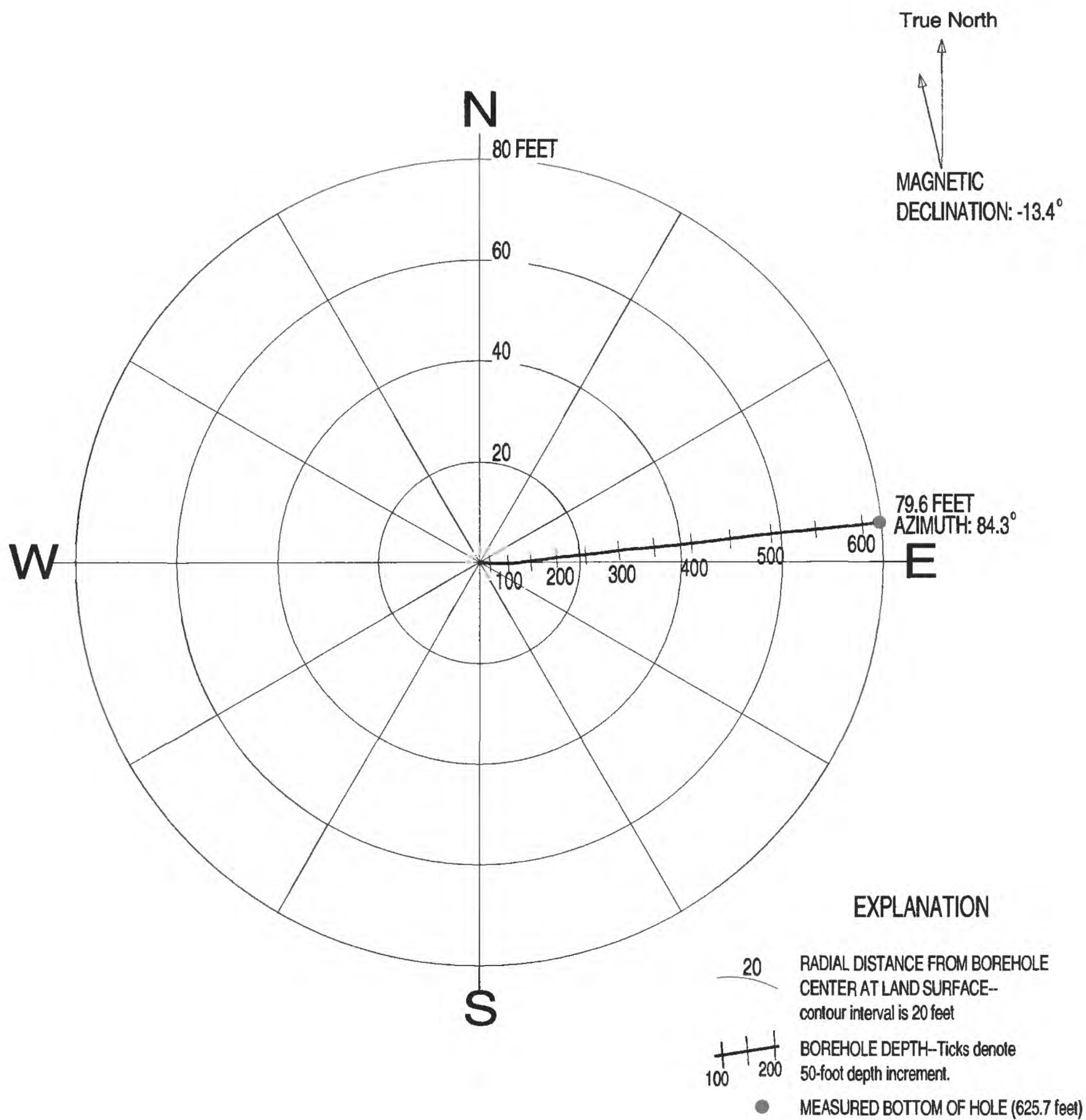


Figure 4. Deviation plot of borehole W34ST-B, Manhattan Island, N.Y., November 1998. (True depth of the borehole is 618.2 feet. Borehole location is shown in fig. 1.)

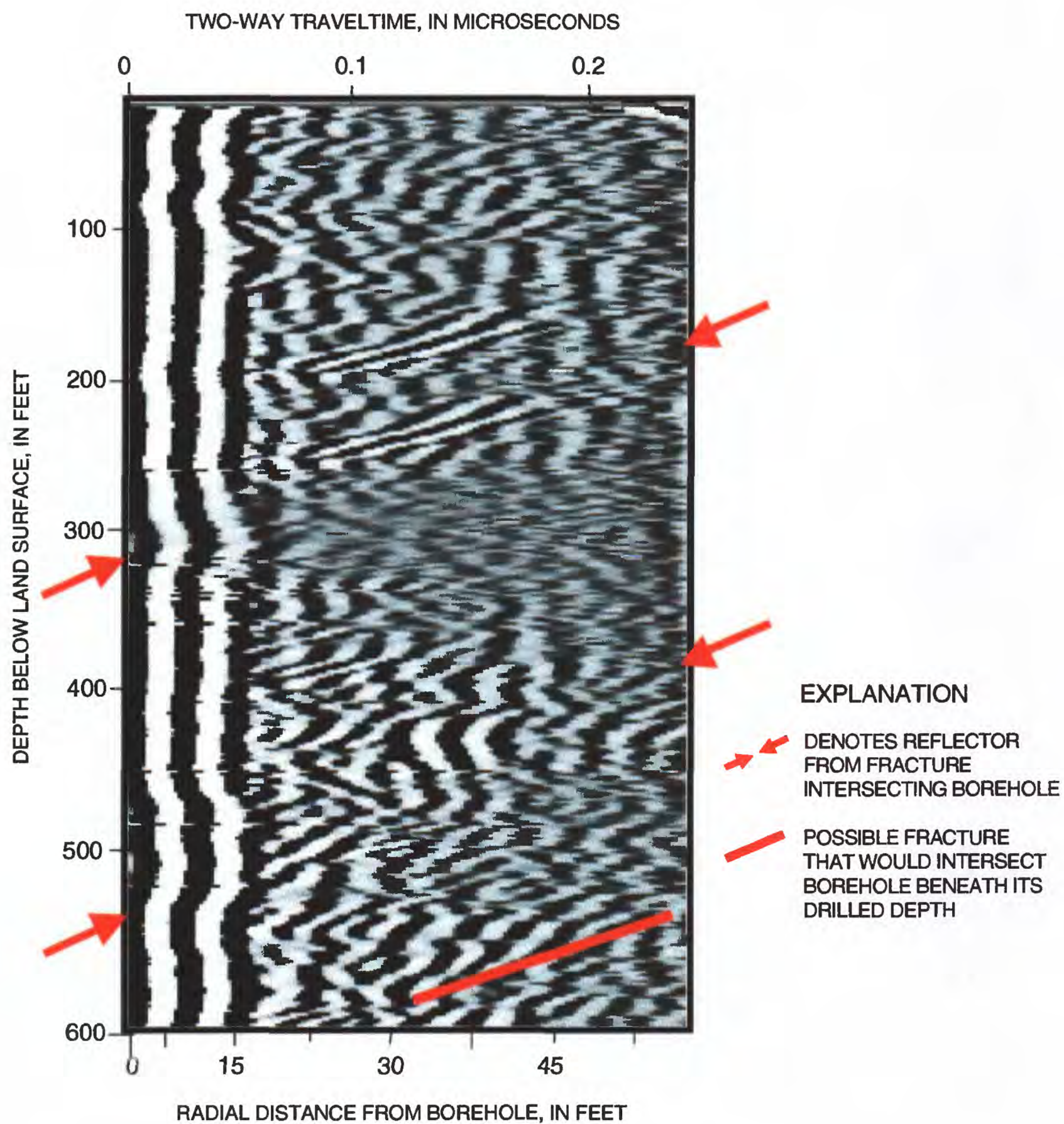


Figure 5. Dipole image of borehole-radar data collected with 60-megahertz antenna from borehole W34ST-B, Manhattan Island, N.Y., 1999. (Borehole location is shown in fig. 1.)

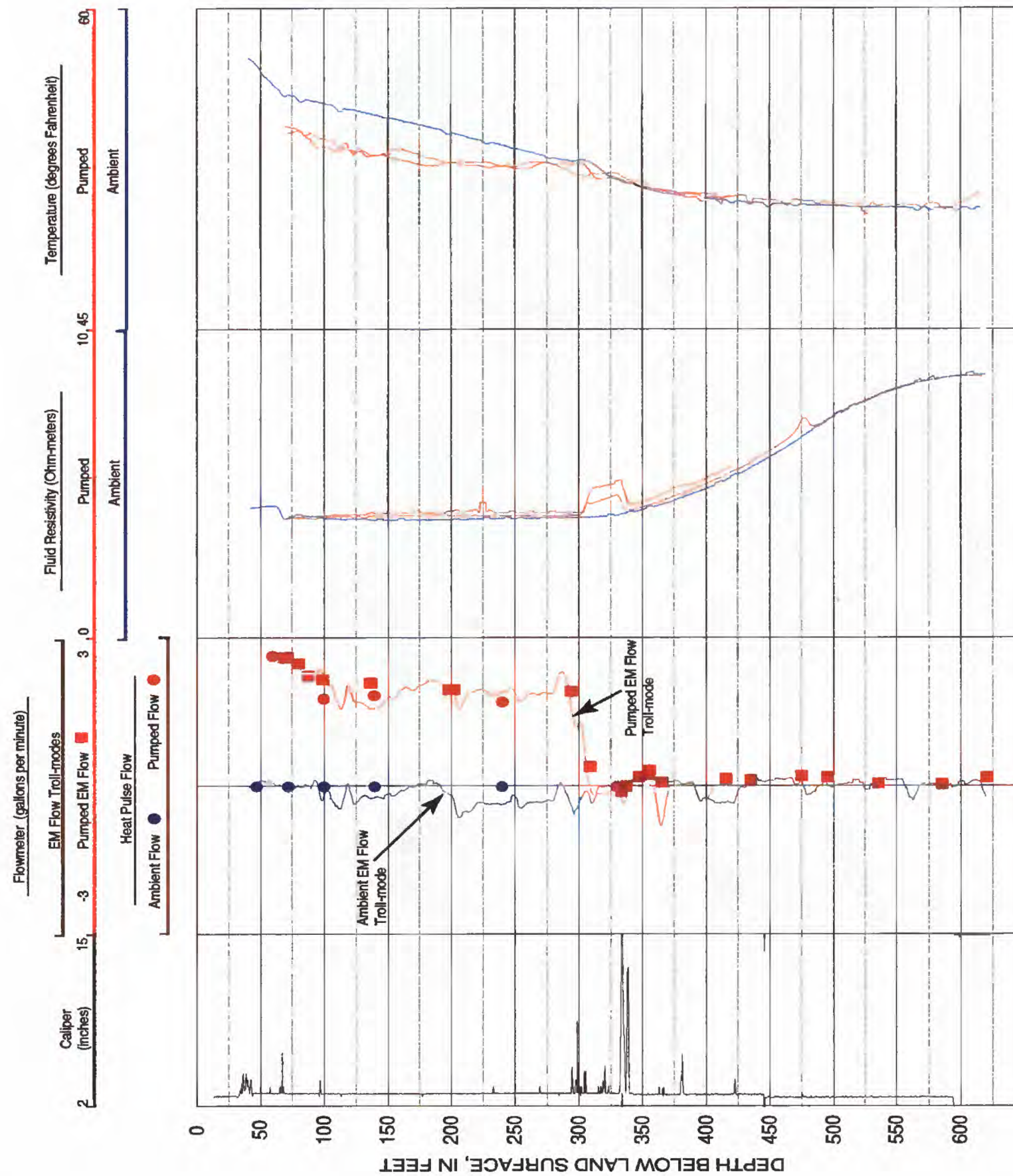


Figure 6. Physical properties of ground-water in borehole W34ST-B, Manhattan Island, N.Y., 1998. (Borehole location is shown in fig. 1.)

azimuths of the three largest fractures within this zone indicate that all have a northeastward dip that may intersect the proposed tunnel within about 220 ft northeast of borehole W34ST-B. The projection of these high-angle features is speculative but is consistent with the absence of such a major feature at borehole W37ST-A, 875 ft to the northeast.

Borehole W37ST-A

Borehole W37ST-A, the second of the three geophysically logged boreholes (fig. 1), extends to a depth of 651.4 ft BLS (-610.09 ft elevation), with steel casing from land surface (41.32 ft elevation) to 15.0 ft BLS (26.32 ft elevation). The bedrock penetrated by the borehole consists of a sequence of gneiss, schistose gneiss, and granite.

Faults, Fractures and Foliation

The ATV and OTV data indicate a total of 254 fractures from below the casing to the bottom of the borehole (see appendix). Large open fractures were detected at 37, 80, 99, 100, 385, and 403 ft BLS (4.32, -38.68, -57.68, -58.68, -343.68 and -361.68 ft elevation). The borehole has a fracture index of 0.40 fracture per foot of borehole. The tadpole plots of fractures (fig. 7) indicate two dense concentrations of fractures at 25 to 150 ft and 350 to 450 ft BLS (16.32 to -108.68 and -308.68 to -408.68 ft elevation). Low-density fracturing is indicated below 500 ft BLS (-458.68 ft elevation). Most small fractures have dip angles less than 45°. No clear pattern of depth and dip azimuths is evident, except that the majority of fractures below 425 ft BLS (-383.68 ft elevation) have dip azimuths toward the northwest (fig. 7). The mean fracture orientation for the 254 fractures is N25°E08°NW (fig. 8). Two fracture-population clusters are indicated in the stereonet plots (fig. 8); one is nearly horizontal; the other dips northwestward. The borehole contains 38 high-angle fractures with dip angles equal to or greater than 70°. Fractures within the proposed TCZ, which extends from 530 ft BLS (-488.68 ft elevation) to the bottom of the borehole, also were analyzed (fig. 8); all fractures from 430 ft BLS (-388.68 ft elevation) to the bottom of the borehole were included to provide a statistically significant sample. Only one small fracture at 624 ft BLS (-582.68 ft elevation) was detected within the proposed TCZ. In all, 20 fractures were used to

calculate the mean fracture orientation of N16°E32°NW for the TCZ (fig. 8).

The majority of the foliation tadpoles (fig. 7) dip northwestward with dip angles of 30 to 70°. The mean orientation of total foliation is N06°E55°NW (fig. 8). The TCZ foliation was analyzed from 530 ft BLS (-488.68 ft elevation) to the bottom of the borehole; the mean foliation orientation of the TCZ is N12°E58°NW (fig. 8).

The gamma-log analysis (fig. 7) indicates uniform gamma counts throughout the borehole except at a few isolated locations that correspond to minor mineralogical changes. The SPR and EM logs (fig. 7) show deflections that indicate weathered alteration minerals at four large fracture zones at 80, 100, 385, and 403 ft BLS (-38.68, -58.68, -343.68 and -361.68 ft elevation). The MAG log (fig. 7) indicates low-response zones that correspond to granite intrusions with low magnetite content.

Borehole-deviation analysis of W37ST-A indicates the bottom of the borehole to be a horizontal distance of 21.2 ft from its surface starting point at an azimuth of 118° (fig. 9). The true vertical depth of the borehole is calculated to be 649.51 ft BLS (-608.19 ft elevation).

Borehole radar data indicate two reflectors (possibly fractures) beyond the borehole (and do not intersect the borehole), which had orientations of N16°W32° NE and N04°E43° NE.

Ground-Water Flow Zones

Hydraulic heads in W37ST-A had an average elevation of 13.54 ft. The water levels at this borehole did not appear to be tidally affected. Resolution of the EM flowmeter at this borehole precluded quantitative estimation of the transmissivity of specific fracture zones.

EM flowmeter, fluid-temperature, and fluid-resistivity logs from W37ST-A indicate several transmissive fracture zones (fig. 10). The OTV detected small and medium fractures at 50 to 60 ft BLS (-8.68 to -18.68 ft elevation) with mineral streaks; other possibly transmissive fracture zones at 79 to 83, 98 to 100, 385, and 403 ft BLS (-37.68 to -41.68, -56.68 to -58.68, -343.68 and -361.68 ft elevation) were indicated from the temperature and resistivity logs. Sev-

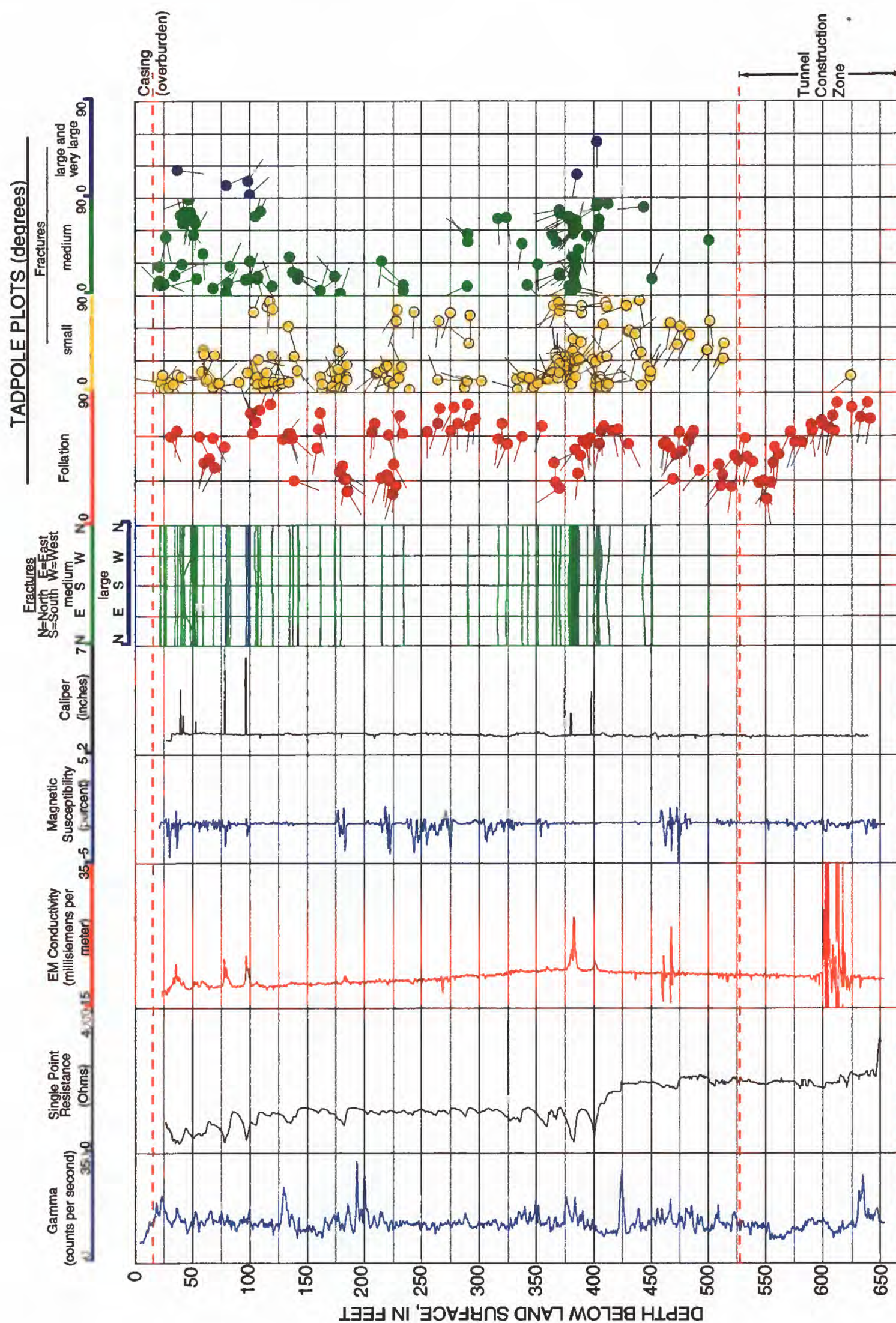
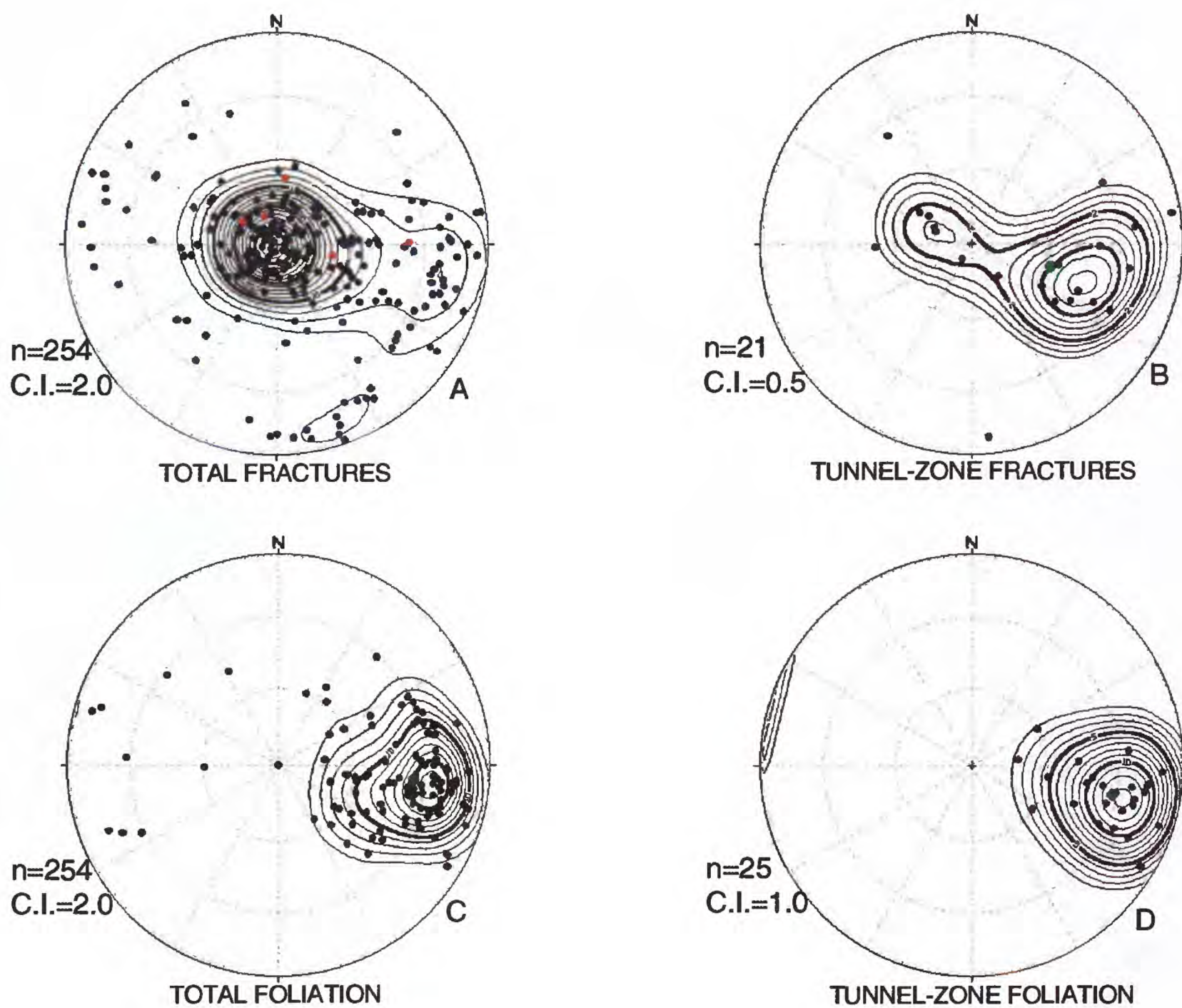


Figure 7. Suite of borehole-geophysical logs from borehole W37ST-A, Manhattan Island, N.Y., 1998. (Borehole location is shown in fig. 1.)



- EXPLANATION**
- SMALL FRACTURES (1 millimeter or less)
 - MEDIUM FRACTURES (> 1 millimeter to 10 millimeters)
 - LARGE AND VERY LARGE FRACTURES (> 10 millimeters)
 - STATISTICAL MEAN ORIENTATION
- C.I. CONTOUR INTERVAL (point density contouring)

Figure 8. Stereonet plots of borehole W37ST-A, Manhattan Island, N.Y., 1998: A. Total fractures. B. Tunnel-zone fractures. C. Total foliation. D. Tunnel-zone foliation. (Borehole location is shown in fig. 1.)

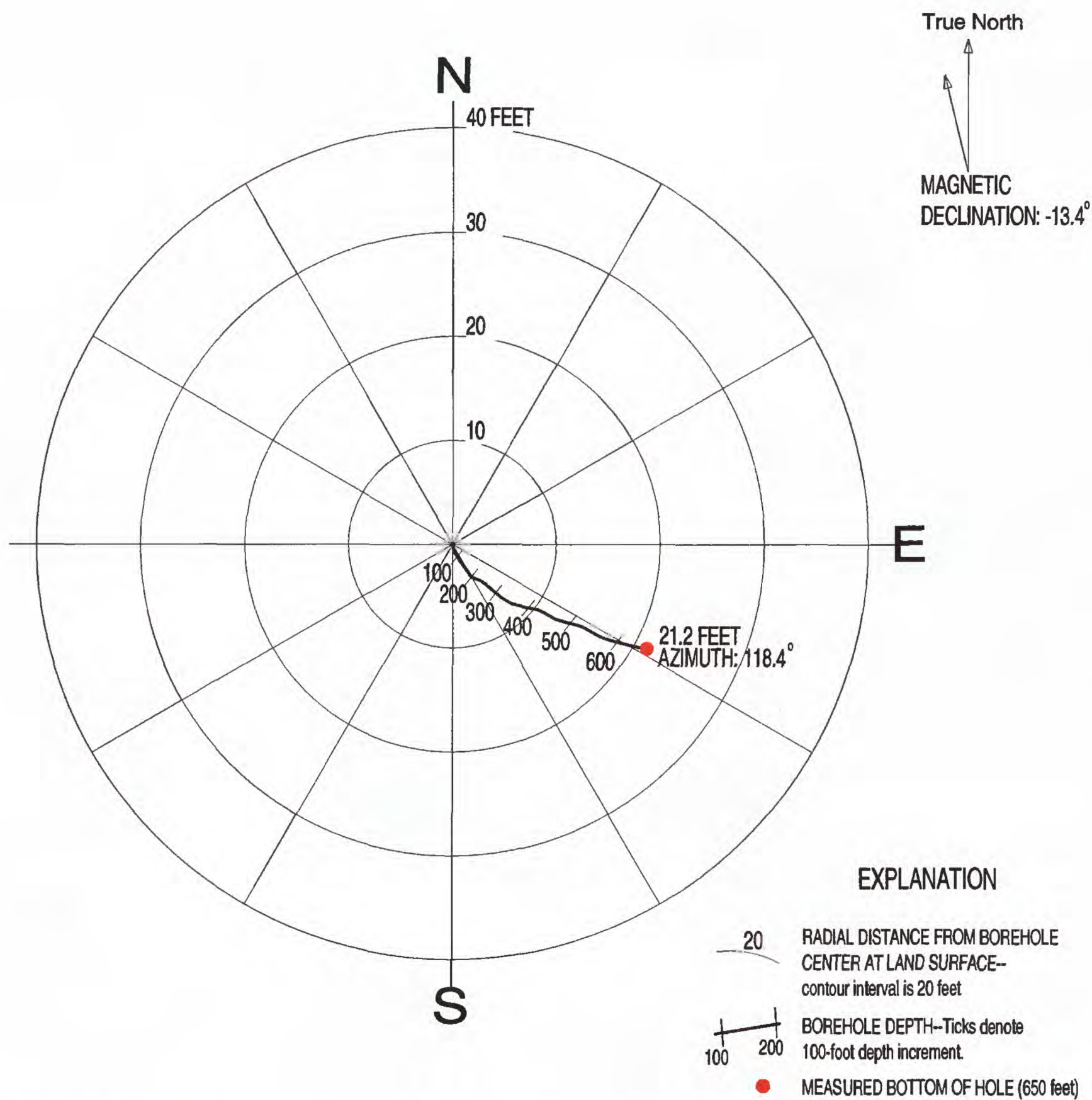


Figure 9. Deviation plot of borehole W37ST-A, Manhattan Island, N.Y., November 1998. (True depth of the borehole is 649.5 feet. Borehole location is shown in fig. 1.)

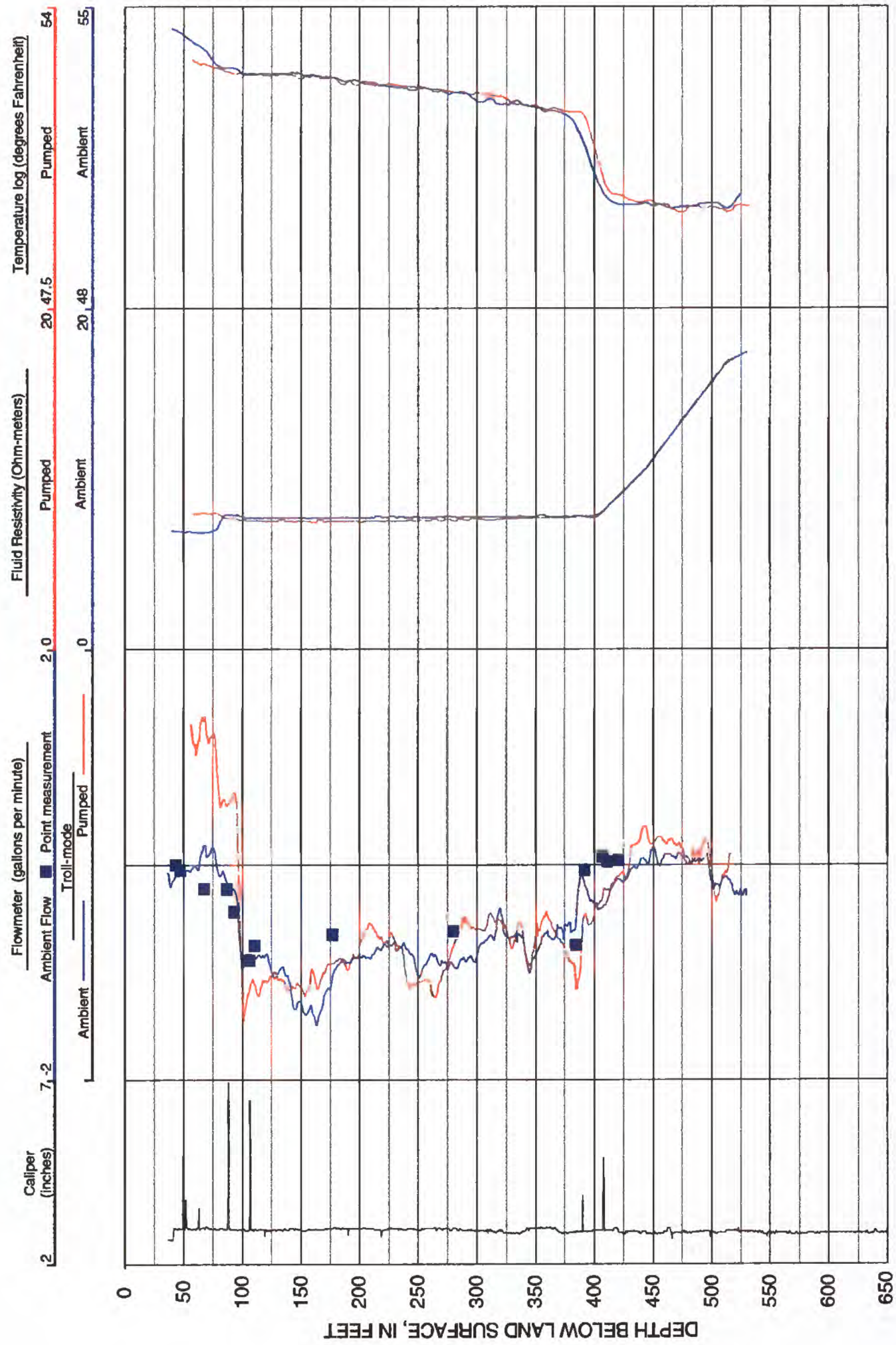


Figure 10. Physical properties of ground water in borehole W37ST-A, Manhattan Island, N.Y., 1998. (Borehole location is shown in fig. 1.)

eral medium fractures and one large fracture were detected by OTV and ATV within the 79- to 83-ft BLS (-37.68- to -41.68-ft elevation) transmissive zone, and two large fractures and several medium fractures were detected within the 98- to 100-ft BLS (-56.68- to -58.68-ft elevation) transmissive fracture zone. The 385- and 403-ft BLS (-343.68- and -361.68-ft elevation) transmissive fracture zones have a large fracture at those depths (fig. 10). EM-flowmeter analysis indicated downward flow from the 50- to 60-ft, 98- to 100-ft, and 385-ft BLS (-8.68- to -18.68-ft, -56.68- to -58.68-ft, and -343.68-ft elevation) zones to the 403-ft BLS (-361.68-ft elevation) zone. The failure of pumping to reverse the direction of flow below the 98- to 100-ft BLS (-56.68- to -58.68-ft elevation) zone indicates significant transmissivity within the 50- to 60-ft, 79- to 83-ft, and 98- to 100-ft BLS (-8.68- to -18.68-ft, -37.68- to -41.68-ft, and -56.68- to -58.68-ft elevation) fracture zones, and relatively low hydraulic head at the 403-ft BLS zone (-361.68-ft elevation, fig. 10).

The borehole was pumped at a rate of 3 gal/min for 1.7 h and produced a drawdown of 2.46 ft, or a specific capacity of 1.22 (gal/min)/ft. Total borehole transmissivity was calculated to be 360 ft²/d.

Borehole W55ST-A

W55ST-A was the last of three boreholes to be logged within the proposed westside tunnel section (fig. 1). The borehole was drilled to an apparent depth of 619.4 ft BLS (-579.99 ft elevation), with steel casing extending from land surface (39.41 elevation) 34 ft through the unconsolidated sediment overburden to bedrock. The bedrock penetrated by the borehole consists of a sequence of gneiss, schistose gneiss, and granite. A partial collapse of the borehole within bedrock required the installation of steel casing to 150 ft BLS (-110.59 ft elevation) to facilitate geophysical logging. As a result no fracture, foliation, or groundwater data were collected from the top of bedrock at 34 ft BLS (5.41 ft elevation) to the bottom of the inserted casing at 150 ft BLS (-110.59 ft elevation). The poor borehole conditions prevented detection of the microfractures to the extent of the previous two boreholes (W34ST-B and W37ST-A). This borehole, thus is considered undersampled.

Faults, Fractures, and Foliation

The ATV and OTV data (not shown) indicate 126 fractures from the bottom of the inserted casing to the bottom of the borehole (see appendix). Large open fractures were detected at 335, 336, 379, 384, and 605 ft BLS (-295.59, -296.59, -339.59, -344.59, and -565.59 ft elevation). The borehole fracture index of 0.25 fracture per foot of open borehole is the lowest of all three boreholes. The tadpole plots of the fractures (fig. 11) indicate somewhat uniform distributions of fractures with depth. Most small fractures appear to have dip azimuths similar to the foliation. The mean fracture orientation for the 126 fractures is N19°E44°NW (fig. 12). Two fracture-population clusters are indicated in the stereonet plot (fig. 12); one is nearly horizontal and dipping slightly to the east; the second dips northwestward (fig. 12). The borehole contains 12 high-angle fractures throughout the borehole with dip angles equal to or exceeding 70°. Fractures within the proposed TCZ from 462 ft BLS (-422.59 ft elevation) to the bottom of the borehole were included to provide a statistically significant sample. In all, 43 fractures (13 of which are medium to large) were detected within the proposed TCZ and have a mean fracture orientation of N13°E51°NW (fig. 12).

The foliation tadpoles (fig. 11) indicate nearly constant dip angles of about 60° with azimuths toward the northwest. The mean orientation of foliation for the entire borehole is N16°E 60°NW; and that for the TCZ is N20°E 61°NW (fig. 12).

The gamma-log (fig. 11) analysis indicates uniform gamma counts throughout most of the borehole except at isolated locations. The SPR log (fig. 11) has conductive spikes, some that correspond to fractures at 226 to 231 and 475 ft BLS (-186.59 to -191.59 and -435.59 ft elevation). The EM log (fig. 11) has a muted response, similar to the SPR log. The bedrock seems to increase in resistance with depth. The MAG log (fig. 11) shows a clear contact at 375 ft BLS (-335.59 ft elevation) that indicates a probable lithologic change to magnetite-poor rock.

Borehole-deviation analysis of W55ST-A (fig. 13) indicates the bottom of the borehole to be a horizontal distance of 28.9 ft from its surface starting point at an azimuth of 82°. The true vertical depth of the borehole is estimated to be 618.2 ft BLS (-578.79 ft elevation, fig. 13).

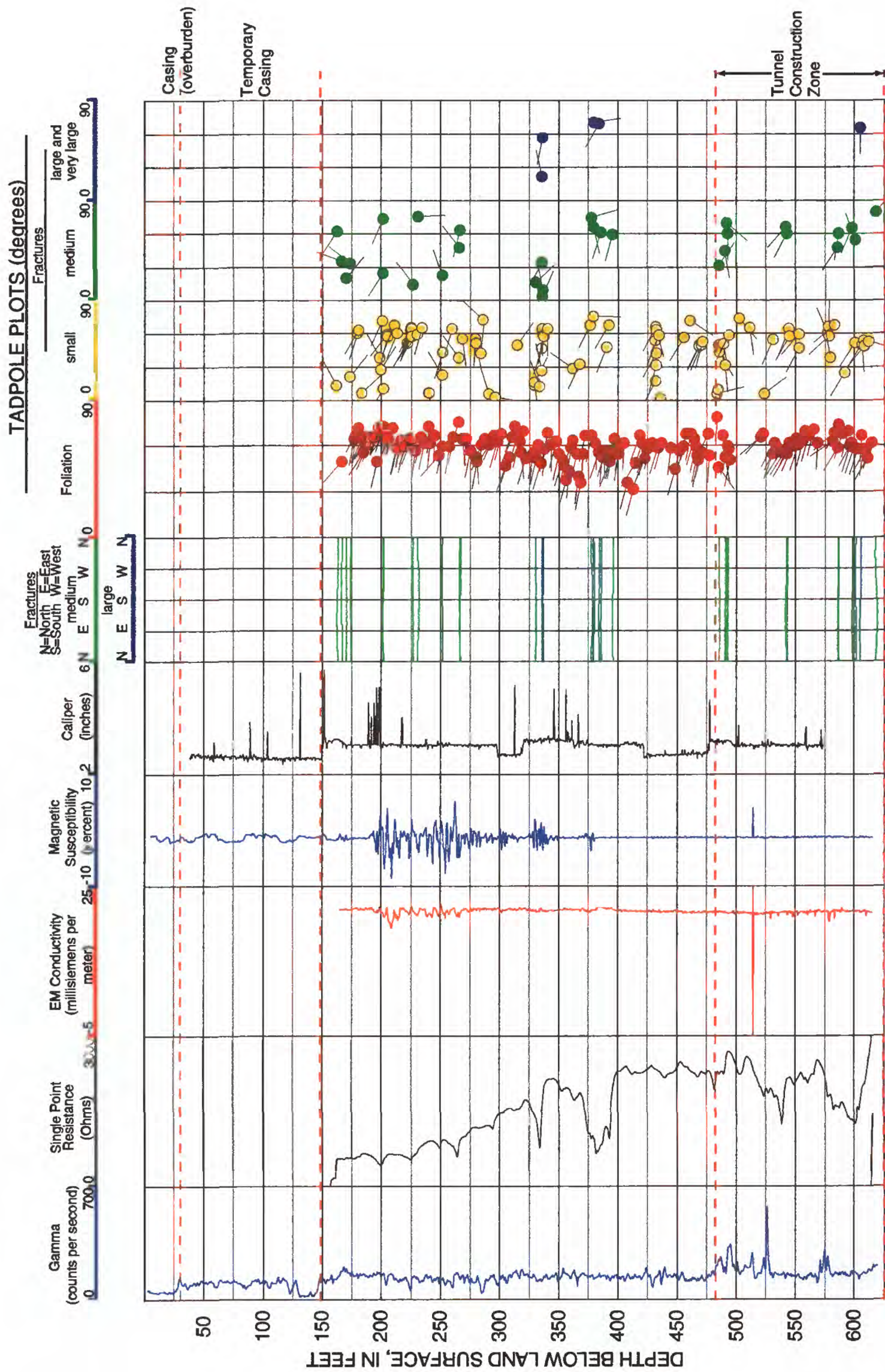


Figure 11. Suite of borehole-geophysical logs from borehole W55ST-A, Manhattan Island, N.Y., 1998. (Borehole location is shown in fig. 1.)

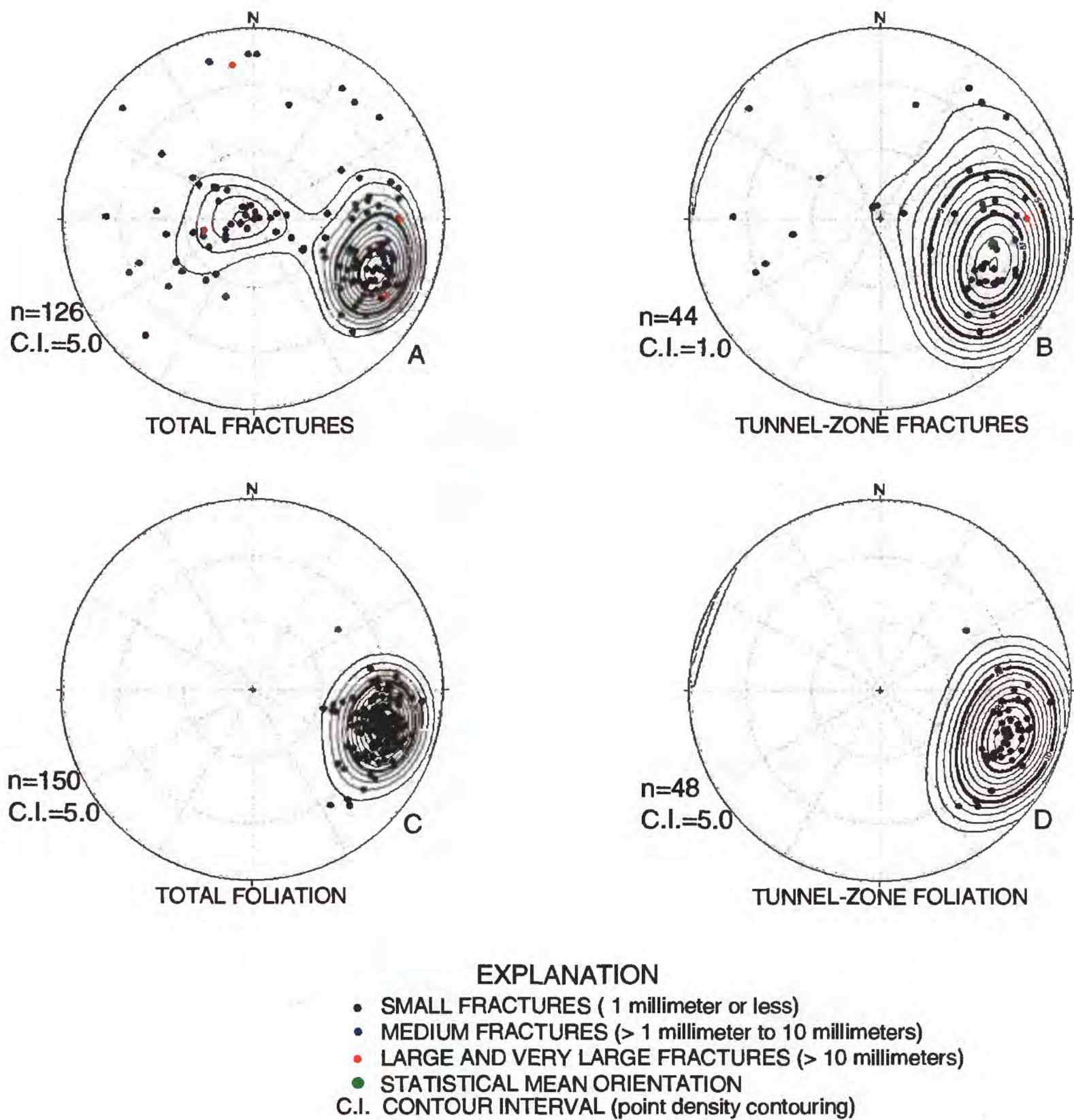


Figure 12. Stereonet plots of borehole W55ST-A, Manhattan Island, N.Y., 1998: A. Total fractures. B. Tunnel-zone fractures. C. Total foliation. D. Tunnel-zone foliation. (Borehole location is shown in fig. 1.)

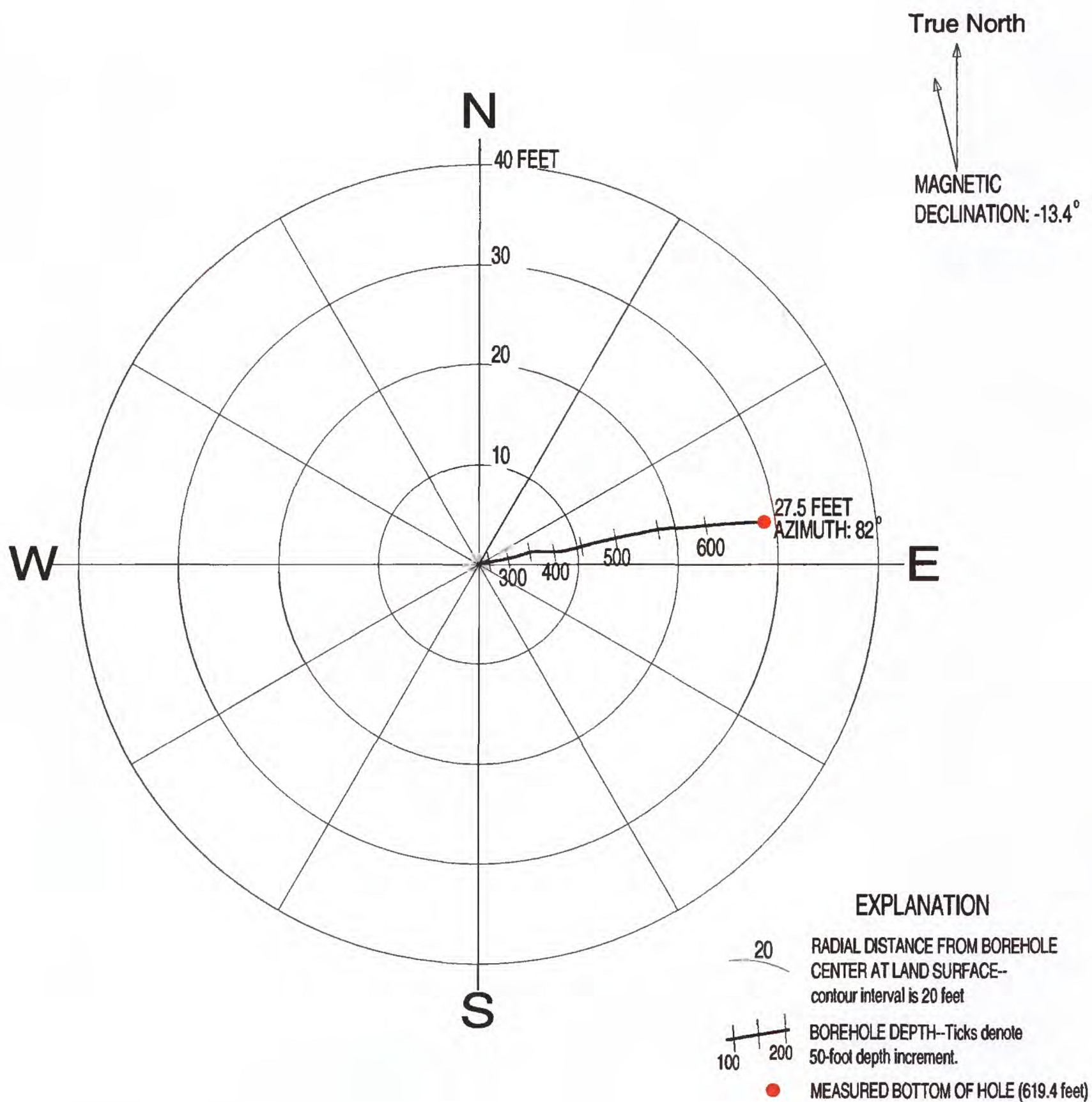


Figure 13. Deviation plot of borehole W55ST-A, Manhattan Island, N.Y., November 1998. (True depth of the borehole is 618.2 feet. Borehole location is shown in fig. 1.)

Borehole radar data indicate four reflectors (possibly fractures) beyond the borehole with orientations of N24°E59°SE, N44°E56°SE, N03°W50°NE, and N64°E53°SE.

Ground-Water Flow Zones

Hydraulic heads in W55ST-A had a mean elevation of 29.13 ft and appeared to be tidally affected. Equipment malfunctions and poor borehole conditions hampered the ability to calculate transmissivity of some fracture zones.

Heat-pulse flowmeter and fluid-resistivity logs indicate transmissive fracture zones at 162 to 170, 226 to 231, and 330 to 619.4 ft BLS (-122.59 to -130.59, -186.59 to -191.59, and -290.59 to -611.29 ft elevation, fig. 14). Three medium fractures at the 162- to 170-ft BLS (-122.59- to -130.59-ft elevation) fracture zone indicate no detectable ambient flow but significant upflow and transmissivity during pumping. The fluid-resistivity log indicates a deflection or slope change at the 226- to 231-ft BLS (-186.59 to -191.59, ft elevation) fracture zone, and the heat-pulse flowmeter indicates no detectable ambient flow and only minor upflow during pumping. The limited measurements from the 330- to 619.4-ft BLS (-290.59- to -611.29-ft elevation, bottom of borehole) fracture zone precluded calculation of specific fracture transmissivity values or hydraulic head. The fluid-resistivity log indicates a deflection or change in slope at 342 to 380 ft BLS (-302.59 to -340.59 ft elevation, fig. 14).

Pumping at a rate of 1.1 gal/min for 1.9 hours produced a drawdown of 24.2 ft, or a specific capacity of 0.05 (gal/min)/ft. Total borehole transmissivity was calculated to be 11 ft²/d. Analysis of the ambient and pumping conditions indicated three transmissive zones at 162 to 170 ft, 226 to 231 ft, and 330 to 619.4 ft BLS (-122.59 to -130.59 ft, -186.59 to -191.59 ft, and -290.59 to -611.29 ft elevation), with estimated transmissivities of 5.6, 0.3, and 5.1 ft²/d, respectively. Thus, 46 percent of the ground water was produced from the 330- to 619.4-ft BLS fracture zone (-290.59- to -611.29-ft elevation, bottom of borehole).

SUMMARY AND CONCLUSIONS

In 1970, the New York City Department of Environmental Protection (NYCDEP) began construction of a third tunnel to supply water to New York City in

case that one of the two present tunnels should require repair. In 1998, the U.S. Geological Survey (USGS), in cooperation with the NYCDEP, began a study to apply advanced borehole-geophysical methods to assess crystalline bedrock in southeastern New York. Three boreholes on western Manhattan Island were drilled by the NYCDEP to provide cores, geophysical logs, and geotechnical information for the design and construction of City Water Tunnel 3. Two additional boreholes (GroveST-A, and W26ST-A) were drilled and only fracture and foliation orientations were measured. The geophysical logs provided data on the deviation of the boreholes from vertical, the location and orientation (dip azimuth and dip) of fractures (OTV and ATV), the orientation (dip azimuth and dip) of rock foliation (OTV), locations of contacts between rock units of differing types, and locations of transmissive (water-producing) fractures; they also provided information on the rocks' magnetic susceptibility, electrical resistivity and resistance, the direction and quantity of ground-water flow within the borehole, resistance and temperature of ground water, a profile of the borehole diameter, and the extent of fractures or geologic features up to 100 ft beyond the borehole.

The bedrock contains numerous fractures that intersect the study area. Depth to bedrock ranges from 8 to 34 ft BLS. Overlying the bedrock are unconsolidated sediments that were cased off with steel in wells completed in the three boreholes. Small fractures had apertures of 0.04 in. (1 mm) or less, medium fractures had apertures of >0.04 to 0.39 in. (>1 to 10 mm), large fractures had apertures >0.39 in. (>10 mm) and very large fractures had apertures >9.8 in. (>25 cm). The tunnel construction zone was defined as a horizon ranging from 50 ft above the roof to 50 ft below the floor of the proposed tunnel; this represents the major area of proposed construction in the interval from 540 to 625.7 ft BLS (-499.73 to -585.43 ft elevation) at W34ST-B, 530 to 651.4 ft BLS (-488.68 to -610.09 ft elevation) at W37ST-A, and 462 to 619.4 ft BLS (-422.59 to -579.99 ft elevation) at W55ST-A. Equal-area nets and tadpole analyses were used to identify foliation and fracture relations. (Tadpoles are circles with tails plotted with respect to a horizontal scale to indicate the degree of dip-plunge angle of the structures from 0 to 90°. The tail of each tadpole points to the dip azimuth of the structure.)

Three-dimensional analysis of the medium and large fractures associated with the 328-330 ft BLS (-287.73 to -289.73 ft elevation) fracture zone in

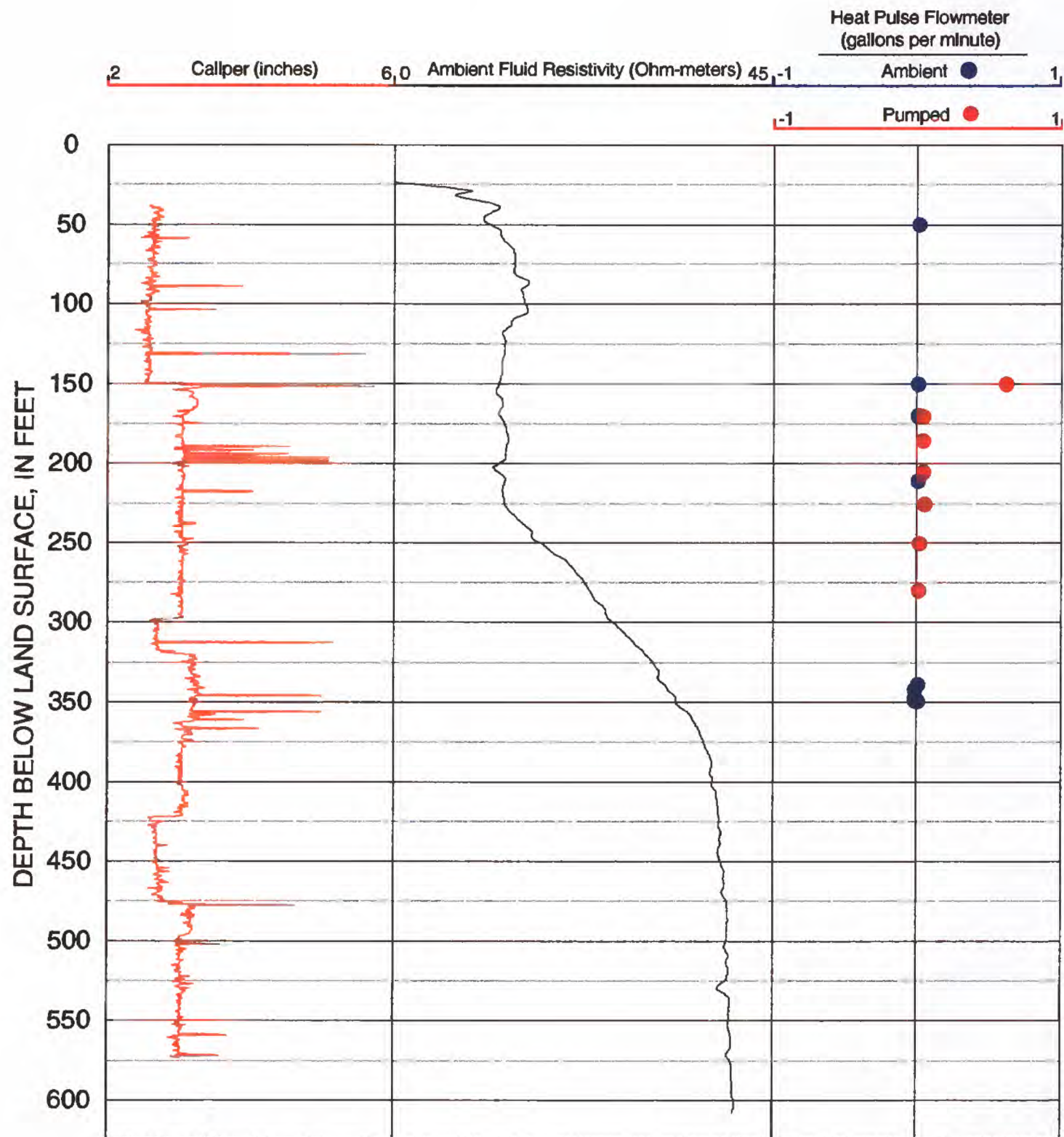


Figure 14. Physical properties of ground-water in borehole W55ST-A, Manhattan Island, N.Y., 1998. (Borehole location is shown in fig. 1.)

W34ST-B indicates that these highly transmissive fractures may intersect the proposed tunnel to within a distance of 220 ft northeast of the borehole. These fractures may produce appreciable quantities of ground-water flow into the tunnel and could thereby affect construction. Fracture indexes range from 0.25 to 0.44 fracture per foot of bedrock. No correlation is indicated between fracture orientation and depth. Total-borehole fracture populations are either nearly horizontal or moderate- to high-angle dip with a northwest azimuth. The intersection of these fracture populations could result in block- or wedge-failure during tunnel construction. Foliation analysis indicates some relation between depth and foliation. Overall, the average foliation of the bedrock ranges from southwest to northwest dip azimuth. Foliation dip azimuths within the Tunnel Construction Zone range from southwest to northwest, with dip angles ranging from 58° to 65°.

Analysis of the 60-Mhz directional radar indicates strong radar reflectors, which probably are fractures that extend beyond the boreholes and probably would intersect the boreholes if the boreholes were deeper. Radar analysis indicates that some of these fractures, if water bearing, could produce appreciable quantities of ground-water flow into the tunnel and could thereby affect construction.

Water levels in the fractured bedrock ranged from 29.1 ft elevation in the northern part of the study area (W55ST-A) to 10.5 ft elevation in the southern part (W34ST-B). Transmissivity values for most transmissive fracture zones in each borehole were estimated, if possible. Transmissive fracture zones were delineated by correlating inflow zones interpreted from heat-pulse flowmeter logs with major fracture zones indicated by other geophysical logs. Each of the three boreholes tested had several transmissive fracture zones. Some of these fractures had high transmissivity, especially at those boreholes with moderate to high total borehole transmissivity.

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Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01

[Depths are in feet below land surface. SM, small fracture (0.04 inch or less); MED, medium fracture (greater than 0.04 to 0.39 inch); LG, large fracture (greater than 0.39 in to 9.8 inches); VLG, very large fracture (greater than 9.8 inches); GW, ground water, FLT, fault. Borehole locations are shown in fig. 1.]

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
W34ST-B			
Fractures			
15.5	223	45	MED
15.6	274	23	MED
15.6	290	21	MED
15.8	235	48	LG
24.6	280	11	LG
24.7	121	6	LG
24.8	211	16	SM
30.8	222	4	LG
35.1	247	33	SM
35.3	246	45	MED
37.2	247	60	SM
40.1	99	35	SM
41.0	277	28	SM
41.1	164	84	SM
41.6	276	55	MED
41.7	262	51	SM
43.4	269	28	MED
43.6	290	30	SM
44.2	240	44	SM
47.3	222	11	MED
48.9	121	37	SM
49.7	238	56	SM
51.0	280	19	MED
51.2	218	30	MED
52.0	12	6	SM
52.0	256	9	MED
54.1	246	24	MED
54.4	261	17	MED
55.9	264	17	SM
58.4	255	65	SM
59.4	216	20	SM
60.0	217	16	LG
60.7	264	38	SM
61.7	247	53	SM
62.2	250	18	MED
63.7	186	9	SM
63.9	226	5	SM
65.2	241	20	SM
65.3	238	21	SM
65.8	238	15	SM

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
67.4	216	6	SM
67.6	311	13	SM
68.7	257	15	MED
69.9	304	9	SM
70.5	253	53	SM
70.6	247	51	SM
72.1	35	6	MED GW
72.2	64	12	MED GW
73.1	281	9	SM
73.4	304	13	SM
73.7	294	22	SM
75.9	267	11	SM
76.6	251	32	SM
77.0	279	6	MED GW
77.1	282	16	MED GW
77.9	62	3	SM
78.0	259	52	SM
78.4	197	9	SM
80.1	222	18	MED
81.0	265	52	SM
82.7	43	19	MED
82.8	52	5	SM
85.8	287	18	SM
86.3	286	26	SM
87.5	298	25	SM
88.4	92	30	SM
89.0	75	29	SM
89.2	282	16	MED GW
89.3	1	22	MED GW
89.6	327	10	MED
89.7	130	7	SM
90.0	45	12	LG GW
90.5	19	26	MED
91.7	135	2	SM
95.2	306	32	SM
100.7	292	37	SM
103.9	278	18	MED
104.4	95	8	MED GW
104.5	47	9	SM
106.8	281	18	SM
112.9	300	5	SM
115.6	127	11	SM
117.7	273	43	SM
118.2	271	31	SM

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
120.7	213	63	SM	284.3	228	65	MED
121.1	272	50	SM	286.2	214	77	MED
121.7	262	37	SM	289.2	314	9	MED
121.9	278	32	SM	289.3	15	15	LG
123.0	282	18	SM	289.4	212	61	LG
124.2	256	58	SM	289.5	20	25	MED
125.5	272	67	SM	290.1	55	30	MED
127.5	16	18	MED	290.4	75	29	MED
127.5	136	4	MED GW	290.8	45	25	SM
128.2	22	12	MED	290.9	49	19	SM
128.3	93	20	MED GW	291.0	213	62	SM
130.2	250	56	SM	292.2	7	9	MED
141.1	37	16	MED GW	292.3	222	70	LG
142.5	302	18	SM	292.3	38	20	MED
165.2	257	55	SM	292.3	37	19	MED
165.3	256	57	SM	292.8	67	34	MED
165.8	263	41	SM	293.1	38	20	LG
167.2	250	12	MED	293.3	74	34	LG
167.9	65	17	SM	293.5	39	39	VLG
169.5	182	72	SM	293.8	320	7	SM
176.9	144	15	SM	294.3	66	13	SM
177.0	130	12	SM	294.4	283	4	LG
177.6	31	45	MED	294.5	133	3	LG
181.8	250	54	SM	295.3	45	26	LG
182.2	283	50	MED	295.4	59	26	MED
186.3	71	24	SM	295.6	37	26	SM
191.9	307	82	MED	296.5	357	82	SM
192.2	299	89	MED	297.0	237	3	MED
193.4	271	75	MED	297.0	114	19	MED
204.3	273	30	SM	297.1	77	18	MED
224.7	165	71	SM	297.7	294	5	SM
226.1	300	73	MED	297.8	133	12	SM
227.8	112	75	MED	297.9	71	16	MED
230.6	77	24	SM	298.1	340	73	MED
230.6	82	14	SM	298.2	346	71	MED
263.7	101	23	SM	298.9	69	26	LG
264.0	131	23	MED	299.7	63	8	LG
266.7	241	34	SM	299.9	31	20	MED
270.0	232	57	MED	300.1	56	16	SM
271.5	222	60	SM	300.3	32	9	SM
273.2	223	77	MED	309.9	327	37	SM
276.2	28	16	SM	310.1	319	45	SM
278.6	201	78	MED	311.3	291	8	SM
281.8	267	25	MED	312.4	291	75	MED

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
312.6	283	46	MED	340.9	287	34	MED
312.8	274	41	MED	341.6	264	44	MED
314.0	309	87	MED	342.0	285	37	MED
315.0	279	33	MED	342.7	273	27	SM
315.2	316	42	MED	343.4	287	38	SM
316.1	293	51	MED	344.7	295	20	SM
317.5	133	32	SM	345.6	317	9	SM
318.0	268	82	SM	346.0	276	27	MED
318.5	161	12	SM	346.4	237	68	SM
320.5	347	20	SM	347.9	272	30	SM
320.7	343	32	SM	348.1	281	9	SM
321.9	2	35	MED	348.3	242	67	SM
322.6	100	73	MED	349.3	315	24	SM
324.5	243	77	MED	349.5	303	32	SM
326.4	259	47	SM	354.6	233	76	MED
327.0	270	51	SM	356.8	225	73	MED
327.5	301	36	SM	357.6	50	82	MED
327.6	314	13	MED	360.7	42	79	MED
328.5	47	52	LG	362.8	281	55	MED
328.9	353	69	VLG	362.9	302	33	MED
329.5	346	69	VLG	363.0	294	23	SM
330.0	359	49	LG	363.2	271	34	SM
330.2	348	34	MED	364.2	44	77	SM
330.5	168	33	MED	366.0	33	71	MED
330.6	341	37	MED	366.5	292	67	SM
330.8	14	32	MED	366.6	21	67	SM
330.9	1	36	MED	366.8	299	22	SM
331.2	339	44	MED	367.1	271	75	MED
331.7	353	49	MED	368.0	277	74	MED
332.0	333	43	MED	368.7	307	31	SM
332.2	358	43	MED	369.0	41	78	MED
332.9	344	68	VLG	370.8	251	25	SM
334.0	304	32	MED	371.4	311	14	SM
334.3	315	18	MED	373.9	299	22	MED
335.5	341	21	SM	374.1	290	38	MED
335.6	272	26	MED	374.4	296	73	MED
335.7	312	47	MED	378.1	335	80	MED
336.1	294	45	MED	379.3	335	80	MED
336.3	322	22	SM	380.5	148	89	MED
336.9	297	78	MED	383.2	145	87	MED
337.3	327	34	MED	396.9	345	41	SM
339.0	341	78	SM	397.9	237	47	MED
339.4	318	70	SM	446.6	304	73	MED
340.0	253	59	SM	470.8	284	50	MED

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
471.3	286	32	SM	170.0	258	63	
473.5	273	43	SM	172.1	259	38	
481.3	359	88	SM	174.4	269	51	
484.6	0	20	SM	177.7	262	53	
494.1	297	25	SM	178.6	272	65	
500.8	23	17	SM	180.2	268	55	
519.1	274	28	SM	182.9	281	74	
531.6	304	59	MED	183.8	282	75	
540.9	300	4	MED	188.1	255	61	
541.5	257	88	MED	207.5	248	48	
544.0	101	39	MED	209.2	245	45	
Foliation				210.5	252	57	
41.8	256	46		220.2	252	62	
44.0	251	48		226.3	251	51	
44.8	267	46		237.6	246	59	
53.6	244	63		245.4	257	44	
54.2	269	57		246.3	302	52	
57.0	268	70		247.3	249	44	
61.3	255	76		253.2	245	54	
64.0	245	70		256.5	252	58	
70.6	249	63		260.4	254	52	
81.6	272	34		261.6	252	59	
92.6	270	60		263.2	248	55	
95.0	306	43		263.8	248	40	
97.0	242	69		264.6	254	38	
102.0	262	77		265.4	253	46	
113.1	255	47		266.8	239	55	
114.6	231	54		275.5	272	61	
116.2	265	55		279.3	273	43	
120.8	253	62		283.6	290	63	
122.0	254	62		302.4	240	48	
124.6	264	61		308.4	359	70	
129.2	246	64		309.4	330	67	
130.1	249	65		311.3	308	49	
131.9	242	58		313.9	306	41	
132.4	236	55		314.8	284	52	
133.9	243	62		316.2	288	38	
135.5	248	64		316.9	305	42	
141.5	259	67		317.6	277	48	
163.1	253	65		318.2	307	31	
165.2	262	55		345.5	311	32	
165.8	252	40		346.0	268	25	
167.3	252	62		351.3	66	65	
168.3	276	68		352.4	93	57	

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
380.1	316	66	
396.2	28	61	
397.1	11	53	
399.6	45	45	
403.4	260	71	
407.2	288	70	
412.6	60	35	
412.9	92	44	
413.4	81	31	
414.9	121	36	
417.1	256	74	
419.1	244	69	
421.3	254	70	
422.2	240	67	
423.6	248	56	
430.7	259	70	
431.9	295	65	
440.6	246	38	
441.1	262	52	
448.7	304	52	
455.2	270	39	
467.4	221	54	
469.1	251	38	
484.0	268	68	
487.0	270	67	
487.8	274	67	
490.6	115	86	
492.6	311	88	
506.5	278	67	
508.8	260	71	
515.7	298	77	
516.5	291	81	
522.4	261	64	
525.2	255	71	
528.8	267	64	
531.6	294	66	
547.4	300	60	
548.9	221	58	
550.2	212	61	
551.4	221	63	
553.0	203	54	
556.9	235	61	
570.5	245	54	
572.9	250	75	

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
588.7	250	64	
591.8	257	66	
617.1	238	69	
617.6	262	65	
618.7	274	60	
W37ST-A			
Fractures			
20.9	203	14	MED
21.3	103	27	MED
21.4	46	10	MED GW
22.0	126	5	SM
22.7	15	19	SM
22.7	8	10	SM
24.1	200	17	SM
25.2	125	11	MED
25.4	234	4	SM
26.5	259	54	MED
29.5	234	5	SM GW
33.3	235	8	SM GW
34.3	155	19	MED GW
36.8	188	17	SM
36.9	187	26	LG
39.5	120	56	MED
39.5	124	74	MED
40.3	188	15	SM GW
41.0	181	29	MEDGW
41.4	227	67	MED
42.2	76	67	MED
42.7	83	77	MED
47.0	341	89	MED
48.2	284	77	MED
48.4	284	71	MED
50.8	119	56	MED
51.4	282	70	MED
52.2	271	67	MED
53.9	345	16	MED GW
58.5	247	20	SM GW
59.4	267	39	MED
59.8	270	40	SM
60.1	269	36	SM
61.8	207	11	SM GW
62.4	356	13	SM GW
67.9	171	5	SM
67.9	142	7	MED GW

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
69.5	295	35	SM	141.9	209	16	MED
71.9	133	9	SM GW	142.3	225	20	MED
73.3	49	9	SM GW	161.5	132	15	SM
78.9	19	3	MED	161.6	144	5	MED
78.9	277	3	MED	161.7	107	5	MED
79.5	156	12	LG	163.0	270	3	SM
79.6	114	2	MED	163.3	164	8	SM
80.8	169	12	MED GW	171.8	126	20	SM
82.9	114	27	MED GW	172.4	81	6	SM
90.5	249	10	SM	173.9	46	14	MED
96.4	149	15	MED	173.9	49	18	MED
97.8	236	19	SM	177.4	90	22	SM
98.5	123	16	LG	177.8	252	39	SM
99.5	137	3	LG	178.5	57	13	SM
99.7	107	16	MED	179.0	253	5	SM
100.2	267	32	MED	179.0	139	8	MED
103.3	108	75	SM	179.0	108	2	MED
104.4	78	11	SM	184.1	323	15	SM
104.9	104	73	MED	184.2	296	12	SM
106.5	255	16	MED	184.5	273	12	SM
106.6	308	15	SM	184.7	289	26	SM
107.1	130	8	SM	210.5	323	18	SM
107.2	233	18	MED	211.2	304	19	SM
107.4	193	31	SM	214.8	277	32	MED
109.1	112	78	MED	217.7	293	23	SM
111.9	65	9	SM	219.6	267	25	SM
114.4	245	11	SM	221.1	73	11	SM
114.7	190	19	SM	221.3	27	11	SM
115.2	270	80	SM	225.3	310	9	SM
116.9	111	84	SM	228.0	288	67	SM
117.4	273	85	SM	228.6	304	77	SM
119.3	70	9	MED	229.9	338	14	SM
119.6	242	35	SM	232.5	67	24	SM
119.7	89	78	SM	233.7	34	5	MED
120.6	105	10	SM	233.8	43	10	MED
124.7	353	7	SM	239.5	316	3	SM
128.0	307	9	SM	243.6	274	75	SM
133.8	254	62	SM	264.2	70	12	SM
134.2	345	10	SM	265.2	277	67	SM
134.4	249	36	MED	275.1	290	74	SM
137.3	201	22	MED	287.4	309	5	SM
138.9	248	34	SM	289.5	17	11	SM
141.5	229	21	SM	289.9	3	11	SM
141.9	224	22	MED	290.0	337	9	MED

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
290.2	35	57	MED	380.7	297	8	SM
290.5	53	50	MED	381.2	123	31	SM
291.3	38	46	SM	381.4	341	36	MED
291.9	269	72	SM	381.5	293	66	MED
302.1	10	11	SM	381.8	355	39	SM
316.5	268	71	MED	382.2	325	57	MED
324.0	261	72	MED	382.2	297	50	SM
333.2	283	13	SM	382.4	79	19	MED
333.3	18	3	SM	382.5	56	17	MED
337.7	279	48	MED	382.5	312	63	MED
337.9	47	15	SM	382.8	57	23	SM
342.3	254	5	MED	382.9	54	13	MED
342.3	226	10	MED	383.1	331	22	MED
344.0	281	14	SM	383.3	134	24	SM
347.7	308	5	SM	383.5	309	62	MED
347.7	34	5	SM	383.7	294	32	SM
351.2	125	9	SM	383.8	291	30	SM
351.2	269	29	MED	383.9	317	34	MED
359.4	126	13	SM	384.0	320	40	MED
360.7	70	13	SM	384.0	307	61	MED
363.7	174	19	SM	384.2	308	28	MED
364.4	160	56	MED	384.3	148	15	SM
365.1	304	81	SM	384.3	308	35	MED
367.0	83	34	SM	384.7	193	8	MED
367.2	83	37	SM	384.9	234	10	MED
367.4	92	50	MED	384.9	114	36	MED
368.5	90	31	SM	384.9	147	69	MED
368.8	20	14	SM	385.1	270	26	MED
369.6	290	84	SM	385.2	281	22	LG GW
370.0	329	27	SM	385.7	103	63	MED
370.1	328	19	MED	386.2	28	33	SM
370.2	351	79	MED	386.6	253	43	MED
370.3	341	21	MED	387.8	305	9	SM
370.3	342	19	SM	387.8	126	31	SM
370.5	341	76	MED	389.0	50	47	SM FLT
370.7	328	76	SM	389.4	9	74	SM
378.0	330	74	MED	389.5	2	81	SM
378.0	333	73	MED	394.1	273	55	MED
378.1	327	71	MED	399.0	347	31	SM
378.9	334	9	MED	401.7	125	7	SM
379.8	47	13	SM	402.0	265	29	SM
380.0	124	2	MED	402.2	278	13	SM
380.0	186	4	MED	402.8	96	83	MED
380.7	337	71	MED	403.0	269	53	LG

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
403.5	261	88	MED	55.9	245	60	
404.3	284	65	MED	60.0	282	42	
404.4	302	64	MED	64.6	294	45	
404.5	287	70	MED	67.8	242	59	
405.5	168	15	SM	69.5	298	39	
405.7	58	3	SM	77.9	283	53	
405.9	55	12	SM	100.5	69	76	
406.0	52	20	SM	102.4	93	62	
406.0	164	6	SM	105.1	67	70	
407.6	138	33	SM	109.0	108	78	
408.2	281	64	SM	117.9	106	82	
410.6	350	84	SM	128.5	129	58	
410.9	123	5	SM	133.8	250	62	
411.2	175	9	SM	134.5	252	59	
411.4	54	34	SM	135.3	258	62	
411.6	0	80	SM	137.3	222	59	
412.4	342	85	MED	138.6	201	30	
412.9	31	8	SM	159.1	280	52	
428.5	341	81	SM	160.1	259	65	
430.6	252	57	SM	161.6	257	76	
431.2	245	58	SM	178.8	211	36	
436.2	142	55	SM	181.2	247	40	
437.2	284	35	SM	182.5	217	31	
439.9	261	86	SM	184.2	282	31	
441.2	35	7	SM	184.9	239	23	
441.4	88	38	SM	206.9	274	63	
443.8	355	82	MED	209.2	272	69	
446.8	121	24	SM	214.6	290	32	
449.0	109	15	SM	219.7	278	34	
449.9	123	20	SM	221.0	254	61	
450.9	114	16	MED	221.8	279	30	
466.9	279	65	SM	224.7	288	21	
473.3	300	45	SM	225.6	242	41	
475.9	296	62	SM	227.3	278	27	
483.9	296	54	SM	231.2	275	74	
499.4	305	40	SM	233.5	64	62	
500.6	271	51	MED	255.0	270	63	
501.7	264	67	SM	263.9	287	69	
513.2	301	32	SM	265.8	282	79	
514.0	294	46	SM	275.4	289	64	
624.3	321	16	SM	278.5	298	80	
Foliation				281.7	271	69	
30.7	248	60		290.2	283	82	
36.1	275	64		291.7	276	67	

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01—continued

Depth	Dip azimuth, In degrees	Dip angle, In degrees	Fracture size
296.9	276	72	
316.9	278	58	
320.3	272	69	
324.8	293	55	
337.5	287	60	
354.9	286	67	
365.7	152	42	
367.0	89	29	
370.0	327	25	
384.1	306	51	
386.5	276	35	
388.6	260	47	
390.8	253	57	
394.0	266	55	
397.0	270	59	
404.9	280	55	
406.4	268	64	
408.7	279	67	
416.8	259	64	
421.3	256	65	
430.6	244	55	
461.2	274	55	
462.8	282	56	
466.1	282	53	
469.6	319	31	
471.9	303	48	
475.0	277	63	
477.3	315	50	
483.0	268	57	
485.2	292	61	
487.5	281	64	
492.2	309	37	
509.3	319	41	
511.4	307	27	
512.6	304	34	
520.2	278	26	
523.1	308	47	
526.2	279	44	
532.5	281	59	
534.1	279	46	
538.9	291	43	
544.4	241	29	
548.3	279	30	
551.0	263	18	

Depth	Dip azimuth, In degrees	Dip angle, In degrees	Fracture size
554.9	306	29	
556.9	268	42	
558.1	279	53	
561.6	276	48	
571.9	294	63	
575.3	286	56	
582.1	295	56	
589.9	284	68	
590.9	265	64	
599.0	295	71	
600.3	282	68	
605.3	278	66	
608.4	276	74	
609.9	287	64	
612.4	288	83	
625.0	272	80	
633.1	277	73	
639.1	301	83	
641.3	279	72	
W55ST-A			
Fractures			
161.8	61	14	SM
162.4	303	63	MED
166.4	20	36	MED
169.9	130	21	MED
173.1	129	22	SM
173.5	38	34	MED
179.8	287	61	SM
180.5	300	64	SM
183.1	137	7	SM
198.4	61	39	SM
199.2	122	28	SM
200.7	295	72	SM
201.3	303	25	MED
201.5	294	74	MED
201.5	301	11	SM
204.7	308	60	SM
205.3	285	58	SM
211.0	292	68	SM
212.9	292	61	SM
222.0	302	52	SM
224.5	292	64	SM
225.0	294	58	SM
225.2	296	66	SM

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
225.4	290	65	SM	379.2	258	67	MED
225.7	301	58	SM	379.4	172	71	LG
226.6	54	15	MED	383.9	300	70	LG
230.2	305	60	SM	386.0	289	62	MED
230.9	178	76	MED	390.3	292	48	SM
234.4	286	66	SM	392.4	302	68	SM
240.0	267	7	SM	395.4	285	60	MED
251.2	58	23	SM	431.2	288	54	SM
251.2	71	23	MED	431.7	297	18	SM
251.8	287	44	SM	431.8	297	67	SM
259.4	286	65	SM	432.1	285	32	SM
265.1	54	39	SM	432.3	299	43	SM
265.8	52	48	MED	432.4	255	64	SM
266.3	284	64	MED	434.6	292	59	SM
268.1	264	56	SM	436.1	255	2	SM
279.3	274	56	SM	455.5	301	57	SM
279.8	259	52	SM	460.5	214	72	SM
283.9	95	43	SM	468.4	296	50	SM
285.9	43	73	SM	468.6	296	49	SM
290.8	73	6	SM	470.3	293	50	SM
296.4	36	5	SM	471.2	285	53	SM
296.4	190	3	SM	483.5	166	6	SM
314.7	125	50	SM	484.8	256	10	SM
329.3	263	14	SM	485.1	249	50	SM
329.5	117	17	SM	485.4	124	32	MED
330.1	137	17	MED	485.5	241	44	SM
333.5	70	13	SM	489.1	261	51	SM
335.2	270	43	SM	490.5	266	32	SM
335.2	77	27	SM	490.7	265	45	MED
335.5	288	47	SM	490.7	262	45	MED
335.6	270	65	SM	492.0	221	70	MED
335.6	113	4	MED	492.9	269	61	MED
335.7	77	22	LG	493.8	298	59	SM
335.9	299	35	MED	502.7	231	74	SM
336.0	78	10	MED	511.2	262	66	SM
336.4	282	57	LG	523.7	143	6	SM
336.9	281	59	SM	530.8	294	55	SM
337.1	281	58	SM	542.1	311	67	MED
340.3	270	65	SM	542.9	297	61	MED
361.5	35	29	SM	544.1	291	65	SM
367.6	295	33	SM	544.9	300	58	SM
376.4	296	68	SM	552.8	311	60	SM
377.6	164	75	MED	553.2	299	47	SM
379.0	181	76	SM	577.0	67	61	SM

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, In degrees	Dip angle, In degrees	Fracture size	Depth	Dip azimuth, In degrees	Dip angle, In degrees	Fracture size
577.8	91	67	SM	244.8	272	67	
578.5	318	58	SM	248.5	311	54	
579.1	80	39	SM	251.1	281	60	
582.7	319	68	SM	257.3	278	60	
585.7	304	48	MED	260.4	280	66	
586.4	279	61	MED	265.0	286	76	
591.8	301	25	SM	268.2	265	65	
598.2	293	66	MED	271.6	274	65	
600.3	303	52	SM	275.3	281	57	
601.0	69	55	MED	280.1	266	53	
605.1	270	66	LG	280.8	280	50	
606.4	267	50	SM	284.3	291	61	
607.8	301	54	SM	287.4	288	65	
608.3	309	49	SM	291.3	302	61	
611.7	197	53	SM	295.2	294	67	
616.4	130	80	MED	297.9	286	63	
Foliation				301.5	284	68	
166.5	311	50		304.9	290	47	
176.8	281	65		308.1	289	53	
177.6	276	67		310.5	292	66	
180.6	297	72		312.7	291	73	
183.6	296	65		315.5	287	68	
184.6	303	56		317.1	285	63	
186.8	300	66		318.0	265	56	
188.3	295	61		319.7	290	70	
190.0	306	66		321.9	287	52	
194.0	296	66		327.1	274	54	
196.1	283	50		328.7	283	56	
197.3	289	72		330.5	283	52	
199.1	291	71		332.7	267	61	
201.5	288	73		334.9	288	49	
203.4	306	69		337.5	273	58	
205.3	291	65		340.5	281	69	
209.6	283	72		342.9	270	61	
212.9	283	59		347.6	285	63	
216.7	281	64		350.2	283	55	
219.4	284	60		353.3	287	51	
223.8	292	65		354.1	283	47	
225.4	291	65		355.8	285	38	
228.7	278	57		358.4	275	44	
233.4	283	66		359.9	278	59	
236.2	282	62		361.6	289	64	
239.8	273	73		365.0	283	55	
241.2	277	62		366.7	278	40	

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, In degrees	Dip angle, In degrees	Fracture size
368.4	281	36	
370.1	273	55	
371.9	283	67	
377.6	282	67	
381.0	269	62	
383.5	289	56	
386.8	276	53	
388.2	269	56	
389.7	288	57	
393.1	292	50	
393.8	280	56	
395.1	280	56	
396.8	283	65	
400.3	279	55	
401.8	282	61	
405.2	273	62	
407.7	285	36	
412.8	285	32	
414.7	301	49	
418.6	290	67	
420.5	288	62	
422.7	292	52	
424.5	287	58	
426.0	295	59	
429.0	288	62	
433.6	287	59	
436.6	285	62	
444.6	277	59	
448.1	286	45	
452.1	284	57	
455.0	285	60	
457.4	282	68	
461.5	281	68	
464.4	286	65	
465.9	283	60	
466.8	281	54	
467.4	281	51	
471.0	285	56	
476.5	298	68	
477.3	275	54	
483.5	274	79	
485.1	235	46	
488.6	268	67	
490.7	260	53	

Depth	Dip azimuth, In degrees	Dip angle, In degrees	Fracture size
492.9	270	60	
493.8	288	58	
494.5	281	51	
520.9	319	66	
522.9	312	68	
530.8	290	55	
532.3	299	62	
533.9	296	60	
537.4	302	56	
538.6	303	57	
541.3	303	56	
543.1	302	55	
544.8	293	62	
547.7	293	60	
550.7	295	65	
552.7	289	61	
556.1	284	64	
558.1	293	70	
561.2	286	67	
565.5	284	71	
568.7	274	62	
581.5	326	63	
582.7	320	69	
585.7	301	59	
586.7	298	74	
589.8	289	68	
594.8	285	70	
596.3	287	60	
597.6	299	62	
599.2	289	59	
602.6	288	58	
605.7	274	67	
607.9	279	58	
609.3	299	58	
611.1	300	52	
614.5	289	62	
W26ST-A			
Fractures			
45.11	249	33	SM
45.93	86	21	MED
48.36	258	33	SM
52.14	267	19	MED
53.36	247	64	SM
54.15	248	51	SM

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
54.69	258	58	SM	167.43	45	16	SM
56.86	251	70	LG	171.04	270	37	MED
57.86	254	63	MED	171.89	198	36	MED
59.93	297	8	SM	182.59	51	52	SM FLT
60.44	286	66	SM	183.12	204	8	SM
61.95	251	42	MED	198.59	222	29	MED
63.21	244	61	SM	215.68	174	62	SM
63.45	231	37	SM	220.62	167	89	MED
64.15	126	6	SM	222.83	282	48	MED
64.2	138	8	MED	225.77	282	47	SM
90.04	260	48	SM	227.26	70	23	MED
90.74	99	57	SM	227.38	281	49	SM
91.09	98	34	SM	227.64	116	7	SM
91.48	269	54	MED	228.92	284	49	SM
93.55	318	66	SM	230.02	283	47	SM
93.85	327	69	MED	230.36	106	26	MED
94.33	265	48	MED	230.66	278	42	MED
96.59	335	23	SM	242.69	155	84	MED
101.86	59	3	SM	254.8	285	63	SM
103.84	88	26	MED	257.37	284	64	SM
105.53	284	33	SM	258.19	57	22	SM
108.4	266	59	SM	258.33	77	16	MED
117.89	270	63	SM	259.15	282	65	MED
118.39	267	61	SM	259.54	271	79	MED
118.8	266	57	MED	261.19	288	64	MED
124.46	272	53	SM	262.39	246	23	MED
127.6	265	51	SM	263.4	288	46	SM
129.53	274	52	SM	263.3	292	50	MED
130.53	249	10	MED	264.05	241	14	SM
131.91	303	10	SM	266.28	282	66	MED GW
132.05	288	35	MED	268.85	310	23	MED
136.78	270	6	MED	268.96	261	33	MED
137.32	87	21	SM	269.32	1	21	MED
137.2	122	28	MED	269.4	326	24	MED
138.58	162	80	MED	269.52	355	3	MED
152.64	350	38	MED	269.52	152	24	MED
152.93	129	40	MED	269.62	133	16	MED
153.14	285	54	MED	269.78	170	46	LG
154.94	305	36	SM	270.26	195	10	VLG
155.11	290	31	SM	270.34	162	35	VLG
157.17	324	40	MED	270.98	111	27	VLG
162.37	263	25	SM	271.26	86	23	VLG
167.27	6	13	MED	271.54	3	37	VLG
167.37	270	23	MED	271.81	279	24	VLG

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
271.88	318	4	MED	295.98	281	50	SM
272.01	284	6	MED	296.14	255	55	SM
272.55	157	19	LG	297.28	192	67	SM
273.08	354	86	MED	297.22	269	43	SM
272.81	75	4	MED	299.3	287	31	SM
274.02	175	15	MED	298.93	291	26	SM
274.09	287	25	MED	303.26	59	55	SM
274.39	301	36	MED	305.05	99	89	SM
274.59	283	49	MED	309.02	268	76	SM
274.62	104	25	MED	311.46	306	24	SM
274.95	47	15	LG	311.5	291	25	SM
275.1	309	40	LG	311.62	310	21	MED GW
275.14	312	41	LG	311.94	295	12	SM
275.22	142	40	MED	312.0	259	14	MED
275.44	116	42	MED	313.0	9	61	SM
275.59	173	31	MED	313.19	291	23	SM
275.96	277	37	LG	313.22	283	22	MED GW
276.08	224	16	LG	314.04	326	19	SM
276.16	177	33	MED	317.3	295	20	SM
276.49	237	71	MED	317.33	285	19	MED
276.49	314	71	LG	323.41	251	37	SM
276.89	67	24	LG	335.31	121	46	SM
276.94	82	22	LG	335.47	57	53	MED
277.05	109	68	MED	336.31	132	68	SM
277.55	24	19	LG	349.18	255	29	MED
277.84	81	4	MED	349.21	266	37	MED
277.88	73	4	MED	349.28	267	35	SM
277.92	308	12	MED	360.61	164	74	SM
278.35	54	16	SM	396.22	329	37	SM
278.47	311	33	SM	397.65	109	78	SM FLT
278.54	15	6	MED	404.06	287	46	MED
278.74	263	7	SM	412.35	43	66	SM FLT
278.76	228	11	MED	414.4	113	18	MED
279.19	200	14	MED	422.58	74	22	SM
279.65	282	46	MED	428.03	201	14	MED
280.13	307	53	SM	429.56	274	61	SM
279.98	301	45	LG	430.21	274	65	MED
280.51	232	8	MED	430.5	289	18	MED
281.45	243	22	SM	430.79	267	17	MED
281.69	256	26	MED	434.52	278	68	MED
282.97	326	72	SM	440.15	114	14	SM
283.52	303	51	SM	443.05	267	27	SM
288.36	272	42	MED	443.16	269	24	SM
291.05	276	57	LG	443.32	263	37	MED

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
447.86	211	13	SM	125.99	270	53	
448.03	223	25	SM	127.01	275	50	
447.57	185	8	SM	128.5	261	55	
495.32	282	32	SM	129.53	274	53	
497.79	296	12	SM	131.44	276	57	
498.01	291	17	SM	132.92	276	51	
498.84	276	26	SM	134.89	281	49	
504.13	283	29	SM	136.32	277	52	
521.61	92	29	SM	140.51	100	49	
523.86	90	34	SM	148.79	292	51	
523.97	74	46	SM	150.84	279	51	
532.8	59	14	SM	154.27	288	54	
532.87	306	55	SM	155.1	281	34	
544.33	43	47	SM	157.58	290	58	
553.9	282	3	SM	158.51	295	47	
567.59	271	55	SM	161.87	272	46	
577.96	353	2	SM	166.32	310	72	
Foliation				173.93	276	67	
42.1	236	64		177.37	279	62	
46.01	246	59		184.87	275	53	
47.11	243	63		188.46	310	67	
50.68	254	67		191.49	309	74	
55.08	253	68		192.45	308	57	
57.21	249	53		194.38	310	53	
59.1	268	70		197.42	294	60	
65.28	273	74		202.08	284	55	
68.23	268	77		206.68	308	46	
72.65	252	79		208.32	306	60	
75.62	266	72		221.24	273	48	
77.19	258	71		222.59	285	52	
80.54	248	70		224.04	279	45	
82.66	259	75		225.48	275	53	
87.98	247	57		228.02	288	58	
90.04	257	49		230.03	289	48	
93.04	269	46		234.13	302	59	
95.11	278	47		246.72	281	60	
107.76	281	52		250.27	296	66	
110.89	271	56		253.9	283	65	
114.99	264	60		256.46	291	60	
117.89	270	61		262.82	305	50	
119.23	271	54		266.63	292	57	
120.44	266	44		268.5	291	41	
122.09	274	48		289.43	277	53	
124.58	272	56		292.39	274	51	

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
295.69	283	52		516.61	268	71	
297.21	275	43		518.73	279	59	
299.15	283	44		534.76	285	60	
300.35	279	48		537.33	99	69	
302.4	191	20		540.85	294	75	
303.0	227	32		544.34	284	67	
309.17	288	66		546.16	259	80	
314.62	281	83		548.06	286	80	
320.95	119	74		552.11	281	83	
323.45	121	67		556.62	291	82	
330.97	309	47		557.9	276	76	
334.89	345	31		562.35	298	87	
347.5	287	66		564.0	287	73	
360.26	298	58		565.18	286	72	
400.25	307	54		566.01	284	67	
403.41	295	37		567.41	284	68	
407.16	294	55		568.92	287	62	
410.15	288	65		569.55	290	69	
412.73	299	55		570.75	271	65	
418.21	285	61		572.5	275	61	
420.55	304	62		573.77	287	67	
425.55	264	59		575.15	284	78	
429.55	274	59		578.0	298	74	
435.34	274	61		579.76	279	76	
436.53	292	70		582.23	281	75	
451.91	290	82		583.8	286	56	
454.8	295	75		585.28	288	56	
457.35	291	71		GroveST-A			
459.26	271	70		Fractures			
461.87	294	79		83.41	170	19	VLG
466.97	303	67		83.53	204	20	VLG
469.3	294	86		84.56	291	39	MED
472.18	288	73		86.01	259	38	MED
474.18	273	67		95.11	357	18	SM
478.8	274	58		95.11	298	17	SM
480.55	285	83		96.97	85	17	SM
485.07	290	84		96.93	87	15	SM
488.84	310	88		109.35	93	19	SM
497.46	307	84		110.57	77	9	SM
505.61	285	69		111.27	281	14	MED
508.1	305	49		113.53	26	21	MED
508.92	297	61		113.56	88	9	SM
511.21	303	59		113.61	135	9	MED
512.03	306	57		114.85	124	24	MED

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
115.33	303	14	SM	168.86	304	13	SM
115.86	280	5	MED	169.46	271	62	SM
116.0	209	7	SM	171.89	247	19	SM
117.68	49	2	MED	174.16	271	43	MED
118.39	298	29	SM	175.47	336	16	SM
118.49	274	26	SM	179.8	127	17	SM
119.36	70	24	SM	181.06	291	31	SM
119.55	152	25	SM	183.14	10	59	SM
119.75	136	6	SM	184.13	154	2	SM
120.05	244	19	SM	185.02	304	13	SM
120.17	299	28	MED	185.29	51	48	SM
120.34	80	37	MED	185.39	355	31	SM
120.59	281	58	MED	185.52	346	19	SM
120.95	343	14	SM	186.31	305	11	SM
120.88	307	29	SM	186.5	32	7	SM
120.55	279	86	MED	186.71	2	26	SM
121.95	283	59	MED	187.39	296	48	LG
123.06	102	26	SM	190.03	264	27	SM
129.64	44	7	SM	196.48	154	4	SM
129.68	65	11	SM	200.76	304	18	SM
134.66	294	33	SM	202.21	126	9	SM
142.45	89	26	SM	209.19	290	42	MED
143.45	126	24	SM	212.67	302	65	SM
145.28	253	24	SM	213.57	121	22	SM
149.17	264	22	SM	213.88	76	39	SM
150.79	285	73	MED	225.62	69	13	SM
152.74	277	37	MED	225.65	25	10	SM
153.88	278	11	MED	244.18	244	15	SM
153.94	122	14	MED	252.82	52	18	SM
154.79	130	14	SM	257.06	122	73	MED
156.08	269	16	MED	262.42	338	33	SM
156.49	298	14	LG	265.29	356	26	SM
156.66	54	12	MED	269.04	314	49	SM
156.71	133	3	SM	269.07	296	9	MED
157.09	276	58	SM	270.74	18	32	SM
156.92	281	52	SM	270.88	113	28	SM
157.51	286	72	MED	286.52	300	44	SM
158.1	312	39	SM	286.91	285	45	SM
162.04	310	30	SM	294.69	288	57	SM
163.64	299	39	MED	295.7	311	38	SM
164.22	119	11	LG	296.14	287	58	SM
164.38	151	29	MED	299.24	297	55	MED
168.4	102	16	MED	304.13	302	34	LG
168.6	94	16	MED	305.57	290	49	SM

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
306.09	281	67	MED	374.47	356	4	SM
307.47	293	62	MED	374.49	295	8	SM
309.71	18	20	MED	378.87	292	74	SM
310.7	290	51	SM	379.91	291	73	SM
311.58	128	47	SM	382.23	294	70	SM
311.6	299	35	SM	382.65	291	79	SM
312.02	292	67	SM	383.5	282	75	SM
312.29	285	58	SM	387.28	151	14	SM
312.51	287	45	SM	389.2	289	84	SM
312.89	295	62	SM	389.44	291	84	MED
313.37	295	48	SM	390.6	155	2	SM
313.64	298	29	SM	390.96	139	29	SM
314.04	301	53	SM	392.52	159	2	SM
319.02	297	39	MED	393.42	292	58	MED
324.25	195	52	SM	394.32	23	6	SM
330.52	302	40	MED	397.34	180	36	SM
334.71	99	81	MED	401.04	280	24	MED
338.88	286	84	LG	421.28	39	3	MED
339.53	288	73	MED	426.7	316	29	SM
340.01	274	78	LG	430.88	311	42	SM
340.45	290	59	MED	436.61	96	79	MED
342.94	93	6	MED	439.88	32	8	SM
348.09	336	30	SM	440.83	285	67	MED
348.71	312	47	MED	440.95	284	68	MED
358.42	302	47	MED	441.24	275	75	SM
359.04	281	41	MED	449.35	278	83	MED
360.26	300	14	SM	456.21	292	49	MED
360.37	92	44	MED	458.31	292	74	SM
360.4	184	24	SM	462.17	281	75	LG
360.54	309	37	SM	462.3	282	80	LG
360.82	222	23	SM	464.96	307	56	MED
360.81	61	53	SM	469.2	321	24	SM
360.96	146	47	MED	470.69	271	74	VLG
361.81	295	38	MED	471.66	126	11	SM
361.96	144	43	SM	475.33	102	87	MED
362.06	305	33	SM	477.37	301	71	MED
362.77	177	48	SM	478.72	286	60	SM
363.51	287	40	MED	482.08	304	24	MED
363.94	175	63	SM	484.88	110	85	MED
365.45	288	74	MED	493.75	191	5	MED
368.46	298	71	SM	494.48	288	47	MED
369.43	290	72	MED	495.81	345	5	SM
373.07	132	29	MED	495.93	359	13	SM
373.14	294	71	MED	496.14	357	6	SM

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
496.26	116	7	SM	616.41	326	21	SM
496.48	195	12	SM	616.8	332	32	SM
497.42	353	3	SM	618.13	46	16	SM
497.44	191	18	MED	618.35	355	11	SM
497.93	122	21	MED	619.74	304	54	MED
520.7	268	8	MED	621.03	297	50	SM
525.9	333	25	SM	621.39	93	41	SM
526.07	341	23	SM	623.26	295	54	SM
530.78	313	46	LG	623.75	84	31	MED
531.04	289	58	MED	626.83	348	30	MED
532.25	320	70	MED	628.88	301	32	MED
532.84	324	68	MED	Foliation			
536.94	56	53	VLG	163.02	278	40	
535.68	188	74	VLG	164.43	283	73	
534.52	271	87	VLG	167.42	265	79	
540.36	301	80	LG	171.52	105	37	
539.79	264	15	MED	173.55	119	71	
541.45	324	5	LG	179.81	100	73	
541.11	322	71	VLG	181.35	95	66	
548.16	355	12	SM	186.07	89	77	
548.09	319	22	MED	195.68	278	86	
548.09	319	22	MED	199.91	287	82	
549.51	295	83	SM	219.83	290	85	
555.22	293	35	SM	223.51	288	43	
556.94	293	38	SM	224.22	294	48	
557.08	302	28	SM	236.81	303	34	
557.17	330	18	SM	237.55	284	24	
557.25	298	14	MED	242.73	44	16	
558.0	159	24	SM	244.47	272	18	
558.11	199	17	SM	246.24	50	22	
564.12	105	88	SM FLT	249.27	111	59	
565.29	285	66	SM	250.6	289	22	
573.7	244	36	MED	257.6	108	78	
598.96	302	41	MED	259.32	93	78	
605.98	303	39	MED	264.1	284	76	
608.11	291	63	MED	266.37	299	75	
607.65	302	61	MED	271.64	285	74	
608.48	299	51	MED	274.8	306	56	
606.69	141	82	SM	276.22	273	79	
610.86	309	49	SM	277.1	289	13	
614.67	301	65	SM	280.13	288	63	
614.65	149	77	SM	284.18	288	29	
615.53	75	27	SM	286.8	309	49	
615.35	294	76	MED	290.44	309	44	

Appendix. Depth, dip azimuth, and dip angle of fractures and foliation observed by optical televiewer in five boreholes (W34ST-B, W37ST-A, W55ST-A, W26ST-A, and GroveST-A), Manhattan Island, N.Y., 2000-01--continued

Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size	Depth	Dip azimuth, in degrees	Dip angle, in degrees	Fracture size
291.93	298	37		438.4	295	85	
293.97	305	43		441.27	272	74	
295.7	304	36		447.82	276	79	
296.34	303	40		450.47	286	81	
302.21	281	86		458.33	293	76	
307.09	302	47		461.28	284	84	
311.5	289	38		463.12	293	81	
313.38	299	46		465.83	304	46	
313.86	302	28		467.7	296	82	
315.23	288	51		477.41	305	68	
315.91	80	38		485.52	275	87	
318.83	288	63		494.55	131	40	
319.73	303	41		497.52	282	86	
322.9	305	16		508.9	338	61	
325.99	90	37		522.34	286	88	
328.86	285	44		543.18	274	76	
332.97	293	55		550.06	280	86	
335.67	103	61		552.6	274	80	
339.85	281	71		557.46	285	80	
343.15	296	44		559.48	286	81	
343.94	301	57		566.2	279	77	
345.69	292	66		574.54	91	88	
350.61	296	45		599.85	294	41	
354.76	312	42		608.78	297	59	
358.81	298	64		609.97	298	46	
361.38	302	38		611.51	296	55	
362.9	301	32		615.95	286	77	
364.79	293	36		622.48	291	64	
369.14	289	79		623.62	295	39	
371.95	286	84		630.68	101	65	
376.43	289	82		632.76	104	62	
379.2	271	76		633.35	111	48	
381.17	283	78		599.85	294	41	
383.49	283	80		608.78	297	59	
385.09	288	79		609.97	298	46	
388.06	287	83		611.51	296	55	
393.62	291	82		615.95	286	77	
395.82	296	82		622.48	291	64	
399.61	276	84		623.62	295	39	
411.17	299	87		630.68	101	65	
420.97	283	85		632.76	104	62	
423.92	305	86		633.35	111	48	
430.89	301	39					