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Transient Electromagnetic Soundings Near Great Sand Dunes National Park and Preserve, San Luis Valley, Colorado (2006 Field Season)

Open-File Report 2009–1051

U.S. Department of the Interior
U.S. Geological Survey

Cover: Near Sand Creek looking northeast toward Great Sand Dunes National Park. The dunes form a tan ribbon sandwiched between the vegetated plain in the forground and the taller Sangre de Cristo Mountains in the background. Photo by David V. Fitterman.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)

SI to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)

Vertical coordinate information is referenced the National Geodetic Vertical Datum of 1929 (NGVD 29).
Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).
Altitude, as used in this report, refers to distance above the vertical datum.

Electrical Conductivity and Electrical Resistivity

Multiply	By	To obtain
Electrical conductivity		
siemens per meter [S/m]	1,000	millisiemens per meter [mS/m]
siemens per meter [S/m]	10,000	microsiemens per centimeter [µS/cm]
Electrical resistivity		
ohm-meters [ohm-m]	0.001	kiloohm-meters [kohm-m]

Electrical conductivity σ in siemens per meter [S/m] can be converted to electrical resistivity ρ in ohm-meters [ohm-m] as follows: $\rho = 1/\sigma$.
Electrical conductivity σ in millisiemens per meter [mS/m] can be converted to electrical resistivity ρ in ohm-meters [ohm-m] as follows: $\rho = 1{,}000/\sigma$.
Electrical conductivity σ in microsiemens per centimeter [µS/m] can be converted to electrical resistivity ρ in ohm-meters [ohm-m] as follows: $\rho = 10{,}000/\sigma$.

Electrical resistivity ρ in ohm-meters [ohm-m] can be converted to electrical conductivity σ in siemens per meter [S/m] as follows: $\sigma = 1/\rho$.
Electrical resistivity ρ in ohm-meters [ohm-m] can be converted to electrical conductivity σ in millisiemens per meter [mS/m] as follows: $\sigma = 1{,}000/\rho$.
Electrical resistivity ρ in ohm-meters [ohm-m] can be converted to electrical conductivity σ in microsiemens per centimeter [µS/m] as follows: $\sigma = 10{,}000/\rho$.

Transient Electromagnetic Soundings Near Great Sand Dunes National Park and Preserve, San Luis Valley, Colorado (2006 Field Season)

By David V. Fitterman[1] and Oderson A. de Souza Filho[2]

Abstract

Time-domain electromagnetic (TEM) soundings were made near Great Sand Dunes National Park and Preserve in the San Luis Valley of southern Colorado to obtain subsurface information of use to hydrologic modeling. Seventeen soundings were made to the east and north of the sand dunes. Using a small loop TEM system, maximum exploration depths of about 75 to 150 m were obtained. In general, layered earth interpretations of the data found that resistivity decreases with depth. Comparison of soundings with geologic logs from nearby wells found that zones logged as having increased clay content usually corresponded with a significant resistivity decrease in the TEM determined model. This result supports the use of TEM soundings to map the location of the top of the clay unit deposited at the bottom of the ancient Lake Alamosa that filled the San Luis Valley from Pliocene to middle Pleistocene time.

Introduction

The supply of groundwater in the San Luis Valley of southcentral Colorado has been an on-going concern of area residents since the first wells were drilled in 1887 (Powell, 1958). Heavy reliance of agriculture on groundwater-supplied irrigation and drought conditions in recent years have intensified this concern. In addition to farming, groundwater is used to meet the requirements of the State of Colorado under the Rio Grande River Compact to furnish adequate surface-water flows to New Mexico, Texas, and Mexico. Great Sand Dunes National Park and Preserve (GSDNPP) also has an interest in the groundwater resources of the area and how they impact the national park and the National Park Service's (NPS) responsibility to preserve and protect it.

The U.S. Geological Survey (USGS) has been involved in geological, geophysical, and hydrological studies to obtain information needed to develop, verify, and refine groundwater flow models used to manage the water resources in the San Luis Valley (see Fig. 1).

Transient (or time-domain) electromagnetic (TEM) soundings were made in the San Luis Valley near GSDNPP to assess their utility in mapping the "blue clay," which separates the unconfined, near-surface aquifer from the deeper confined aquifer (Emery and others, 1973; Brendle, 2002). A second reason for making the TEM soundings was to assist in calibrating a helicopter electromagnetic (HEM) survey flown over four widely spaced lines in the area in December 2005. Data-quality problems with the HEM survey were sufficiently severe that they could not be resolved with the TEM data and will not be discussed in this report.

Description of Transient Electromagnetic Soundings

TEM soundings, which are well suited for mapping conductive targets such as saltwater intrusion and clay zones, have been used for a number of groundwater studies (Fitterman and Stewart, 1986; Fitterman,1989; Goldman

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and others, 1991; Fitterman and others, 1999). The TEM method is described in detail by Kaufman and Keller (1983), McNeill (1990), and Fitterman and Labson (2005).

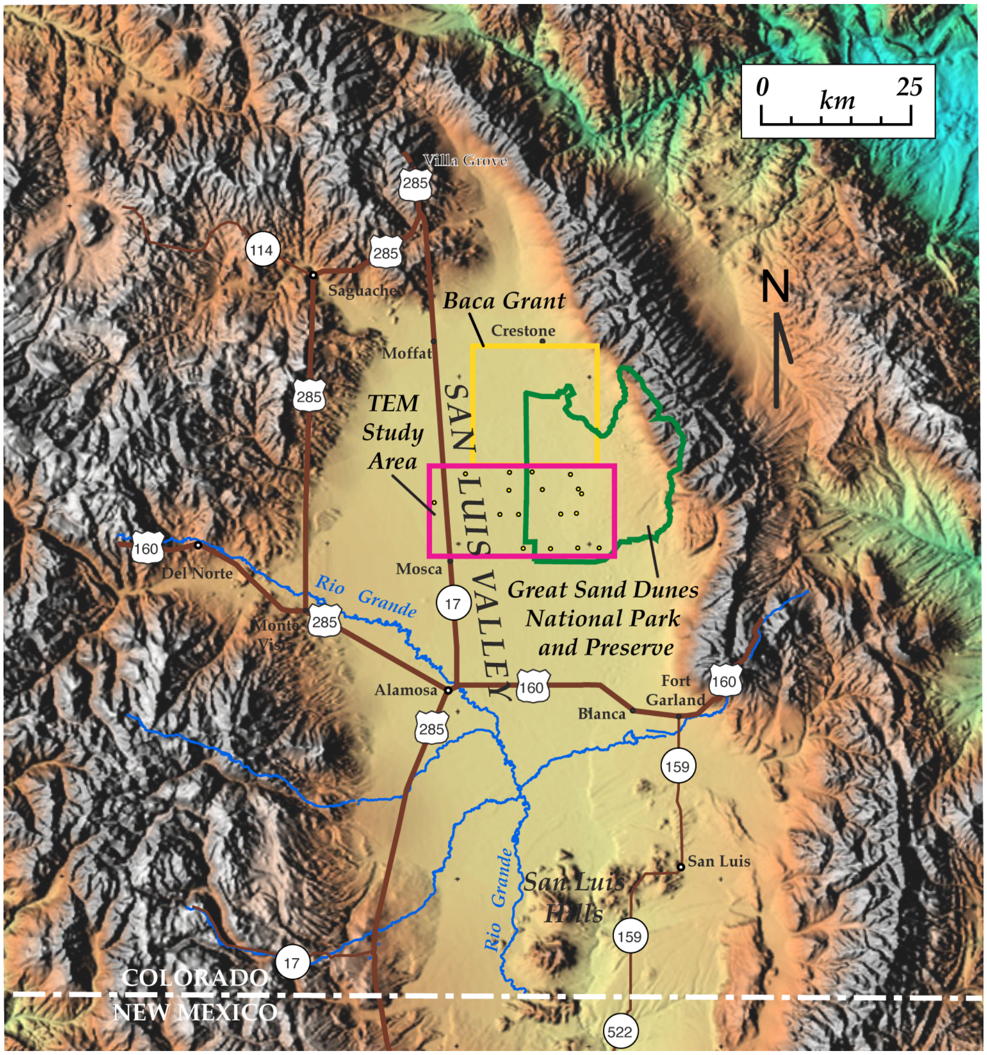

Figure 1. Location of San Luis Valley, Great Sand Dunes National Park and Preserve, and study area.

Soundings are made by passing a current through a large, square transmitter loop. The current flow generates a steady magnetic field. Abruptly cutting off the current flow disrupts the magnetic field and induces a circulating current system in the ground below the loop. The diffusion of these induced currents is controlled by the electrical conductivity of the ground. The current attenuation is small in conductive regions, and the current passes slowly through such regions. Resistive regions (low conductivity), on the other hand, attenuate the current flow. Current traverses these regions more rapidly than conductive regions. The circulating induced currents produce a secondary magnetic field that is sensed by a receiver coil located at the middle of the transmitter loop. Because of the relationship between the electrical conductivity structure of the ground, the current diffusion, and the secondary magnetic field, the voltage recorded by the receiver can be used to estimate the ground conductivity. The result is that the measured voltage-time curves, or transients, can be converted into resistivity-depth functions by a nonlinear parameter estimation process call inversion (Oldenburg and Li, 2005; Fitterman and Labson, 2005).

A Geonics PROTEM transient EM system with an analog receiver and an EM–47 battery powered transmitter were used. The transmitter loop was set up as a square with a nominal side length of 38.1 m. Transmitter current was typically 2.5 A. The receiver coil was a rigid loop about 1 meter in diameter with a moment of 31.4 m^2. After adjusting receiver gain to an appropriate level, between five and 21 measurements were made using base-frequency repetition rates of 285 Hz and 30 Hz. The base frequency controls the time range over which the transient is recorded. There are

20 logarithmically spaced gates in the measurement associated with each base frequency. Each measurement represents a stack of several hundred individual transients. Data processing procedures are discussed in Appendix A.

Sounding Locations and Elevation

A total of 17 TEM soundings were made along four east-west lines situated west of GSDNPP (see fig. 2). Coordinates of the soundings were determined by GPS measurements and are given in table 1. Horizontal positions are referenced to NAD 27. The GPS unit reported positioning error uncertainty of between 4 to 9 m. Elevations were obtained by using the GPS coordinates to locate the soundings on 7.5-minute topographic maps and then interpolating between the elevation contours. The vertical reference is NGVD 29.

Data Quality and Averaging Procedure

All but four of the TEM soundings were of very good quality. (Data quality is summarized in Table 1. Data plots can be found in Appendix E.) Sounding GSD10 was made next to a buried pipeline, resulting in a very linear apparent resistivity-time plot (see fig. E–10). Sounding GSD15 (fig. E–15) has very discontinuous behavior in the time range of approximately 0.1 to 1 ms. This is likely due to coupling to nearby metallic objects, such as a fence or a buried conductor, or (less likely) from electrical noise. Sounds GSD16 and GSD17 show a pronounced discontinuous behavior, and the measurement noise is very large. This behavior is attributed to nearby electric fences used to contain a bison herd.

Anywhere from five to 21 TEM measurements were averaged for each sounding for each base frequency using program NTEMAVG to reduce and estimate measurement error. Some selective editing of the data was performed manually when it was obvious that a particular datum was significantly different from neighboring points. The average and standard deviation were calculated with the remaining measurements. The standard deviation of the apparent resistivity for the ultra high (UH) base frequency (285 Hz) was as low as 0.1 percent at early times. For most of the soundings the noise only increased to 1 to 3 percent at channel 20. The high (HI) base frequency data had noise levels of 0.5 percent at channel 1 often increasing to very high levels (>25 percent) at the last channels. The percent standard deviation usually increases with time after transmitter turnoff because the signal due to the ground becomes small with respect to the background noise level. By the time the noise level reaches 10 percent in apparent resistivity the data are usually behaving discontinuously from one channel to the next and are not useable.

Inversion of Transient Electromagnetic Measurements

The TEM soundings were individually inverted using the simplest model that fit the data. The major features of most soundings could be adequately described with a three-layer model whose resistivities decrease with depth. After determining a preliminary model for each sounding and comparing the results with nearby soundings, additional layers were sometimes added to the models to improve the fit between the observed and computed apparent resistivities. Layers that were unresolvable because they were too thin, or their resistivity was not significantly different from adjacent layers, were eliminated from the final model. Most final models have between three and five layers. A detailed description of each sounding is given in Appendix C.

Table 1. Coordinates of TEM soundings and data quality

Sounding	Easting[1] [m]	Northing[1] [m]	Altitude[2] [m]	Data Quality/Comments
GSD01	447883	4170723	2,342.6	very good
GSD02	444296	4170718	2,330.8	very good
GSD03	444939	4179770	2,336.6	very good
GSD04	443075	4182999	2,332.5	very good
GSD05	441451	4176374	2,327.0	very good
GSD06	436634	4183430	2,323.9	very good
GSD07	432845	4183327	2,319.3	very good
GSD08	432749	4180343	2,317.6	very good
GSD09	438358	4180486	2,327.2	very good
GSD10	439729	4170606	2,316.2	not useable, near buried pipe
GSD11	435143	4170653	2,313.0	very good
GSD12	434357	4176316	2,312.8	very good
GSD13	420246	4178283	2,308.7	very good
GSD14	431245	4176318	2,301.0	very good
GSD15	425482	4183105	2,307.8	good, near buried conductor
GSD16	444081	4176510	2,338.5	not good, near electric fence
GSD17	444403	4180567	2,350.5	not good, near electric fence

[1]Coordinates are in UTM Zone 13 S are referenced to NAD27.

[2]Altitude is relative to NGVD 29. Altitudes were determine by locating sounding on 1:24,000 topographic sheets, interpolating between contours, and converting the altitude to SI units.

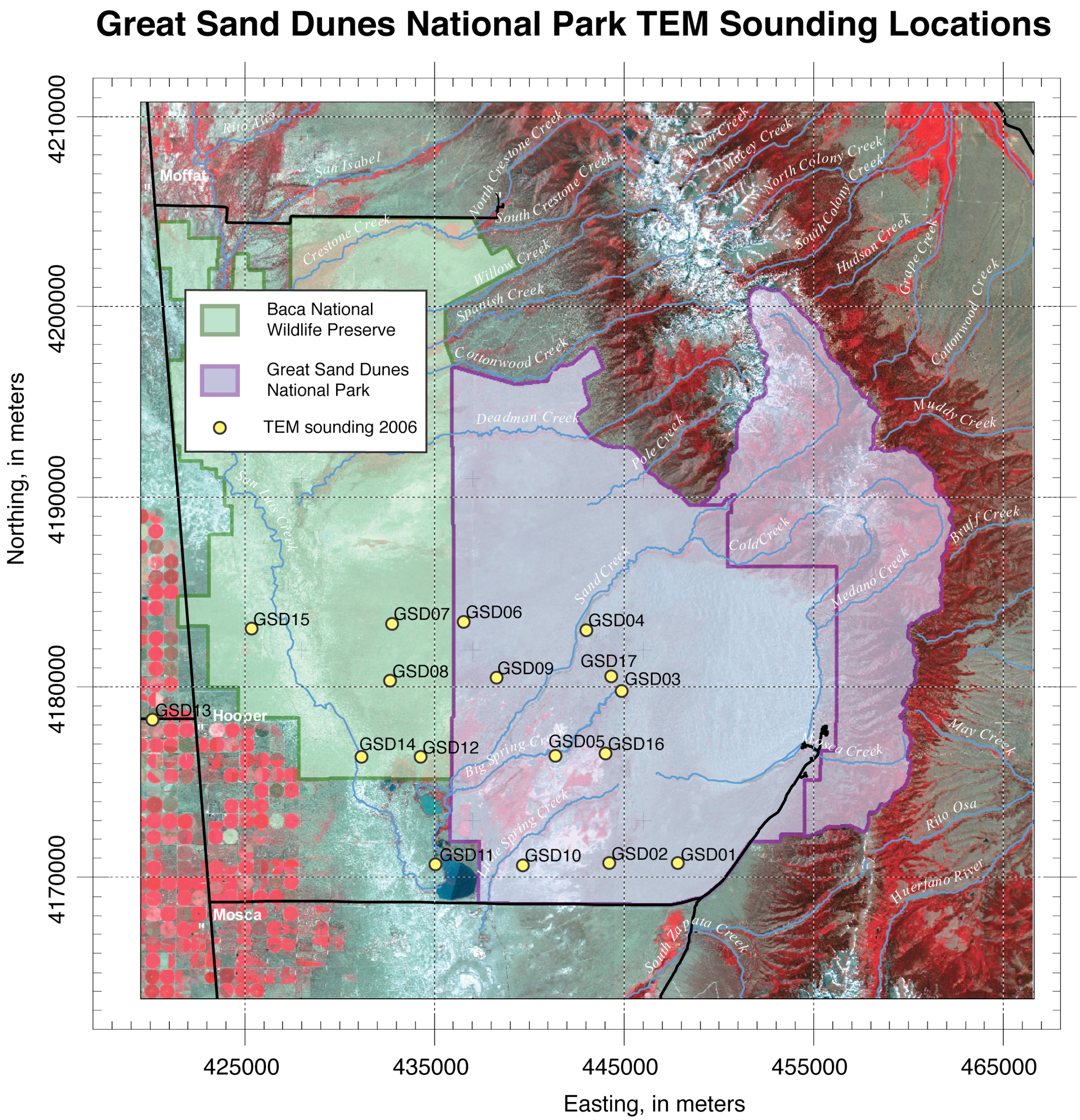

Figure 2. Location of TEM soundings

Interpretation of Results

Geology of Study Area

Great Sand Dunes National Park is located on the eastern margin of the central portion of the San Luis Valley. The valley is a structural basin bounded by volcanic rocks of the San Juan Mountains on its western side and sedimentary and igneous rocks of the Sangre de Cristo Mountains on its eastern side (Siebenthal, 1910; Upson, 1938; Powell, 1958). The northward trending Alamosa horst divides the valley into two basins (Leonard and Watts, 1989). These depressions are filled with sediments derived from the eastern and western bounding mountain ranges.

The valley basin is filled with the Tertiary age Santa Fe Formation and the Quaternary age Alamosa Formation. The Santa Fe Formation in the San Luis Valley, as revealed in limited outcrops and well logs, consists of conglomerate, sand, gravel, clay, lava, and volcanic deposits (Powell, 1958). The upper part of the Santa Fe consists of well rounded sand and gravel indicating stream deposition. Clay layers of varying color and thickness are also present in the Santa Fe. These layers are often interfingered with sand and gravel units.

The Alamosa Formation is composed of unconsolidated gravel, sand, silt, and clay (Powell, 1958). It underlies a large portion of the valley, but exposures are limited to the southern part of the valley where the Rio Grande and other drainages have cut into it. Clay in the Alamosa Formation ranges in color from brown to green to bluish-gray.

Siebenthal (1910) hypothesized that a large lake existed in the San Luis Valley during the Pleistocene. He named the sediments deposits in this lake the Alamosa Formation (Machette and others, 2007). Recent geologic mapping by Machette (2004) provides further evidence of the existence of a large lake, which he named Lake Alamosa. Knowledge of the extent of the lake is critical to understanding the hydrology of the San Luis Valley and is discussed in the following section.

Hydrology of Study Area

The groundwater resources of the San Luis Valley have been studied for a long time because of their importance for domestic, live stock, irrigation, and other uses (Siebenthal, 1910; Powell, 1958; Harmon, 1987; Schenk and Harmon, 1999). The latter reference provides a concise discussion of the hydrology and its relationship to the various geologic units present. In general, there are three hydrologic units, which are controlled by structural and stratigraphic factors. The hydrologic units going from the surface to depth are: (1) the unconfined aquifer, (2) a confined aquifer that produces large quantities of water, and (3) a less productive, deeper confined aquifer of lower hydrologic transmissivity. During the last deep-water cycle of the lake, the blue clay that forms the aquitard between upper unconfined aquifer and the lower confined aquifer was deposited. The location and thickness of this clay is critical to modeling the hydrology of the San Luis Valley. Machette and others (2007) point out that 95 percent of all artesian wells in the basin fall inside the highest level of Lake Alamosa. They also point out that most groundwater models of the area are multilayered with little or no regard to lateral discontinuities in the blue clay caused by interfingering of lacustrine and alluvial deposits at the margins of Lake Alamosa or by structural features.

Comparison With Well Logs

A search of the USGS National Water Information System and Groundwater Site-Inventory System for wells with geologic logs near the TEM soundings found eight wells which are summarized in table 2 (K.R. Watts, written commun., 2007). Well logs for the HRS wells came from HRS Water Consultants (1999).

Figure 3 shows the interpreted TEM resistivity-depth functions for soundings that were near wells with geologic logs. The strata are categorized as sand and clay units based on the log descriptions. In general, there is a decrease in interpreted resistivity associated with thick clay zones. This behavior is seen for soundings GSD03, GDS07, GSD08, GSD13, and GSD17.

The correspondence between the depth of the clay and the resistivity decrease is good, but not perfect. This can be attributed to three factors: (1) the drill logs, if not based on cores, will have some error in depth estimates, (2) there is uncertainty in the TEM inversion results that tends to increase with depth, and (3) the distance between the well and the sounding may be sufficiently large that the geology is not the same at the two locations. Resistivity decreases can also be caused by poor water quality. This point is important only in cases where the interpreted resistivity decreases and there is no corresponding change from sand to clay, and the resistivity is less than 10 ohm-m. Information about water-quality changes with depth was not considered in making this comparison.

Conclusions

Time-domain electromagnetic soundings obtained subsurface resistivity information from depths of 75 to more than 150 m. Layered earth models do a very good job of modeling the data. For the most part, electrical resistivity decreases with depth. This behavior is expected for the usual situation of near-surface, unsaturated sand and gravel underlain by similar, but saturated, material. At greater depth clay units are often encountered, which further decrease the resistivity. Decreases in water quality could also contribute to this general trend of resistivity decreasing with depth.

Comparison of soundings with nearby wells having geologic logs shows a fairly good correspondence between interpreted resistivity decreases and the location of clay units. This result is significant in that it supports the idea of using TEM soundings to map the top of the blue clay deposited in ancient Lake Alamosa. The location and extent of the blue clay is of great importance to groundwater flow models of the region.

No attempt was made to compare the geophysical interpretations with water-quality data, though this is a point that warrants further investigation.

Table 2. Inventory of wells near TEM soundings

TEM Sounding	Site Number Well ID	Site Name.	Easting[1] [m]	Northing[1] [m]	Distance From Sounding [m]	Well TD [ft]	Comment
GSD03	374557105372901	SC04101235ABB2	444975	4179812	55	351	HRS Well Y [2] ??
	374558105373101	NA04101226DCC	444977	4179842	82	351	HRS Well Y ??
	374558105372801	SC04101235ABB1	445000	4179842	94	76	HRS Well X
GSD04	374746105385203	SC04101215CDC2	442986	4183185	214	394	HRS Well V
GSD07	374754105465201	NA04101116CBC1	431231	4183521	1,626	200	
GSD08	374600105464301	NA04101128CCD1	431422	4180006	1,370	200	
GSD12	374403105445201	NA04001110AA	434108	4176378	256	202	
GSD13	374502105543001	NA04101032CCC	419978	4178321	270	127	Higgins Farm well
GSD14	374355105460702	NA04001109ACA2	432271	4176146	1,040	120	main well[3] ??
GSD14	374355105460701	NA04001109ACA1	432271	4176146	1,040	96	observation well
GSD17	374558105373101	NA04101226DCC	444977	4179842	924	351	HRS Well Y ??
	374558105372801	SC04101235ABB1	444500	4179842	939	76	HRS Well X
	374557105372901	SC04101235ABB2	444975	4179812	948	351	HRS Well Y ??

[1]Coordinates are in UTM Zone 13 S are referenced to NAD27.

[2]Several descriptions associated with the listed site number well ID appeared to correspond to HRS Well Y, but could not be definitively confirmed. They are marked by (??).

[3]The well near GSD14 appears to correspond to the one called "main well" in the description.

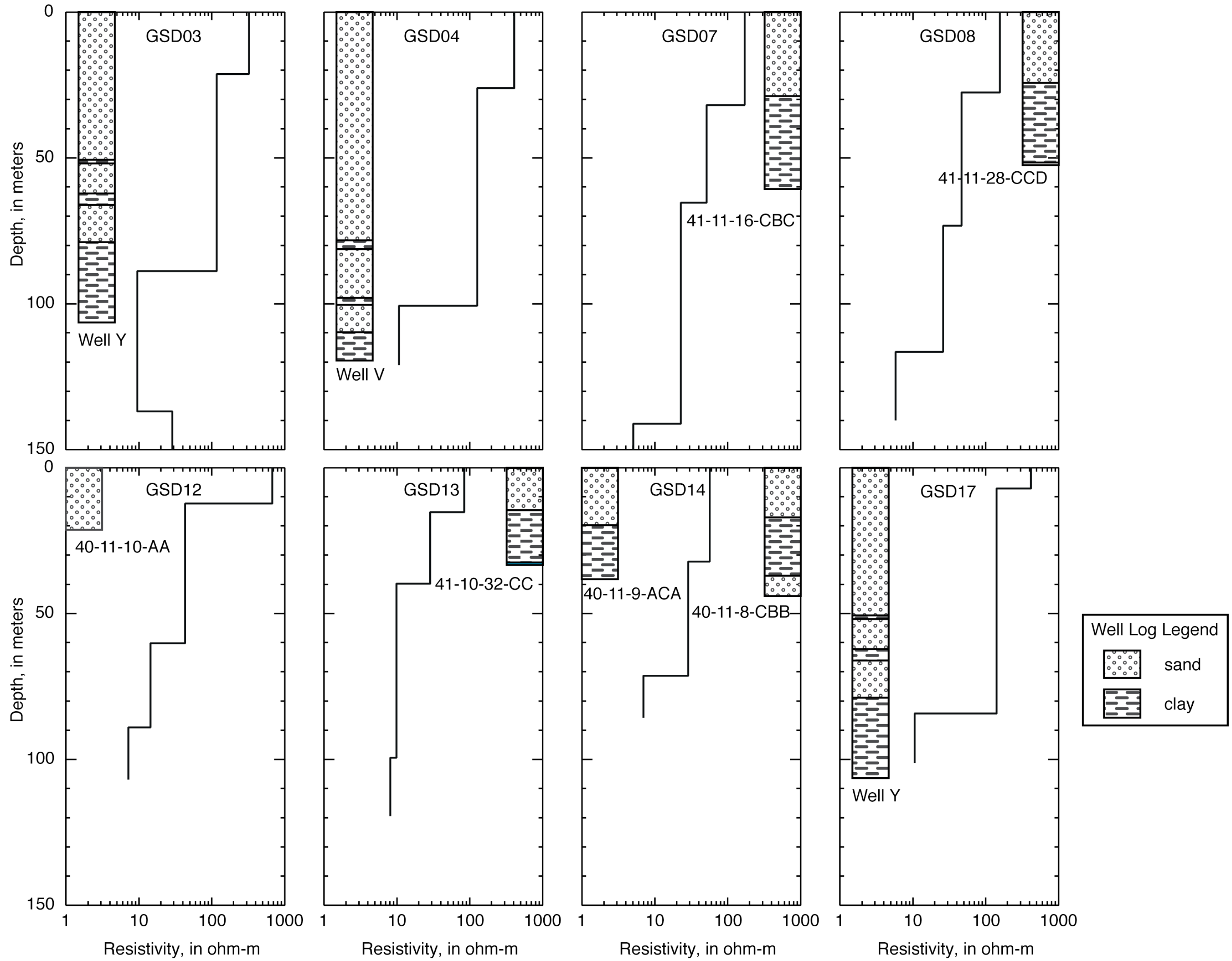

Figure 3. Comparison of interpreted resistivity-depth functions and geologic logs from nearby wells.

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Appendix A. Description of TEM Data Processing

Processing of the TEM data included the following steps: (1) downloading, (2) averaging, (3) inversion, (4) extracting results, (5) plotting results, and (6) report generation. Figure 2 summarizes the data flow and processing programs used.

The data in the Geonics PROTEM receiver are downloaded to a PC using program PROTEM, which is supplied by Geonics. Typically data from one sounding location are downloaded into a single raw data file. The format of this file is referred to as Geonics TEM File (GTF) format. Following downloading, selected data records from the raw data file are averaged using program NTEMAVG[3]. Data are usually selected to include measurements made with the same receiver gain and integration time, though this is not mandatory. The averaged data files are saved in GTF format. In addition to the averaged data file, a file containing a summary of the averaging process is saved.

Both the raw and averaged data files can be read into TEMIXXL, a program commercially available from Interpex Ltd., that was used for data interpretation. TEMIXXL stores a copy of the data, the model, and the calculated response of the model in a proprietary, binary database file. The database can hold a large number of soundings, so one database is usually enough for an entire survey. Sometimes it is helpful to retain several alternative models for a given data set. These are stored as separate soundings in the TEMIXXL database. Typically these alternative models have the original sounding name with up to 3 characters added at the end. For example a sounding called ABC01, might have variants ABC01L4 and ABC01L5 to indicate models with four and five layers, respectively. There are no restrictions on the extra characters added to the sounding name other than the total number of characters in the sounding name cannot exceed 8. The results of the inversion are reported in an inversion output file.

Program TEM_EXTRACT is used to extract apparent-resistivity-time and interpreted-resistivity-depth files for plotting. After the interpretation process is complete a report file is generated using program TEM_REPORT. This file contains all of the information about the sounding parameters, the data values, the model parameters, and the model response. There is adequate information in this file to enter the data into another inversion program to verify the results.

[3] Programs NTEMAVG, TEM_EXTRACT, and TEM_REPORT were developed at the U.S. Geological Survey.

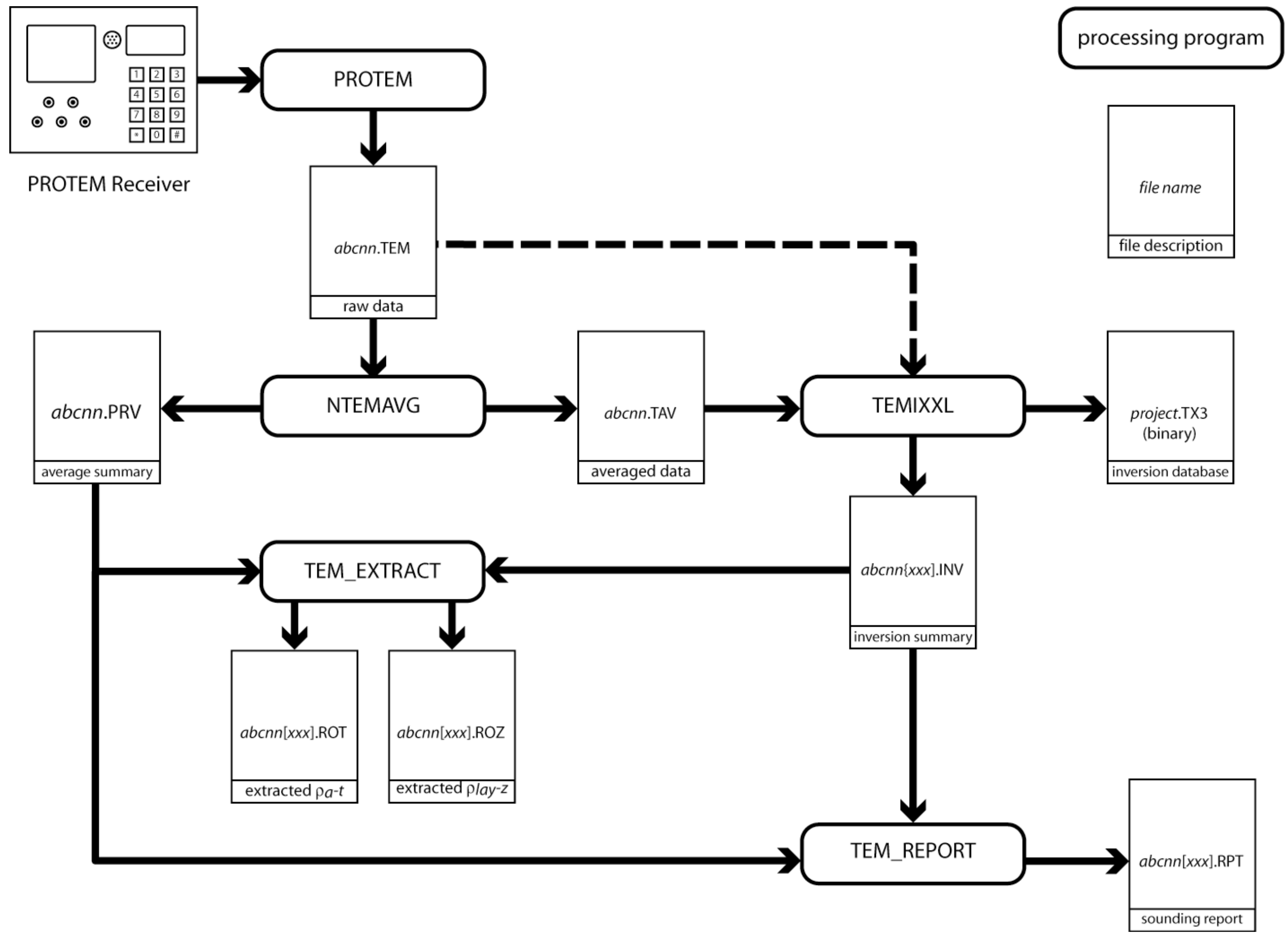


Figure A–1. Data processing programs, files, and flow. Solid lines show processing flow. Dashed arrow is alternative path. Program PROTEM is available from Geonics Limited. Program TEMIXXL is available from Interpex Limited. Programs NTEMAVG, TEM_EXTRACT, and TEM_REPORT were developed at the U.S. Geological Survey.

Appendix B. Voltage Units and Apparent Resistivity

Measured electromagnetic transients can be reported in two different ways: either as the voltage recorded in the receiver itself, or the voltage at the receiver coil normalized by the receiver-coil moment (number of coil turns times the coil area). The voltage at the receiver coil can be determined using Faraday's Law

$$V_{coil} = -M_{Rx} \frac{d\mathbf{B} \bullet \hat{\mathbf{n}}}{dt} = -M_{Rx} \frac{dB}{dt},$$

where $\mathbf{B}$ is the magnetic induction in units of webers per meter squared [Wb/m^2], $\hat{\mathbf{n}}$ is the unit normal to the receiver coil (assumed to be vertical), and M_{Rx} is the receiver-coil moment. Rearranging gives

$$V_{coil} / M_{Rx} = -\frac{dB}{dt}.$$

This representation of the data is convenient for comparison against background electromagnetic noise levels, which are typically 0.1–1 nV/m^2 (Fitterman, 1989).

For the PROTEM receiver used in this study the voltage at the coil V_{coil} and the voltage recorded at the receiver V_{Rx} are related by

$$V_{coil}[\text{nV}] = \frac{10^{-6} V_{Rx}[\text{mV}]}{52.1 \bullet 2^{G}},$$

where G is the receiver gain setting (see table C–2), and the factor 52.1 accounts for additional fixed receiver gain. The magnitude of the time derivative of the magnetic induction is then

$$\frac{dB}{dt}[\text{nV/m}^2] = V_{coil}[\text{nV}] / M_{Rx}[\text{m}^2] = \frac{10^{-6} V_{Rx}[\text{mV}]}{52.1 \bullet 2^{G} M_{Rx}[\text{m}^2]}.$$

The late stage apparent resistivity (Kaufman and Keller, 1983; Fitterman and Labson, 2005) is computed from the receiver voltage using

$$\rho_a^{LS} = \frac{\mu_o}{4\pi t} \left(\frac{2\mu_o L^2 M_{Rx} I_{Tx}}{5 t V_{coil}} \right)^{2/3},$$

where t is the time after current turn off, L is the square transmitter loop side length, I_{Tx} is the transmitter current, $\mu_o = 4\pi \bullet 10^{-7} [H/\text{m}]$ is the magnetic permeability of free space, and all units are SI. Recasting equation into typical field units and incorporating the PROTEM gain constants gives

$$\rho_a^{LS}[\text{ohm-m}] = \frac{10^{-4}}{t[\text{ms}]} \left\{ \frac{0.16 \bullet \pi \bullet 52.1 \bullet 2^{G} L^2[\text{m}^2] M_{Rx}[\text{m}^2] I_{Tx}[\text{A}]}{t[\text{ms}] V_{Rx}[\text{mV}]} \right\}^{2/3}$$

and

$$\rho_a^{LS}[\text{ohm-m}] = \frac{0.1}{t[\mu\text{s}]} \left\{ \frac{160 \bullet \pi \bullet 52.1 \bullet 2^{G} L^2[\text{m}^2] M_{Rx}[\text{m}^2] I_{Tx}[\text{A}]}{t[\mu\text{s}] V_{Rx}[\text{mV}]} \right\}^{2/3}.$$

Appendix C. Description of TEM Data Files

The file naming conventions and formats of files generated during downloading, processing, inversion, and extraction are described below.

File Naming Conventions

The downloaded GTF format files are typically given a name of the form *aaann*.TEM, where *aaa* is a three character identifier, typically associated the survey and *nn* is a two digit number. The sounding "name" would be considered *aaann*. Geonics and some software vendors give these files an extension of .RED.

Averaged data files are named *aaann*.TAV. These files are also in GTF format. The printed summary of the averaging process is written to a file named *aaann*.PRV

TEMIXXL database file are binary files in a proprietary format. They are named with suffix of .TX3. Data sets include observed data, measurement parameters, calculated model response, and inversion model parameters. A data set is identified by a name of up to 8 characters.

A summary of the inversion is written to a file name *aaann*[*xxx*].INV, where [*xxx*] represents optional characters added to the sounding name in TEMIXXL to identify alternative models.

Extracted apparent-resistivity-time and interpreted-resistivity-depth files suitable for plotting are named *aaann*[*xxx*].ROT and *aaann*[*xxx*].ROZ, respectively.

File Formats and Contents

Geonics TEM File (GTF) Format

The raw data collected in the field are written in Geonics TEM file (GTF) format. GTF files consist of 256-character long records, containing a 50-character header field followed by 25 eight-character data fields. The last two characters of the record are a carriage return and a line feed. Two types of records are created during PROTEM receiver downloading. The record type is indicated by characters 19–21 of the header field: "HDR" for a header record, and "OPR" for a data record. A header record is created every time a change is made in certain measurement parameters in the PROTEM receiver. For example, changes in the sounding name, transmitter current, transmitter loop size, turnoff time, or receiver moment will produce a new header record. Figure C–1 shows the structure of the header fields for header (HDR) and data (OPR) records; descriptions for these two types of header fields are given in tables C–1 and C–2, respectively.

The data fields of header and data records contain 25 eight-character data fields. Geonics' documentation refers to these data fields as gates. The contents of the gates is given in Tables C–3 and C–4.

The raw data files from this survey can be found in directory raw_data_files on the accompanying data CD.

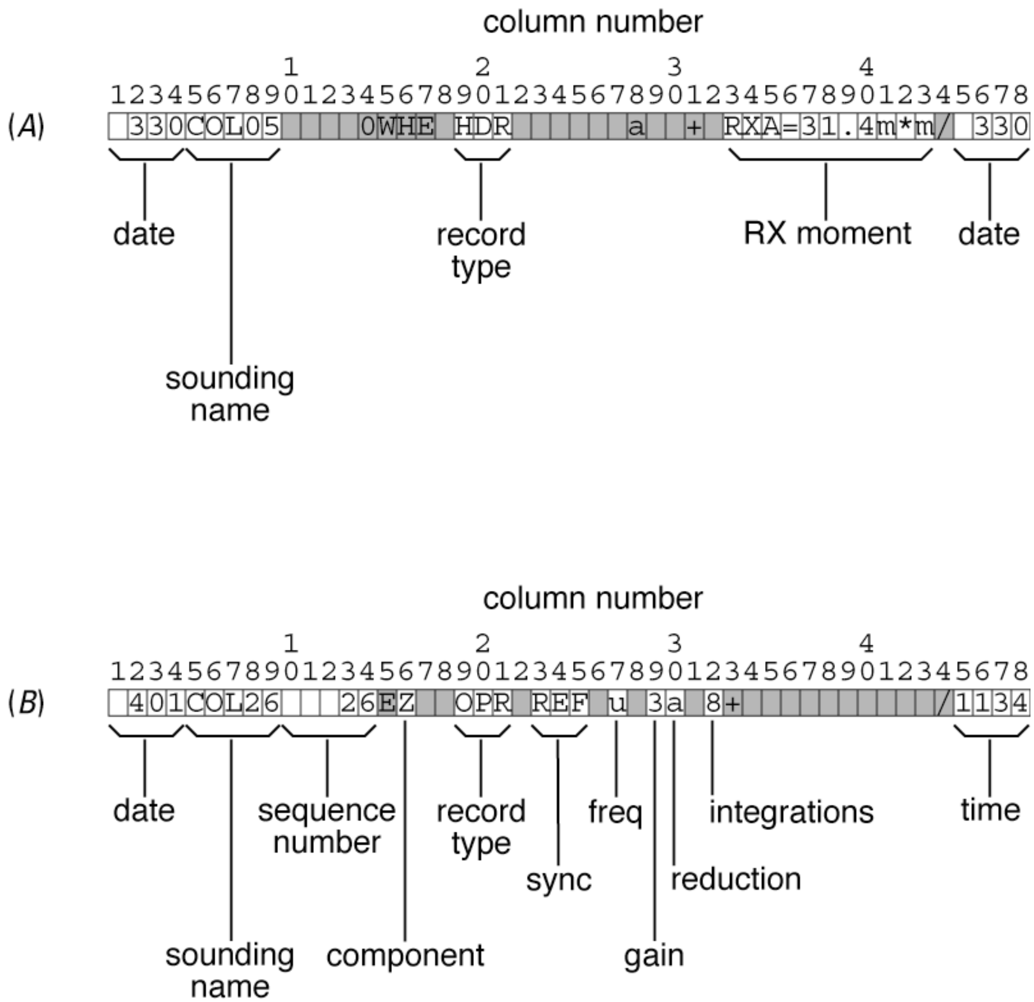


Figure C–1. Diagram showing contents of header records. *A* Header record (HDR), header fields. *B* Data record (OPR), header fields. The contents of shaded cells are ignored in further processing.

Table C–1. Description of header record (HDR) header fields.

Field	Columns	Description
date	1–4	date of measurement [mmdd]
sounding name	5–9	sounding name
record	19–21	"HDR" to indicate header record
RX moment	33–43	RX coil moment [turn-m^2]
date	45–48	date of measurement [mmdd]

Table C–2. Description of data record (OPR) header fields.

Field	Columns	Description
date	1–4	date of measurement [mmdd]
sounding name	5–9	sounding name
sequence number	10–14	sequence number of sounding; requires operator to manually update or values will not be significant
record type	19–21	"OPR" to indicate data record
sync	23–25	synchronization method; REF indicates reference cable, XTL indicates crystal oscillators
freq	27	transmitter repetition frequency; determines measurement times: u= ultra high, v= very high, h = high, m = medium, l = low
gain	29	additional PROTEM gain factor of 2^{gain} (G)
reduction	30	value of "a" indicates that receiver 4x and 10x gain factors have been removed
integrations	32	PROTEM coded integration time setting
time	45–48	time of measurement [hhmm]

Table C–3. Description of header record (HDR) data fields (gates).

Field (Gate)	Contents
0	date of measurement [mmdd]
2	time of measurement [hhmm]
4	TX current [A]
5	TX turnoff time [µs]
6, 7	TX loop side length [m] LX and LY
8. 9	RX coil position XR and YR relative to center of TX loop [m]
10	RX coil moment [turn-m^2] (RXA)
11	TX number
22	logger record number for this header record

Table C–4. Description of data record (OPR) data fields (gates).

Field (Gate)	Contents
0	logger record number for this data record
1-20	channels 1–20 TEM data
21	TX turnoff time [ms]
22	first RX gate time [ms]
23	TX current [A]
24	TX moment [turn-m^2], may include trailing "/"
25	time of measurement [hhmm]

PRV Files

PRV files are text files that summarize the data averaging process. The first page of the file consists of a listing of all of the header record (HDR) and data record (OPR) header fields. The first line is a descriptive header indicating that the data came from a PROTEM logger. The second line usually contains HDR header fields. Subsequent lines are OPR header fields associated with the recorded data. Additional HDR header fields will be present whenever the operator made a change in the header information on the PROTEM receiver. The output concludes with two records whose headers contain X's to indicate the end of the data processing.

Following the summary page, a separate page is devoted to data records that were averaged together. There is usually one page for each transmitter repetition frequency used for the sounding. The first line of these pages indicates the program version used to average the data, the averaged-output file name, the record number of the averaged-output file to which this page corresponds, and the GTF format input file name.

Each data page of the PRV file contains a summary of all of the data recorded by the PROTEM receiver for a single frequency. For each measurement there is a data record number, frequency, transmitter current, receiver gain, integration value NSTK, transmitter turnoff time, and a time shift. The time shift is applied during data averaging to adjust for incorrect turnoff time settings during data recording. If no adjustment was made this value will be zero. This part of the output is followed by a list of the SI units of the various reported quantities, the TEM system used, the receiver coil moment (RXA), the transmitter loop dimensions (LX and LY), and the location of the receiver coil with respect to the center of the transmitter loop (XR and YR).

The next section of the data page gives the channel number, the voltage induced in the receiver coil in units of [$\mu V/m^2$]. The average of these voltages is computed and expressed as PROTEM receiver units [mV]. The standard deviation as a percentage of the average data value is also reported.

The last section of the data page presents the voltages after they have been transformed to apparent resistivity. The print out includes the channel number, the receiver channel time, the square root of the time in seconds [$s^{1/2}$], the late stage apparent resistivity, the average of the resistivity values, and the percentage deviation of the apparent resistivity.

The PRV files from this survey can be found in directory averaged_report_files on the accompanying data CD.

TAV Files

The averaged data are contained in TAV files and use the GTF format described above. The header of the first record indicates the type of instrument the data came from, and whether the data have been averaged. The data fields of this record are all set to zero. The second record is an HDR record with header fields and data fields as described in Tables C-1 and C-3. Next comes an OPR record for each frequency average computed by program NTEMAVG. If different groups of data records were averaged, there will be multiple output records, one for each group. Following the last OPR record comes a record with "XXXXX" in the header field. The numbers in the data fields are meaningless.

The averaged data files from this survey can be found in directory averaged_data_files on the accompanying data CD.

INV Files

This file is a report generated by TEM inversion program TEMIXGL. It provides information on the sounding location, the measurement geometry, the model misfit error, the model parameter estimates, the measured resistivity and calculated model response, and usually a resolution matrix.

Misfit error reported by the TEM inversion program (TEMIXXL) is given as percentage RMS misfit for voltage data. The apparent resistivity misfit is approximately 2/3 of this value.

The inversion output files from this survey can be found in directory inversion_files on the accompanying data CD.

ROT and ROZ Files

These are text files that contain data and models in a form for plotting. The ROT file contains the following information:

1. The sounding name.
2. Tab delimited column headings for the data that follow.
3. Tab delimited time and apparent resistivity data consisting of 6, 9, or 12 columns corresponding to 1, 2, or 3 transmitter repetition frequencies, respectively. Typically the data are given in order of decreasing repetition frequency. The contents of the columns are specified in table C–5.

The ROZ files contain the following information:

1. The sounding name.
2. Tab delimited titles for the data that follow: Depth (m) Resistivity (ohm-m).
3. Tab delimited data for plotting a resistivity depth plot. Depths are given as positive values below the surface. The depth sequence will be: 0, z_1, z_1, z_2, z_2, . . . ,z_{n-1} ,z_{n-1}, 1.2*z_{n-1}. The resistivity sequence will be ρ_1, ρ_1, ρ_2, ρ_2, . . . ρ_{n-1}, ρ_{n-1}, ρ_n, ρ_n.

The extracted data files (ROT and ROZ) from this survey can be found in directory extracted_data_files on the accompanying data CD.

Table C–5. Description of plottable data in ROT files.

Column[1]	Contents	Description
1	time [msec]	time of data point after TX turnoff
2	freq1_avg	averaged apparent resistivity, FREQ1
3	freq1_std	standard error in FREQ1 averaged apparent resistivity
4	freq1_cal	calculated FREQ1 apparent resistivity
5	freq2_avg	averaged apparent resistivity, FREQ2
6	freq2_std	standard error in FREQ2 averaged apparent resistivity
7	freq2_cal	calculated FREQ2 apparent resistivity
8	freq3_avg	averaged apparent resistivity, FREQ3
9	freq3_std	standard error in FREQ3 averaged apparent resistivity
10	freq3_cal	calculated FREQ3 apparent resistivity
11	masked	apparent resistivity of a masked data point
12	m_err	standard error of a masked data point

[1]When sounding has fewer than 3 sweeps, the unnecessary columns are removed. The masked and m_err data follow immediately after the last sweep.

RPT Files

The sounding report files are presented in Appendix D and can be found in directory sounding_report_file on the accompanying data CD.

The report file contains all relevant information for the sounding and its interpretation summarized on a single sheet.

TEMIXXL Database File

The TEMIXXL database file GRSANDUN.TX3 used for interpretation of the TEM soundings can be found in directory TEMIXXL_database_file on the accompanying data CD..

Appendix D. TEM Sounding Report Files

Sounding: GSD01 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Alamosa [Colorado]

Date: 07-JUN-06
UTM Coord: E[m] 447887.0 N[m] 4170723.0
Elevation[m]: 2359.1

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	248.30	44.4	2359.1
2	48.90	33.2	2314.6
3	7.37	15.7	2281.4
4	11.32	--	2265.7

Fit Error[%]: 2.741

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 4

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	232.1	0.3	u	232.4
2	0.00890	261.9	0.1	m	235.6
3	0.01200	230.3	0.1	u	230.2
4	0.01570	216.3	0.2	u	218.6
5	0.02000	209.6	0.2	u	207.5
6	0.02610	197.0	0.2	u	195.4
7	0.03340	183.7	0.1	u	184.9
8	0.04210	172.3	0.2	u	172.6
9	0.05410	154.4	0.3	u	155.1
10	0.06820	137.4	0.2	u	136.1
11	0.08380	119.0	0.2	u	118.5
12	0.10460	102.6	0.3	u	101.2
13	0.13560	84.8	0.4	u	83.9
14	0.17230	71.8	0.2	u	71.1
15	0.21490	62.1	0.2	u	61.5
16	0.27500	54.0	0.3	u	53.3
17	0.34900	47.8	0.5	u	47.1
18	0.43600	42.8	0.8	u	42.6
19	0.55500	39.3	1.7	u	39.0
20	0.70100	37.1	1.4	u	36.5

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	100.0	0.4	u	102.5
2	0.12100	88.0	0.5	u	88.8
3	0.15100	74.9	0.5	u	75.2
4	0.18800	63.4	0.3	u	64.3
5	0.23100	55.7	0.9	u	55.8
6	0.29100	47.6	0.7	u	48.2
7	0.36500	41.7	1.0	u	42.1
8	0.45200	37.1	1.9	u	37.4
9	0.57000	32.7	2.3	u	33.3
10	0.71200	30.1	2.4	u	30.1
11	0.87100	27.2	3.1	u	27.6
12	1.08000	24.5	5.4	u	25.5
13	1.39000	23.0	6.2	u	23.4
14	1.75000	22.7	7.0	u	21.8
15	2.18000	21.9	15.0	u	20.6
16	2.78000	19.6	18.1	u	19.6
17	3.52000	18.1	16.1	u	18.8
18	4.39000	22.4	63.2	d	-
19	5.56000	17.4	75.3	d	-
20	7.04000	46.1	100.0	d	-

Sounding: GSD02 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Alamosa [Colorado]

Date: 07-JUN-06
UTM Coord: E[m] 444289.0 N[m] 4170722.0
Elevation[m]: 2327.1

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	170.90	24.5	2327.1
2	68.09	36.2	2302.5
3	6.99	51.2	2266.3
4	4.14	--	2215.1

Fit Error[%]: 3.123

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 3

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	149.1	0.2	u	148.5
2	0.00890	150.0	0.1	m	140.6
3	0.01200	138.2	0.1	u	137.3
4	0.01570	133.4	0.1	u	135.2
5	0.02000	135.0	0.2	u	134.5
6	0.02610	132.7	0.1	u	133.5
7	0.03340	129.2	0.1	u	129.6
8	0.04210	123.0	0.2	u	122.1
9	0.05410	110.6	0.4	u	109.3
10	0.06820	97.7	0.3	u	95.9
11	0.08380	84.6	0.1	u	83.9
12	0.10460	73.5	0.1	u	72.2
13	0.13560	61.9	0.1	u	60.6
14	0.17230	53.4	0.2	u	52.0
15	0.21490	46.9	0.3	u	45.7
16	0.27500	41.3	0.3	u	40.1
17	0.34900	36.9	0.5	u	35.9
18	0.43600	33.4	0.5	u	32.8
19	0.55500	30.7	0.9	u	30.1
20	0.70100	29.1	1.4	u	28.1

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	69.7	0.2	u	73.0
2	0.12100	61.9	0.2	u	63.8
3	0.15100	53.5	0.3	u	54.7
4	0.18800	45.9	0.2	u	47.2
5	0.23100	40.7	0.4	u	41.5
6	0.29100	35.4	0.7	u	36.1
7	0.36500	31.0	0.9	u	31.8
8	0.45200	27.4	0.7	u	28.3
9	0.57000	24.3	1.6	u	25.1
10	0.71200	22.0	2.1	u	22.4
11	0.87100	20.1	1.8	u	20.2
12	1.08000	18.2	0.6	u	18.2
13	1.39000	16.3	2.4	u	16.1
14	1.75000	14.8	4.6	u	14.6
15	2.18000	13.4	3.9	u	13.3
16	2.78000	12.1	6.9	u	12.1
17	3.52000	11.2	16.4	u	11.2
18	4.39000	10.8	26.7	u	10.6
19	5.56000	9.9	23.6	u	10.0
20	7.04000	12.1	81.2	d	-

Sounding: GSD03 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 08-JUN-06
UTM Coord: E[m] 444942.0 N[m] 4179766.0
Elevation[m]: 2342.4

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	326.30	21.3	2342.4
2	118.10	67.6	2321.0
3	9.55	48.1	2253.4
4	28.89	--	2205.3

Fit Error[%]: 3.754

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 4

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	183.5	0.1	m	216.3
2	0.00890	205.8	0.3	u	201.8
3	0.01200	191.7	0.4	u	193.2
4	0.01570	186.0	0.5	u	187.6
5	0.02000	187.6	0.5	u	185.4
6	0.02610	184.5	0.2	u	185.9
7	0.03340	185.7	0.2	u	188.2
8	0.04210	187.7	0.3	u	188.5
9	0.05410	182.8	0.3	u	183.5
10	0.06820	178.3	0.3	u	171.7
11	0.08380	158.5	0.3	u	156.3
12	0.10460	141.3	0.2	u	137.1
13	0.13560	117.6	0.2	u	114.5
14	0.17230	97.9	0.3	u	95.8
15	0.21490	82.3	0.5	u	81.2
16	0.27500	69.2	0.5	u	68.0
17	0.34900	60.0	0.7	u	58.3
18	0.43600	53.1	0.6	u	51.6
19	0.55500	48.0	1.2	u	46.4
20	0.70100	45.3	1.1	u	43.0

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 3.0 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	131.8	0.2	u	137.9
2	0.12100	117.7	0.6	u	120.6
3	0.15100	99.8	0.6	u	101.8
4	0.18800	82.4	0.6	u	85.5
5	0.23100	70.7	0.9	u	72.6
6	0.29100	59.1	0.8	u	60.9
7	0.36500	50.5	0.5	u	52.0
8	0.45200	44.6	1.5	u	45.5
9	0.57000	39.3	1.7	u	40.0
10	0.71200	35.9	2.3	u	36.1
11	0.87100	32.9	3.5	u	33.5
12	1.08000	30.7	3.6	u	31.3
13	1.39000	29.1	8.8	u	29.4
14	1.75000	28.0	5.1	u	28.3
15	2.18000	27.4	12.7	u	27.7
16	2.78000	28.6	30.2	u	27.4
17	3.52000	31.2	69.0	m	27.3
18	4.39000	23.4	33.8	d	-
19	5.56000	19.2	56.7	d	-
20	7.04000	30.1	100.0	d	-

Sounding: GSD04 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 08-JUN-06
UTM Coord: E[m] 443073.0 N[m] 4183004.0
Elevation[m]: 2347.0

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	409.70	26.2	2347.0
2	127.00	74.6	2320.7
3	10.74	--	2246.0

Fit Error[%]: 4.486

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 4

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	225.1	0.1	m	273.1
2	0.00890	253.9	0.2	u	252.0
3	0.01200	235.2	0.3	u	237.0
4	0.01570	223.3	0.3	u	226.1
5	0.02000	222.6	0.1	u	219.4
6	0.02610	215.8	0.1	u	216.2
7	0.03340	215.0	0.2	u	216.4
8	0.04210	216.0	0.0	u	216.9
9	0.05410	211.5	0.1	u	213.6
10	0.06820	208.2	0.7	u	203.8
11	0.08380	186.4	0.4	u	189.0
12	0.10460	174.1	0.7	u	169.0
13	0.13560	150.5	0.8	u	144.2
14	0.17230	128.5	1.3	u	123.2
15	0.21490	109.2	1.5	u	106.5
16	0.27500	91.8	2.2	u	91.1
17	0.34900	78.7	2.9	u	79.2
18	0.43600	68.0	3.4	u	70.3
19	0.55500	60.7	4.6	u	62.8
20	0.70100	53.4	5.3	u	57.3

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	161.5	0.8	u	169.1
2	0.12100	148.7	1.1	u	149.9
3	0.15100	131.6	0.8	u	128.8
4	0.18800	112.2	1.2	u	109.9
5	0.23100	95.8	1.6	u	94.7
6	0.29100	80.1	2.4	u	80.4
7	0.36500	67.7	3.4	u	68.8
8	0.45200	58.1	2.6	u	59.8
9	0.57000	49.2	2.6	u	51.7
10	0.71200	44.0	4.8	u	45.4
11	0.87100	41.0	9.0	u	40.6
12	1.08000	38.1	6.2	u	36.4
13	1.39000	34.3	11.2	u	32.4
14	1.75000	30.5	14.7	u	29.4
15	2.18000	34.3	15.6	m	27.0
16	2.78000	34.8	37.6	m	25.0
17	3.52000	42.0	100.0	d	-
18	4.39000	81.5	100.0	d	-
19	5.56000	14.4	100.0	d	-
20	7.04000	12.1	100.0	d	-

Sounding: GSD05 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Alamosa [Colorado]

Date: 08-JUN-06
UTM Coord: E[m] 441449.0 N[m] 4176374.0
Elevation[m]: 2311.9

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	132.80	28.4	2311.9
2	49.53	30.3	2283.4
3	10.72	39.9	2253.1
4	5.13	--	2213.1

Fit Error[%]: 3.339

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 3

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	123.6	0.1	u	125.2
2	0.00890	125.0	0.3	u	121.9
3	0.01200	118.8	0.4	u	119.4
4	0.01570	114.0	0.3	u	115.9
5	0.02000	113.7	0.3	u	112.5
6	0.02610	109.0	0.2	u	108.8
7	0.03340	103.7	0.3	u	104.2
8	0.04210	98.3	0.4	u	98.2
9	0.05410	89.8	0.6	u	89.8
10	0.06820	82.5	0.7	u	81.0
11	0.08380	73.7	0.1	u	73.4
12	0.10460	67.4	0.1	u	65.7
13	0.13560	59.9	0.2	u	58.1
14	0.17230	53.8	0.1	u	52.1
15	0.21490	48.6	0.2	u	47.5
16	0.27500	43.9	0.3	u	42.9
17	0.34900	39.8	0.6	u	39.1
18	0.43600	36.5	1.2	u	35.9
19	0.55500	33.7	1.2	u	32.9
20	0.70100	31.9	2.3	u	30.6

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	62.9	0.2	u	66.2
2	0.12100	58.6	0.3	u	60.0
3	0.15100	53.0	0.4	u	53.7
4	0.18800	47.1	0.5	u	48.2
5	0.23100	42.8	0.4	u	43.6
6	0.29100	37.9	0.6	u	38.9
7	0.36500	33.6	0.8	u	34.6
8	0.45200	30.0	1.5	u	30.9
9	0.57000	26.4	1.4	u	27.4
10	0.71200	24.1	1.3	u	24.3
11	0.87100	21.9	1.1	u	21.9
12	1.08000	19.7	2.2	u	19.7
13	1.39000	17.8	4.0	u	17.5
14	1.75000	15.8	3.3	u	15.8
15	2.18000	14.5	7.0	u	14.5
16	2.78000	12.9	10.4	m	13.3
17	3.52000	13.0	17.7	m	12.4
18	4.39000	14.2	16.3	m	11.8
19	5.56000	10.6	18.5	m	11.3
20	7.04000	10.3	72.6	d	-

Sounding: GSL06 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 09-JUN-06
UTM Coord: E[m] 436634.0 N[m] 4183429.0
Elevation[m]: 2322.6

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	652.20	16.1	2322.6
2	137.10	75.0	2306.4
3	30.42	68.3	2231.3
4	6.84	--	2163.0

Fit Error[%]: 5.051

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 4

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	193.3	0.3	m	237.9
2	0.00890	223.3	0.1	u	221.0
3	0.01200	211.5	0.3	u	211.5
4	0.01570	204.3	0.3	u	205.2
5	0.02000	204.5	0.0	u	201.3
6	0.02610	196.6	0.1	u	198.4
7	0.03340	193.2	0.2	u	195.7
8	0.04210	190.9	0.3	u	191.1
9	0.05410	183.4	0.5	u	182.6
10	0.06820	177.8	0.8	u	171.7
11	0.08380	158.6	1.7	u	160.7
12	0.10460	153.4	1.0	u	149.1
13	0.13560	142.4	0.2	u	137.3
14	0.17230	133.7	0.7	u	128.5
15	0.21490	125.4	1.1	u	121.6
16	0.27500	116.4	1.2	u	114.3
17	0.34900	111.5	2.4	u	106.9
18	0.43600	99.0	2.1	u	99.3
19	0.55500	91.4	1.8	u	91.2
20	0.70100	80.6	7.9	u	83.6

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	140.6	0.8	u	149.5
2	0.12100	134.9	0.6	u	139.5
3	0.15100	128.0	0.7	u	129.5
4	0.18800	119.0	1.4	u	120.6
5	0.23100	111.0	1.3	u	112.6
6	0.29100	101.9	2.3	u	103.1
7	0.36500	89.4	3.2	u	93.3
8	0.45200	80.3	3.9	u	83.2
9	0.57000	69.3	4.3	u	72.7
10	0.71200	64.2	8.4	u	63.2
11	0.87100	56.2	10.3	u	55.6
12	1.08000	52.1	15.1	u	48.5
13	1.39000	41.6	14.5	u	41.5
14	1.75000	39.8	22.5	u	36.3
15	2.18000	32.1	20.8	u	32.2
16	2.78000	27.4	29.3	u	28.5
17	3.52000	24.4	44.7	u	25.7
18	4.39000	25.7	63.6	d	-
19	5.56000	23.1	85.0	d	-
20	7.04000	12.4	69.9	d	-

Sounding: GSL07 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 09-JUN-06
UTM Coord: E[m] 432848.0 N[m] 4183329.0
Elevation[m]: 2307.3

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	172.30	32.0	2307.3
2	51.61	33.4	2275.2
3	22.91	75.8	2241.7
4	5.10	--	2165.9

Fit Error[%]: 4.360

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 3

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	150.3	0.3	m	160.6
2	0.00890	158.0	0.1	u	155.7
3	0.01200	147.8	0.2	u	149.8
4	0.01570	139.9	0.2	u	141.7
5	0.02000	135.7	0.2	u	133.7
6	0.02610	126.1	0.1	u	125.1
7	0.03340	117.1	0.1	u	117.0
8	0.04210	109.6	0.1	u	109.3
9	0.05410	99.9	0.1	u	100.5
10	0.06820	92.5	0.2	u	92.3
11	0.08380	84.4	0.3	u	85.3
12	0.10460	79.1	0.2	u	78.3
13	0.13560	73.5	0.1	u	71.6
14	0.17230	70.2	0.4	u	66.7
15	0.21490	66.8	0.4	u	63.5
16	0.27500	63.0	0.4	u	60.9
17	0.34900	60.0	0.7	u	59.1
18	0.43600	57.3	0.7	u	57.5
19	0.55500	54.2	1.6	u	55.5
20	0.70100	53.7	2.8	u	53.3

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	74.2	0.6	u	79.0
2	0.12100	71.3	0.7	u	73.4
3	0.15100	67.7	0.6	u	68.0
4	0.18800	63.8	0.6	u	63.6
5	0.23100	60.8	1.0	u	60.3
6	0.29100	56.7	1.1	u	57.0
7	0.36500	52.5	1.4	u	53.8
8	0.45200	47.9	1.6	u	50.4
9	0.57000	44.1	3.6	u	46.3
10	0.71200	41.2	5.2	u	41.9
11	0.87100	38.2	6.5	u	37.9
12	1.08000	33.7	8.7	u	33.8
13	1.39000	30.7	6.6	u	29.4
14	1.75000	27.2	8.7	u	26.0
15	2.18000	24.6	13.4	u	23.3
16	2.78000	20.8	25.1	u	20.7
17	3.52000	18.0	27.3	u	18.8
18	4.39000	16.6	47.1	u	17.3
19	5.56000	12.4	38.3	d	-
20	7.04000	14.5	65.3	d	-

Sounding: GSL08 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 09-JUN-06
UTM Coord: E[m] 432749.0 N[m] 4180346.0
Elevation[m]: 2305.8

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	158.20	27.6	2305.8
2	46.69	45.7	2278.1
3	26.27	43.3	2232.4
4	5.83	--	2189.0

Fit Error[%]: 2.979

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 3

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	142.7	0.1	u	145.6
2	0.00890	143.3	0.2	u	137.9
3	0.01200	129.0	0.3	u	129.7
4	0.01570	118.8	0.2	u	120.5
5	0.02000	112.8	0.2	u	112.1
6	0.02610	103.9	0.2	u	103.8
7	0.03340	96.4	0.2	u	97.2
8	0.04210	91.6	0.3	u	91.8
9	0.05410	86.3	0.4	u	86.4
10	0.06820	83.6	0.6	u	82.0
11	0.08380	79.7	0.2	u	78.5
12	0.10460	77.4	0.1	u	75.5
13	0.13560	74.3	0.2	u	72.7
14	0.17230	72.5	0.2	u	70.4
15	0.21490	69.7	0.5	u	68.0
16	0.27500	65.4	0.3	u	64.8
17	0.34900	61.6	0.9	u	60.7
18	0.43600	57.5	1.1	u	56.5
19	0.55500	52.1	0.7	u	51.9
20	0.70100	49.2	1.6	u	47.9

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	71.7	0.4	u	75.4
2	0.12100	71.0	0.3	u	72.7
3	0.15100	69.1	0.5	u	70.0
4	0.18800	65.9	0.8	u	67.0
5	0.23100	63.2	1.0	u	63.7
6	0.29100	57.9	1.1	u	59.0
7	0.36500	52.3	1.3	u	53.5
8	0.45200	46.5	1.5	u	48.1
9	0.57000	41.2	2.6	u	42.3
10	0.71200	37.8	3.5	u	37.2
11	0.87100	32.9	4.1	u	33.1
12	1.08000	29.2	4.4	u	29.2
13	1.39000	25.7	7.6	u	25.5
14	1.75000	22.9	10.2	u	22.7
15	2.18000	20.5	16.3	u	20.5
16	2.78000	17.4	14.7	m	18.5
17	3.52000	16.2	17.9	m	17.0
18	4.39000	16.9	41.1	m	15.9
19	5.56000	14.1	48.5	d	-
20	7.04000	11.3	56.1	d	-

Sounding: GSL09 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 09-JUN-06
UTM Coord: E[m] 438354.0 N[m] 4180480.0
Elevation[m]: 2318.0

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	268.50	44.7	2318.0
2	78.30	46.8	2273.2
3	18.63	57.0	2226.3
4	6.69	--	2169.2

Fit Error[%]: 3.819

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 4

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	233.3	0.2	u	245.7
2	0.00890	266.4	0.1	u	244.4
3	0.01200	239.8	0.1	u	241.1
4	0.01570	224.0	0.2	u	230.8
5	0.02000	218.5	0.3	u	219.9
6	0.02610	207.5	0.3	u	208.3
7	0.03340	198.3	0.4	u	198.8
8	0.04210	191.4	0.3	u	189.0
9	0.05410	177.3	0.2	u	176.6
10	0.06820	165.9	0.1	u	162.6
11	0.08380	149.6	0.5	u	149.2
12	0.10460	137.2	0.3	u	134.9
13	0.13560	122.7	0.5	u	119.7
14	0.17230	111.1	0.4	u	108.1
15	0.21490	101.3	0.3	u	99.1
16	0.27500	92.0	0.4	u	90.6
17	0.34900	84.4	0.9	u	83.2
18	0.43600	76.9	1.3	u	77.0
19	0.55500	71.8	2.3	u	70.7
20	0.70100	65.4	2.2	u	65.4

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	128.7	0.7	u	135.7
2	0.12100	120.4	0.9	u	123.3
3	0.15100	109.9	1.0	u	110.9
4	0.18800	98.7	1.2	u	100.0
5	0.23100	90.4	1.4	u	91.0
6	0.29100	79.3	1.8	u	81.7
7	0.36500	71.8	2.6	u	73.0
8	0.45200	64.3	2.9	u	65.3
9	0.57000	56.9	4.9	u	57.4
10	0.71200	49.5	6.6	u	50.4
11	0.87100	45.2	8.2	u	44.7
12	1.08000	39.8	9.2	u	39.5
13	1.39000	35.0	10.3	u	34.2
14	1.75000	30.9	15.5	u	30.2
15	2.18000	26.7	18.3	u	27.1
16	2.78000	23.4	26.1	u	24.3
17	3.52000	22.6	41.4	u	22.1
18	4.39000	21.3	62.0	d	-
19	5.56000	28.9	100.0	d	-
20	7.04000	22.3	100.0	d	-

Sounding: GSL10 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Alamosa [Colorado]

Date: 10-JUN-06
UTM Coord: E[m] 439727.0 N[m] 4170606.0
Elevation[m]: 2296.7

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	74.36	20.6	2296.7
2	15.79	27.1	2276.0
3	6.50	--	2248.8

Fit Error[%]: 4.393

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 2

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	79.9	0.4	u	78.6
2	0.00890	74.1	0.1	u	74.0
3	0.01200	65.9	0.1	u	68.2
4	0.01570	59.7	0.2	u	61.6
5	0.02000	55.9	0.1	u	55.6
6	0.02610	51.2	0.1	u	50.0
7	0.03340	46.8	0.1	u	45.6
8	0.04210	43.7	0.1	u	42.2
9	0.05410	39.8	0.2	u	38.8
10	0.06820	36.6	0.1	u	35.9
11	0.08380	33.2	0.1	u	33.4
12	0.10460	30.5	0.1	u	30.7
13	0.13560	27.4	0.1	u	27.6
14	0.17230	25.3	0.3	u	25.1
15	0.21490	23.2	0.2	u	23.0
16	0.27500	21.3	0.2	u	20.9
17	0.34900	20.0	0.2	u	19.3
18	0.43600	18.8	0.3	u	18.1
19	0.55500	17.9	0.4	u	17.1
20	0.70100	17.4	0.8	u	16.4

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	28.9	0.5	u	30.9
2	0.12100	27.1	0.5	u	28.6
3	0.15100	25.0	0.4	u	25.9
4	0.18800	22.9	0.5	u	23.5
5	0.23100	21.1	0.5	u	21.5
6	0.29100	19.2	0.4	u	19.5
7	0.36500	17.7	0.6	u	17.7
8	0.45200	16.2	0.6	u	16.3
9	0.57000	15.0	0.9	u	14.9
10	0.71200	14.1	1.3	u	13.9
11	0.87100	13.1	2.2	u	13.0
12	1.08000	12.1	3.2	u	12.2
13	1.39000	11.1	4.4	u	11.4
14	1.75000	10.7	7.4	u	10.9
15	2.18000	9.9	14.8	u	10.4
16	2.78000	9.3	13.4	m	10.0
17	3.52000	9.1	24.2	m	9.7
18	4.39000	9.9	51.7	m	9.6
19	5.56000	10.4	100.0	d	-
20	7.04000	15.8	100.0	d	-

Sounding: GSL11 Client: USGS/NPS Date: 10-JUN-06
Location: Great Sand Dunes National Park UTM Coord: E[m] 435143.0 N[m] 4170651.0
Project: San Luis Valley Blue Clay Elevation[m]: 2293.6
County: Alamosa [Colorado]

TX loop size: X[m] 38.1 Y[m] 38.1 RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	237.00	5.1	2293.6
2	28.19	40.3	2288.4
3	9.97	29.0	2248.0
4	5.69	--	2219.0

Fit Error[%]: 3.124

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 1

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	54.0	0.6	u	54.8
2	0.00890	49.9	0.2	u	48.8
3	0.01200	45.1	0.1	u	45.0
4	0.01570	42.0	0.2	u	42.4
5	0.02000	40.8	0.1	u	40.6
6	0.02610	39.0	0.1	u	39.2
7	0.03340	37.8	0.2	u	38.2
8	0.04210	37.4	0.1	u	37.4
9	0.05410	36.4	0.2	u	36.3
10	0.06820	36.0	0.1	u	35.1
11	0.08380	34.3	0.2	u	33.8
12	0.10460	33.2	0.2	u	32.3
13	0.13560	31.2	0.2	u	30.4
14	0.17230	29.3	0.2	u	28.5
15	0.21490	27.4	0.1	u	26.8
16	0.27500	25.5	0.2	u	25.0
17	0.34900	23.9	0.4	u	23.4
18	0.43600	22.4	0.3	u	22.0
19	0.55500	21.2	0.6	u	20.7
20	0.70100	20.4	1.3	u	19.8

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	30.6	0.4	u	32.4
2	0.12100	29.9	0.4	u	30.8
3	0.15100	28.5	0.4	u	29.0
4	0.18800	26.5	0.5	u	27.1
5	0.23100	24.9	0.4	u	25.3
6	0.29100	22.8	0.4	u	23.3
7	0.36500	20.9	0.5	u	21.3
8	0.45200	19.2	0.7	u	19.6
9	0.57000	17.5	0.7	u	17.9
10	0.71200	16.3	1.0	u	16.4
11	0.87100	14.9	1.2	u	15.2
12	1.08000	13.8	1.9	u	14.0
13	1.39000	12.6	2.4	u	12.9
14	1.75000	11.9	3.2	u	12.0
15	2.18000	11.2	5.5	u	11.3
16	2.78000	10.9	8.4	u	10.7
17	3.52000	10.6	13.7	u	10.2
18	4.39000	9.8	16.4	u	9.9
19	5.56000	13.1	40.7	d	-
20	7.04000	11.0	44.7	d	-

Sounding: GSL12 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Alamosa [Colorado]

Date: 10-JUN-06
UTM Coord: E[m] 434360.0 N[m] 4176318.0
Elevation[m]: 2295.8

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	682.00	12.4	2295.8
2	43.59	47.9	2283.3
3	14.58	28.8	2235.3
4	7.23	--	2206.5

Fit Error[%]: 2.643

System: EM-47 Freq[Hz]: 315 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 3

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	117.5	0.1	u	119.6
2	0.00890	107.7	0.2	u	104.6
3	0.01200	94.3	0.2	u	94.1
4	0.01570	85.9	0.2	u	86.8
5	0.02000	81.7	0.1	u	81.5
6	0.02610	76.6	0.1	u	77.0
7	0.03340	73.3	0.2	u	73.8
8	0.04210	71.4	0.1	u	71.0
9	0.05410	68.1	0.1	u	67.9
10	0.06820	66.1	0.1	u	64.8
11	0.08380	62.7	0.2	u	61.8
12	0.10460	59.5	0.2	u	58.5
13	0.13560	55.0	0.2	u	54.3
14	0.17230	51.0	0.1	u	50.4
15	0.21490	47.2	0.3	u	46.8
16	0.27500	43.3	0.2	u	42.8
17	0.34900	39.8	0.4	u	39.2
18	0.43600	36.8	0.6	u	36.3
19	0.55500	34.2	0.8	u	33.7
20	0.70100	31.6	1.0	u	31.8

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	55.8	0.5	u	58.4
2	0.12100	53.8	0.5	u	55.1
3	0.15100	50.5	0.5	u	51.1
4	0.18800	46.3	0.8	u	47.0
5	0.23100	42.9	0.5	u	43.0
6	0.29100	38.5	0.7	u	38.7
7	0.36500	34.7	0.8	u	34.7
8	0.45200	31.3	1.3	u	31.3
9	0.57000	27.9	1.3	u	27.9
10	0.71200	25.2	2.6	u	25.1
11	0.87100	22.5	2.3	u	22.9
12	1.08000	20.4	3.3	u	20.9
13	1.39000	18.7	4.2	u	18.9
14	1.75000	17.2	8.6	u	17.4
15	2.18000	16.1	7.0	u	16.2
16	2.78000	15.4	15.1	u	15.1
17	3.52000	13.9	16.0	u	14.3
18	4.39000	14.5	37.2	u	13.8
19	5.56000	15.7	50.3	m	13.4
20	7.04000	17.0	94.0	d	-

Sounding: GSL13 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 11-JUN-06
UTM Coord: E[m] 420232.0 N[m] 4178294.0
Elevation[m]: 2302.8

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	84.15	15.1	2302.8
2	28.90	24.5	2287.6
3	9.93	59.7	2263.0
4	8.22	--	2203.3

Fit Error[%]: 4.390

System: EM-47 Freq[Hz]: 315 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 2

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	75.7	0.4	u	76.4
2	0.00890	71.2	0.2	u	69.5
3	0.01200	64.4	0.1	u	64.6
4	0.01570	59.7	0.1	u	60.8
5	0.02000	57.7	0.0	u	57.8
6	0.02610	54.3	0.1	u	54.6
7	0.03340	51.0	0.2	u	51.5
8	0.04210	48.5	0.1	u	48.0
9	0.05410	44.5	0.2	u	44.1
10	0.06820	41.7	0.2	u	40.2
11	0.08380	38.1	0.2	u	37.0
12	0.10460	34.9	0.2	u	33.7
13	0.13560	31.0	0.2	u	30.4
14	0.17230	28.1	0.1	u	27.8
15	0.21490	25.9	0.3	u	25.8
16	0.27500	24.0	0.4	u	23.9
17	0.34900	22.9	0.4	u	22.6
18	0.43600	22.0	0.8	u	21.6
19	0.55500	21.4	1.6	u	20.9
20	0.70100	21.6	1.8	u	20.5

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	32.5	0.2	u	34.0
2	0.12100	30.5	0.2	u	31.3
3	0.15100	27.9	0.2	u	28.6
4	0.18800	25.2	0.2	u	26.2
5	0.23100	23.4	0.3	u	24.2
6	0.29100	21.7	0.3	u	22.3
7	0.36500	20.3	0.4	u	20.8
8	0.45200	19.1	0.5	u	19.4
9	0.57000	18.0	0.8	u	18.2
10	0.71200	17.6	1.1	u	17.1
11	0.87100	16.5	1.5	u	16.2
12	1.08000	15.6	2.6	u	15.4
13	1.39000	14.4	3.8	u	14.5
14	1.75000	13.8	7.2	u	13.8
15	2.18000	12.7	8.1	u	13.3
16	2.78000	11.9	13.0	u	12.8
17	3.52000	12.2	20.6	u	12.5
18	4.39000	12.6	35.2	u	12.3
19	5.56000	13.1	64.3	u	12.2
20	7.04000	23.5	100.0	d	-

Sounding: GSL14 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Alamosa [Colorado]

Date: 12-JUN-06
UTM Coord: E[m] 431247.0 N[m] 4176321.0
Elevation[m]: 2295.1

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	56.80	32.3	2295.1
2	28.96	39.1	2262.7
3	6.99	--	2223.5

Fit Error[%]: 4.446

System: EM-47 Freq[Hz]: 285 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 1

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	58.8	0.4	u	58.4
2	0.00890	58.9	0.0	u	57.1
3	0.01200	57.4	0.2	u	57.8
4	0.01570	56.1	0.2	u	58.0
5	0.02000	56.9	0.2	u	57.6
6	0.02610	55.8	0.1	u	56.5
7	0.03340	55.1	0.1	u	55.0
8	0.04210	55.1	0.1	u	53.7
9	0.05410	53.8	0.3	u	52.5
10	0.06820	53.5	0.4	u	51.5
11	0.08380	50.9	0.2	u	50.6
12	0.10460	49.8	0.2	u	49.1
13	0.13560	47.3	0.3	u	46.5
14	0.17230	44.5	0.5	u	43.4
15	0.21490	41.1	0.5	u	40.1
16	0.27500	38.2	0.9	u	36.5
17	0.34900	34.7	1.8	u	33.2
18	0.43600	32.0	2.3	u	30.6
19	0.55500	29.3	3.2	u	28.2
20	0.70100	28.7	6.2	d	-

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	45.7	0.4	u	48.9
2	0.12100	45.0	0.4	u	47.0
3	0.15100	42.9	0.3	u	44.1
4	0.18800	39.8	0.4	u	40.6
5	0.23100	36.8	0.4	u	37.2
6	0.29100	33.0	0.5	u	33.4
7	0.36500	29.6	0.7	u	29.8
8	0.45200	26.2	1.0	u	26.9
9	0.57000	23.3	0.9	u	24.0
10	0.71200	21.3	1.8	u	21.7
11	0.87100	19.3	2.0	u	19.9
12	1.08000	17.6	2.4	u	18.3
13	1.39000	16.2	2.7	u	16.6
14	1.75000	15.1	4.5	u	15.4
15	2.18000	14.4	6.6	u	14.4
16	2.78000	13.6	9.2	u	13.6
17	3.52000	13.5	13.9	u	12.9
18	4.39000	12.9	32.0	u	12.5
19	5.56000	14.4	40.6	d	-
20	7.04000	14.4	88.5	d	-

Sounding: GSL15 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Saguache [Colorado]

Date: 12-JUN-06
UTM Coord: E[m] 425480.0 N[m] 4183103.0
Elevation[m]: 2296.7

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	132.20	3.5	2296.7
2	38.42	4.7	2293.1
3	28.83	59.7	2288.4
4	12.48	19.9	2228.7
5	7.47	--	2208.8

Fit Error[%]: 5.326

System: EM-47 Freq[Hz]: 315 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 1

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	52.6	0.2	u	51.4
2	0.00890	48.1	0.1	u	46.4
3	0.01200	42.7	0.2	u	43.2
4	0.01570	39.3	0.2	u	41.0
5	0.02000	38.0	0.2	u	39.2
6	0.02610	36.4	0.2	u	37.6
7	0.03340	36.0	0.3	u	36.4
8	0.04210	35.9	0.2	u	35.5
9	0.05410	35.4	0.4	u	34.8
10	0.06820	36.3	0.7	u	34.4
11	0.08380	34.0	0.1	u	34.3
12	0.10460	37.0	0.1	u	34.1
13	0.13560	33.1	0.1	u	33.9
14	0.17230	41.6	0.3	m	33.5
15	0.21490	42.7	0.7	m	32.9
16	0.27500	33.1	0.8	m	31.8
17	0.34900	28.3	0.7	m	30.5
18	0.43600	37.5	2.1	m	29.3
19	0.55500	29.2	3.2	m	28.1
20	0.70100	30.9	4.5	d	-

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	33.0	0.4	u	33.9
2	0.12100	33.1	0.4	u	33.6
3	0.15100	31.5	0.4	u	33.1
4	0.18800	40.9	0.6	m	32.4
5	0.23100	40.7	0.6	m	31.3
6	0.29100	29.1	0.5	m	29.6
7	0.36500	25.4	0.7	m	27.8
8	0.45200	30.8	1.2	m	25.8
9	0.57000	23.1	1.2	u	23.8
10	0.71200	23.6	1.9	u	21.9
11	0.87100	20.0	2.1	u	20.3
12	1.08000	18.5	2.2	u	18.8
13	1.39000	17.0	3.5	u	17.3
14	1.75000	15.9	6.6	u	16.1
15	2.18000	14.8	5.7	u	15.2
16	2.78000	14.8	13.4	u	14.3
17	3.52000	14.7	27.4	m	13.7
18	4.39000	15.1	35.0	m	13.2
19	5.56000	22.7	100.0	d	-
20	7.04000	30.9	100.0	d	-

Sounding: GSL16 Client: USGS/NPS
Location: Great Sand Dunes National Park
Project: San Luis Valley Blue Clay
County: Colorado

Date: 12-JUN-06
UTM Coord: E[m] 444083.0 N[m] 4176509.0
Elevation[m]: 2325.6

TX loop size: X[m] 38.1 Y[m] 38.1

RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	477.60	9.3	2325.6
2	91.65	62.1	2316.2
3	6.87	--	2254.1

Fit Error[%]: 15.385

System: EM-47 Freq[Hz]: 315 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 3

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	125.7	0.3	m	139.3
2	0.00890	129.2	0.3	u	130.5
3	0.01200	127.6	0.3	u	127.0
4	0.01570	127.6	0.2	u	125.6
5	0.02000	132.2	0.5	u	126.2
6	0.02610	136.2	0.4	u	128.8
7	0.03340	134.7	0.7	u	131.5
8	0.04210	134.7	1.8	u	131.9
9	0.05410	118.9	2.0	u	127.4
10	0.06820	104.1	2.9	u	117.9
11	0.08380	104.9	5.8	u	106.5
12	0.10460	88.0	3.9	u	93.2
13	0.13560	81.4	5.5	u	78.5
14	0.17230	72.9	6.5	u	66.9
15	0.21490	52.4	18.7	u	58.0
16	0.27500	54.3	31.9	u	49.9
17	0.34900	45.1	44.8	u	43.8
18	0.43600	38.2	55.5	u	39.2
19	0.55500	51.9	100.0	u	35.4
20	0.70100	28.7	55.2	u	32.7

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	84.3	2.2	u	93.3
2	0.12100	79.0	2.5	u	81.7
3	0.15100	69.6	3.8	u	69.7
4	0.18800	60.1	5.9	u	59.5
5	0.23100	50.0	6.5	u	51.4
6	0.29100	44.1	9.6	u	43.8
7	0.36500	39.8	12.1	u	37.7
8	0.45200	32.9	12.0	u	33.0
9	0.57000	30.3	20.8	u	28.8
10	0.71200	23.1	24.2	u	25.5
11	0.87100	23.0	32.7	u	23.0
12	1.08000	22.3	49.0	u	20.7
13	1.39000	17.9	32.7	u	18.6
14	1.75000	18.3	46.0	u	17.0
15	2.18000	12.6	69.9	u	15.8
16	2.78000	13.3	93.4	u	14.7
17	3.52000	15.1	100.0	u	13.9
18	4.39000	28.9	100.0	d	-
19	5.56000	13.7	100.0	m	12.9
20	7.04000	52.0	100.0	d	-

Sounding: GSL17 Client: USGS/NPS Date: 12-JUN-06
Location: Great Sand Dunes National Park UTM Coord: E[m] 444403.0 N[m] 4180568.0
Project: San Luis Valley Blue Clay Elevation[m]: 2337.8
County: Saguache [Colorado]

TX loop size: X[m] 38.1 Y[m] 38.1 RX location: X[m] 0.0 Y[m] 0.0

Model Layer	Resistivity [ohm-m]	Thickness [m]	Elevation [m]
1	421.80	7.2	2337.8
2	141.30	77.1	2330.5
3	10.62	--	2253.4

Fit Error[%]: 21.706

System: EM-47 Freq[Hz]: 315 Data Set Code: uh
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 3

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.00680	160.8	0.1	u	165.7
2	0.00890	171.0	0.1	u	160.9
3	0.01200	164.8	0.2	u	161.7
4	0.01570	154.0	0.2	u	163.9
5	0.02000	170.0	0.3	u	167.9
6	0.02610	160.6	0.6	u	174.2
7	0.03340	181.3	1.1	u	179.9
8	0.04210	215.8	1.9	u	181.6
9	0.05410	142.6	2.1	u	176.1
10	0.06820	146.9	4.5	u	163.3
11	0.08380	206.5	18.9	u	147.8
12	0.10460	120.8	13.1	u	129.7
13	0.13560	127.5	14.8	u	109.7
14	0.17230	99.5	27.2	u	93.9
15	0.21490	73.5	8.6	u	81.7
16	0.27500	83.1	41.3	u	70.7
17	0.34900	58.2	24.3	u	62.3
18	0.43600	55.0	29.7	u	56.0
19	0.55500	44.3	31.0	u	50.9
20	0.70100	32.9	79.1	u	47.2

System: EM-47 Freq[Hz]: 30 Data Set Code: hi
TX Cur[A]: 2.5 Turn Off[usec]: 2.5
RX Moment[turns-m^2]: 31.4 Gain Setting: 7

	Time [ms]	rhoa_obs [ohm-m]	obs_err [%]	mask	rhoa_cal [ohm-m]
1	0.10000	133.3	3.6	u	130.0
2	0.12100	103.1	3.6	u	114.2
3	0.15100	110.2	10.4	u	97.9
4	0.18800	93.6	11.1	u	83.9
5	0.23100	67.5	9.4	u	72.8
6	0.29100	59.4	14.0	u	62.4
7	0.36500	54.0	18.3	u	54.0
8	0.45200	45.9	21.9	u	47.5
9	0.57000	38.4	18.8	u	41.6
10	0.71200	38.8	29.2	u	37.0
11	0.87100	33.3	40.7	u	33.5
12	1.08000	32.2	48.5	u	30.4
13	1.39000	25.9	59.0	u	27.4
14	1.75000	26.4	100.0	u	25.1
15	2.18000	33.0	100.0	u	23.4
16	2.78000	19.4	100.0	u	21.8
17	3.52000	21.9	100.0	u	20.7
18	4.39000	37.7	100.0	d	-
19	5.56000	12.8	100.0	d	-
20	7.04000	18.5	100.0	d	-

Appendix E. TEM Sounding Plots and Descriptions

Plots of the measured apparent resistivity, calculated apparent resistivity for the inversion model, and the inversion estimated resistivity-depth function are given below along with a description of the results.

The number of transients used in the data averages was nominally set at seven for the first five soundings (GSD01 through GSD05), while for the remaining 12 soundings 21 transients were averaged. For this second group of soundings the sounding name was changed from GSDnn to GSLnn to indicated that more data were averaged.

In most of the soundings the channel 2 data appeared to be biased upwards and were not used in the inversion, but preserved in the plots (masked). The masked data points are plotted as solid diamonds (◆).

Sounding GSD01

A four-layer model with decreasing resistivity in the first three layers followed by a slight increase in the fourth layer resistivity gave a voltage misfit error of 2.74 percent. The channel 2 datum was masked. Attempts to fit the data with a three-layer model resulted in misfit error of 3.84 percent.

Sounding GSD02

A four-layer model with decreasing resistivity produced a very good fit to the data (3.12 percent). Dropping the bottom layer and reinverting the data could not give as good a fit (6.88 percent). The channel 2 datum was masked.

Sounding GSD03

The four-layer model starts with a very high near surface resistivity that drops to a minimum in layer three, followed by an increase in fourth layer resistivity. Channel 1 was dropped from the inversion resulting in a final misfit error of 3.75 percent. Including channel 1 in the inversion increased the misfit to 4.39 percent.

Sounding GSD04

A three-layer model was chosen for the data after masking the channel 1 datum. The last two data (2.18 and 2.78 ms) were also masked. If these two points were included, the model required a poorly determined high resistivity (150 ohm-m) basement, which is not geologically reasonable. Misfit error is 4.49 percent.

Sounding GSD05

Interpreted resistivity decreases from a high of 130 ohm-m at the surface to around 5 ohm-m at depth. While there is some sort of very small irregularity in the first two channels, masking either channels 1, 2, or both did not significantly alter the misfit error or the first-layer resistivity and thickness. Accordingly all early channels were retained in the inversion. Misfit error was 3.34 percent. Data at times greater than 2.18 ms were masked.

Sounding GSD06 (GSL06)

Better fits to the data were obtained by masking the channel 1 datum. The best fit (5.05 percent) was obtained with a four-layer model whose resistivity decreases with depth. The high first-layer resistivity (650 ohm-m) is poorly determined, while the other layer resistivities and thicknesses are well constrained.

Sounding GSD07 (GSL07)

The data are fit with a four-layer model that becomes less resistive with depth. Channel 1 was masked. Most model parameters are well resolved, however, the transition from the first to the third layer is ambiguous, that is, there are any number of models that fit the transition equally well. Misfit error is 4.36 percent.

Sounding GSD08 (GSL08)

A four-layer model fits the data well with resistivity decreasing with depth. Data points at times greater than 2.18 ms were masked. Misfit error was 3.00 percent. Aside from the transition between the second and fourth layer, the layers are fairly well resolved.

Sounding GSD09 (GSL09)

The data are modeled with a four-layer model with decreasing resistivity with depth. Data points up to 3.52 ms were used. Misfit error was 3.82 percent. All layer are fairly well resolved.

Sounding GSD10 (GSL10)

A three-layer model does a good job of fitting the data. Resistivities decrease with depth, and aside from the depth of the transition between the second and third layer the model is well resolved. Data points at times greater than 2.18 ms were masked. The misfit error was 4.39 percent.

Sounding GSD11 (GSL11)

A three-layer model was used for these data. Resistivities decrease with depth. The thickness of the fist layer is the least well resolved parameter. The misfit error was 4.34. percent.

Sounding GSD12 (GSL12)

A three-layer model with resistivity decreasing with depth fits the data very well. All model parameters are well resolved. The data point at time 5.56 ms was masked. The misfit error was 4.29 percent.

Sounding GSD13 (GSL13)

A four-layer model gives the best results for this sounding. The layer resistivities decrease with depth. The transition from the first layer to the third layer is moderately well constrained. The fourth layer resistivity is only 30 percent less than that of the third layer. The misfit error was 4.39 percent. Trying to use a three-layer model increased the misfit error to 4.99 percent.

Sounding GSD14 (GSL14)

The data are modeled with a three-layer model with layer resistivity decreasing with depth. The first layer resistivity is very well determined. The transition depth between the first and second layer is the least well determined feature of the sounding. The misfit error was 4.45 percent.

Sounding GSD15 (GSL15)

A three-layer model was used to fit this noisy sounding. Layer resistivity decreases with depth. The high noise level between 0.17 and 0.56 ms is caused by an unidentified metal object near the site. Masking these noisy points, resistivity of the second layer is well determined. The resistivity and thickness of the first layer is not well determined. This misfit error was 5.96 percent. Without masking data in the time range indicated, the misfit error increased to 14.6 percent.

Sounding GSD16 (GSL16)

A three-layer model provides a model fit to this sounding. The data are corrupted by noise from a nearby electric fence. Layer resistivity is found to decrease with depth. The second and third layer are fairly well determined, while the near surface layer is not well resolved. The misfit error is 15.7 percent.

Sounding GSD17 (GSL17)

This sounding also exhibits noise from a nearby electric fence. The three-layer model resistivity decreases with depth. The second layer is pretty well determined. The first-layer resistivity and thickness are not well determined. The misfit error is 21.7 percent.

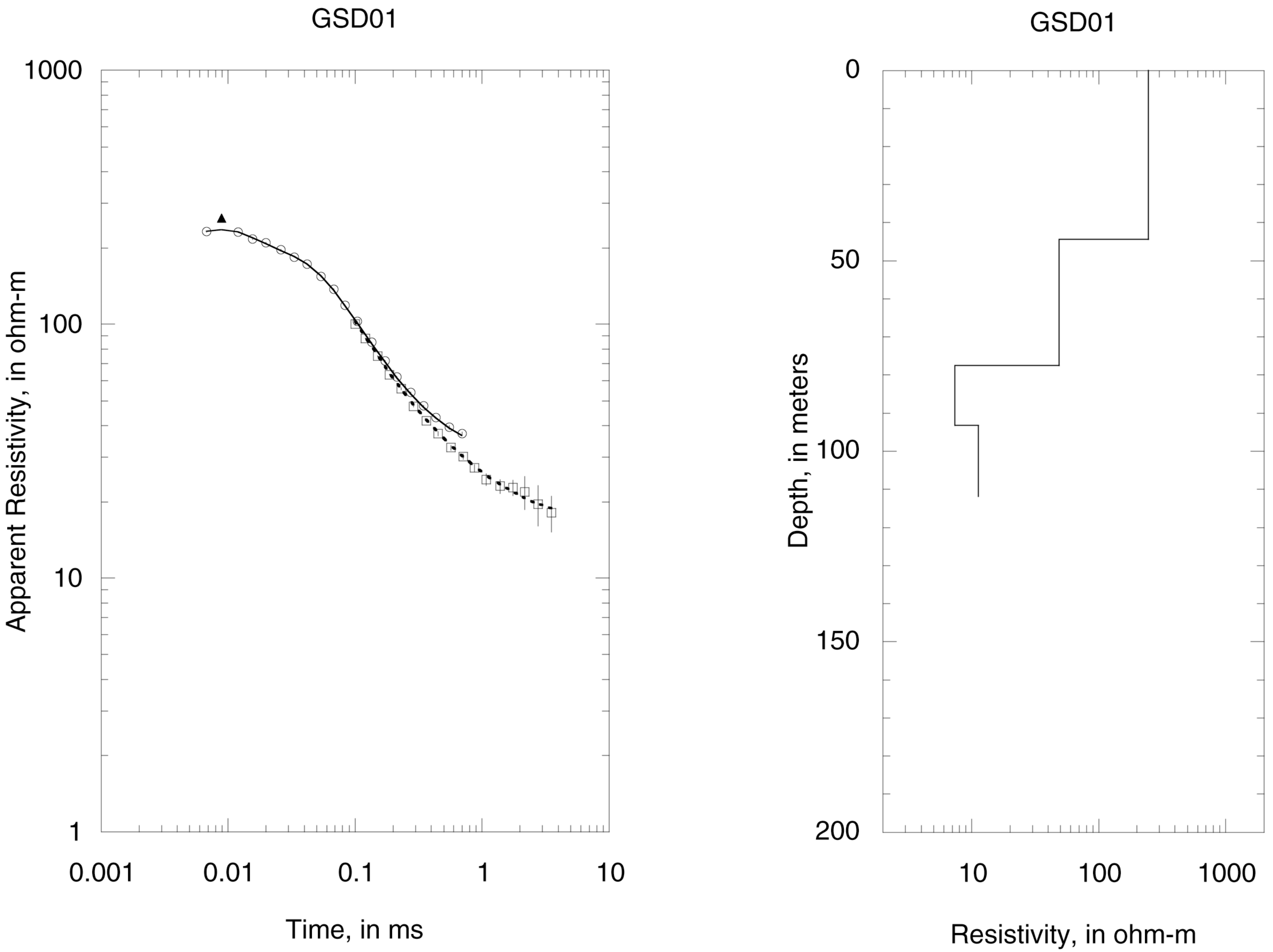


Figure E–1. Sounding GSD01

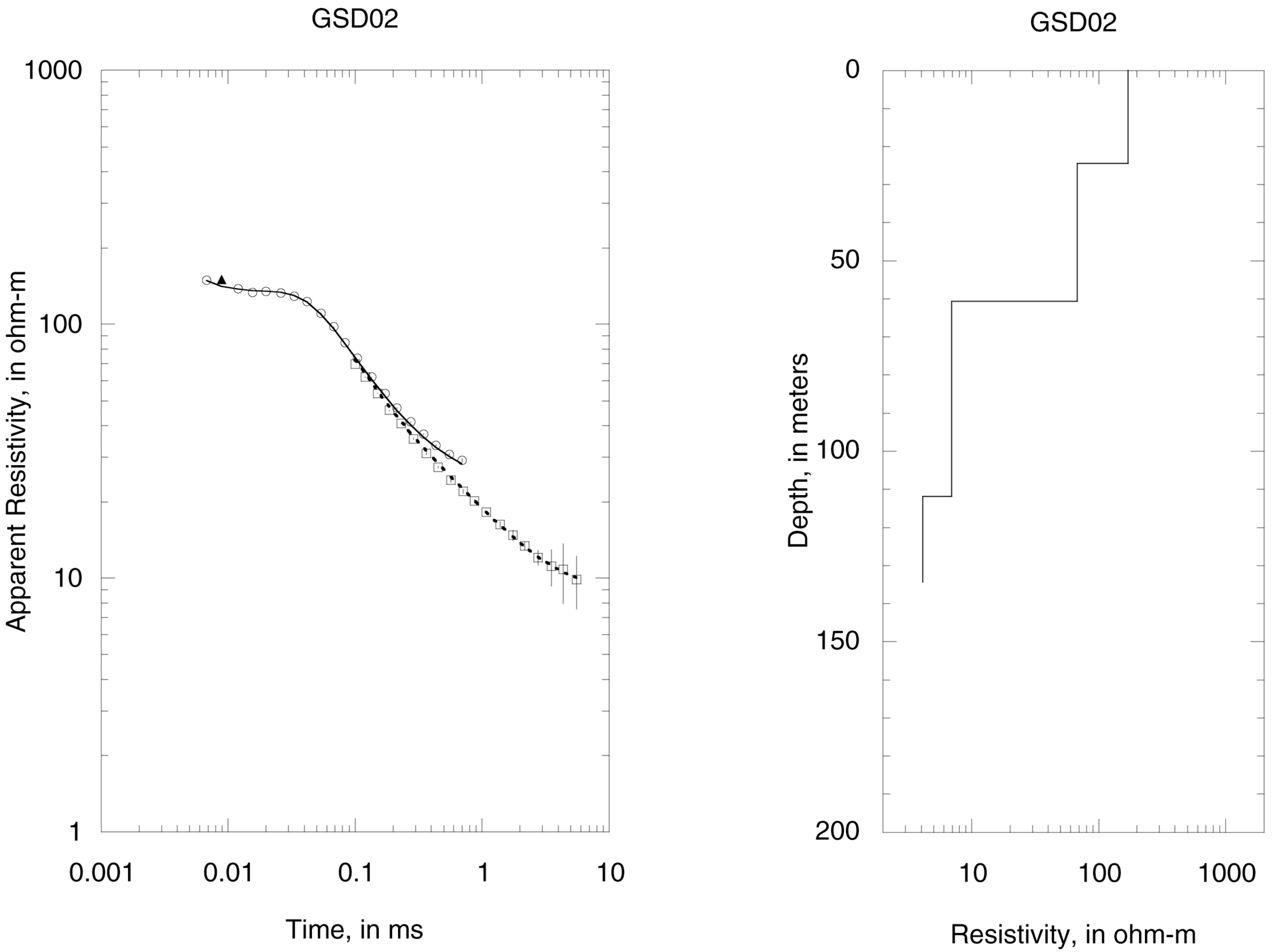


Figure E–2. Sounding GSD02

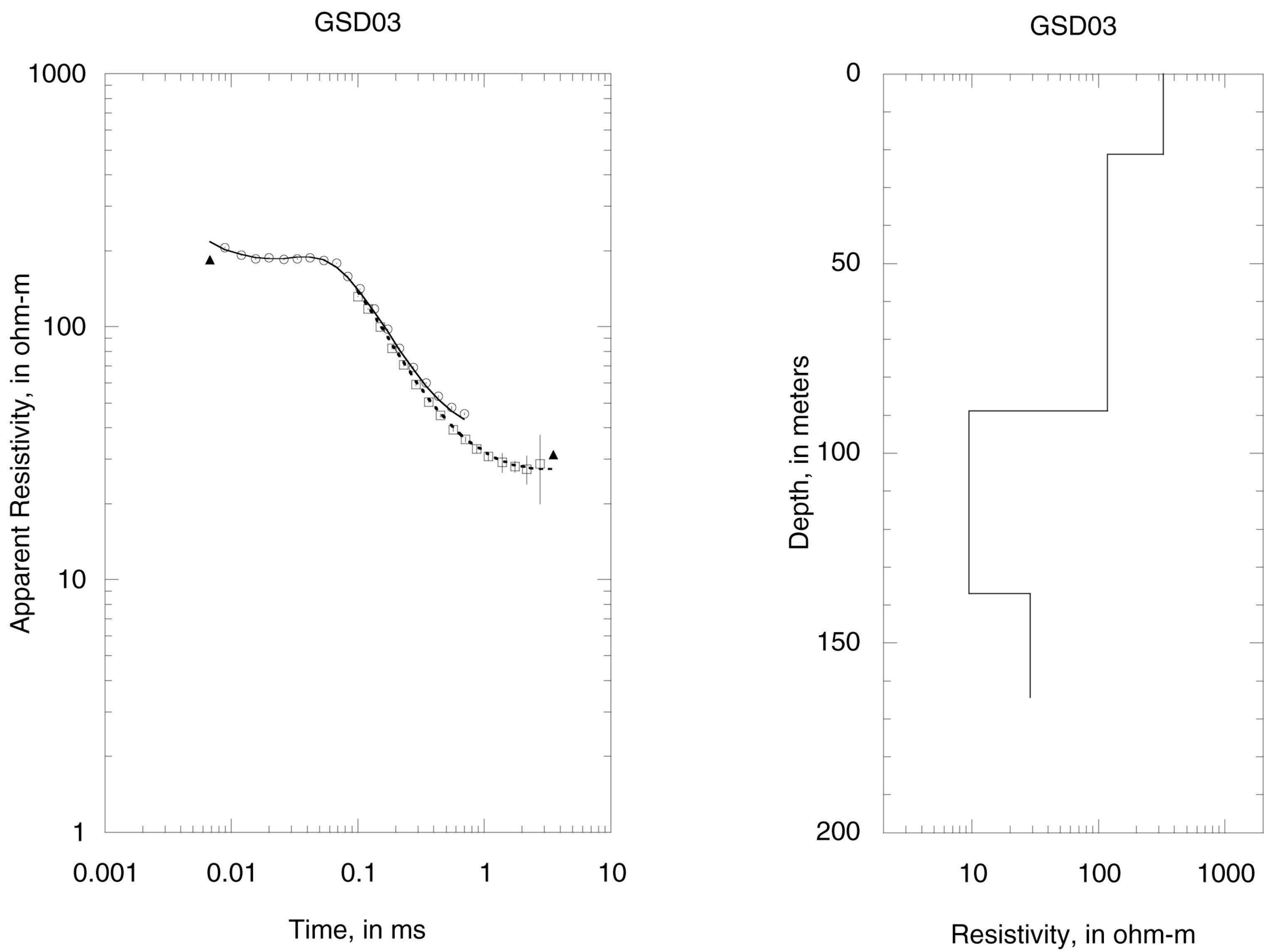


Figure E–3. Sounding GSD03

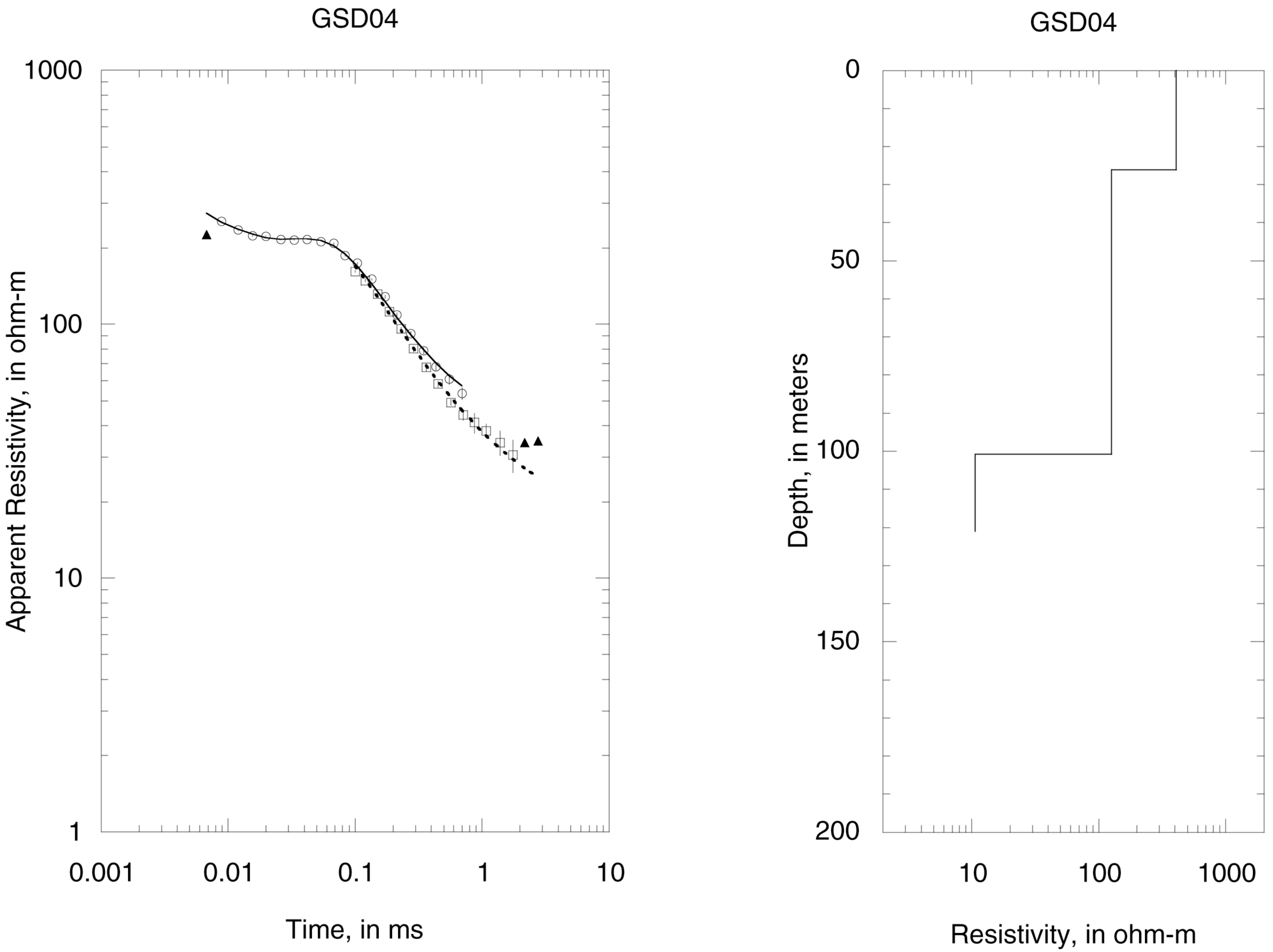
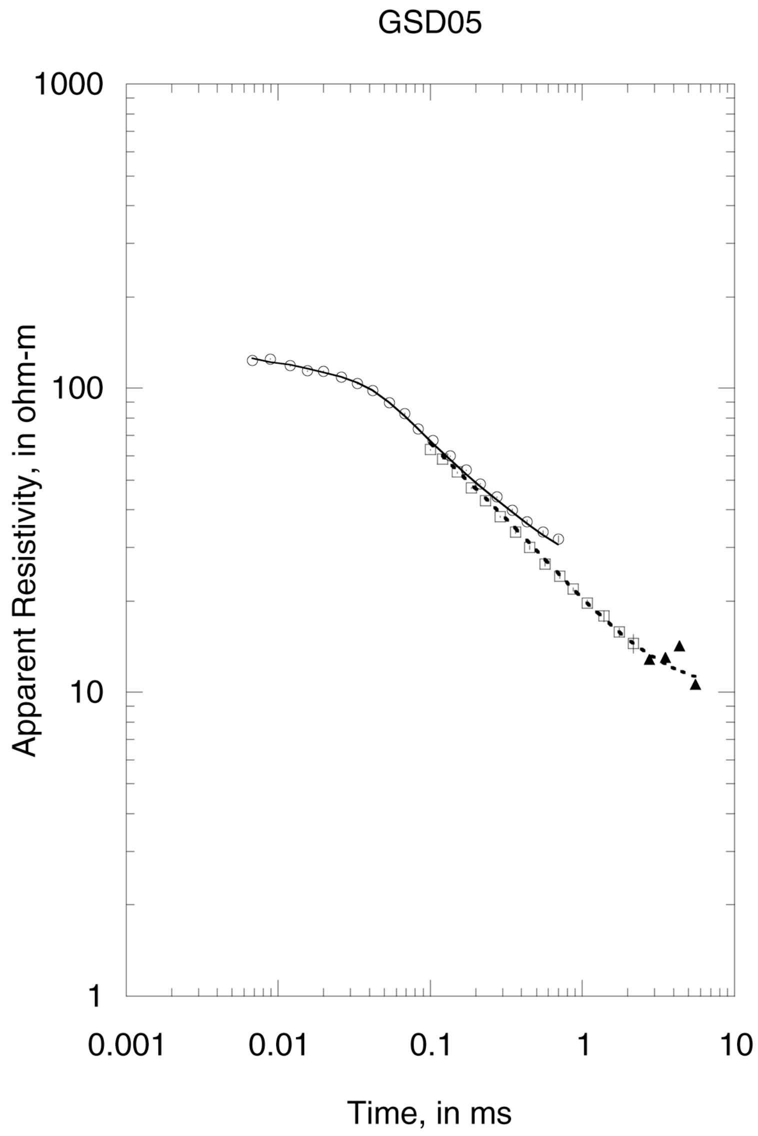


Figure E–4. Sounding GSD04



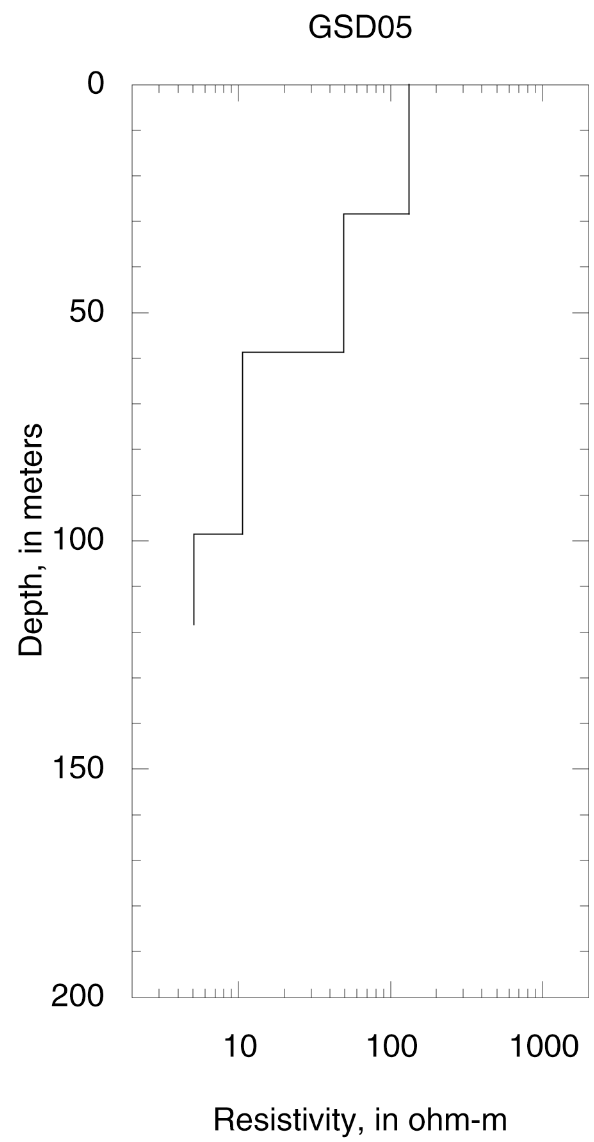


Figure E–5. Sounding GSD05

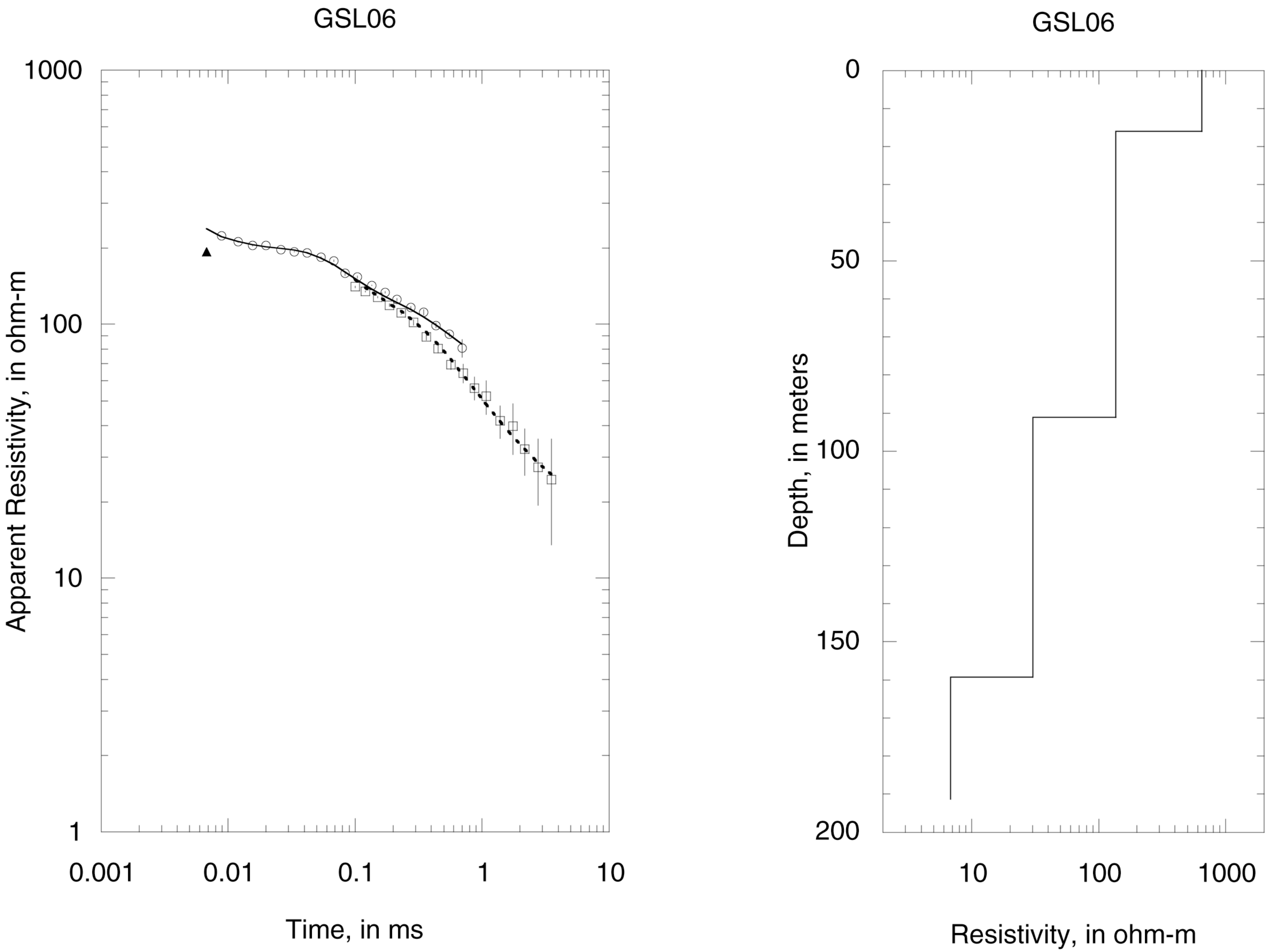


Figure E–6. Sounding GSD06 (GSL06)

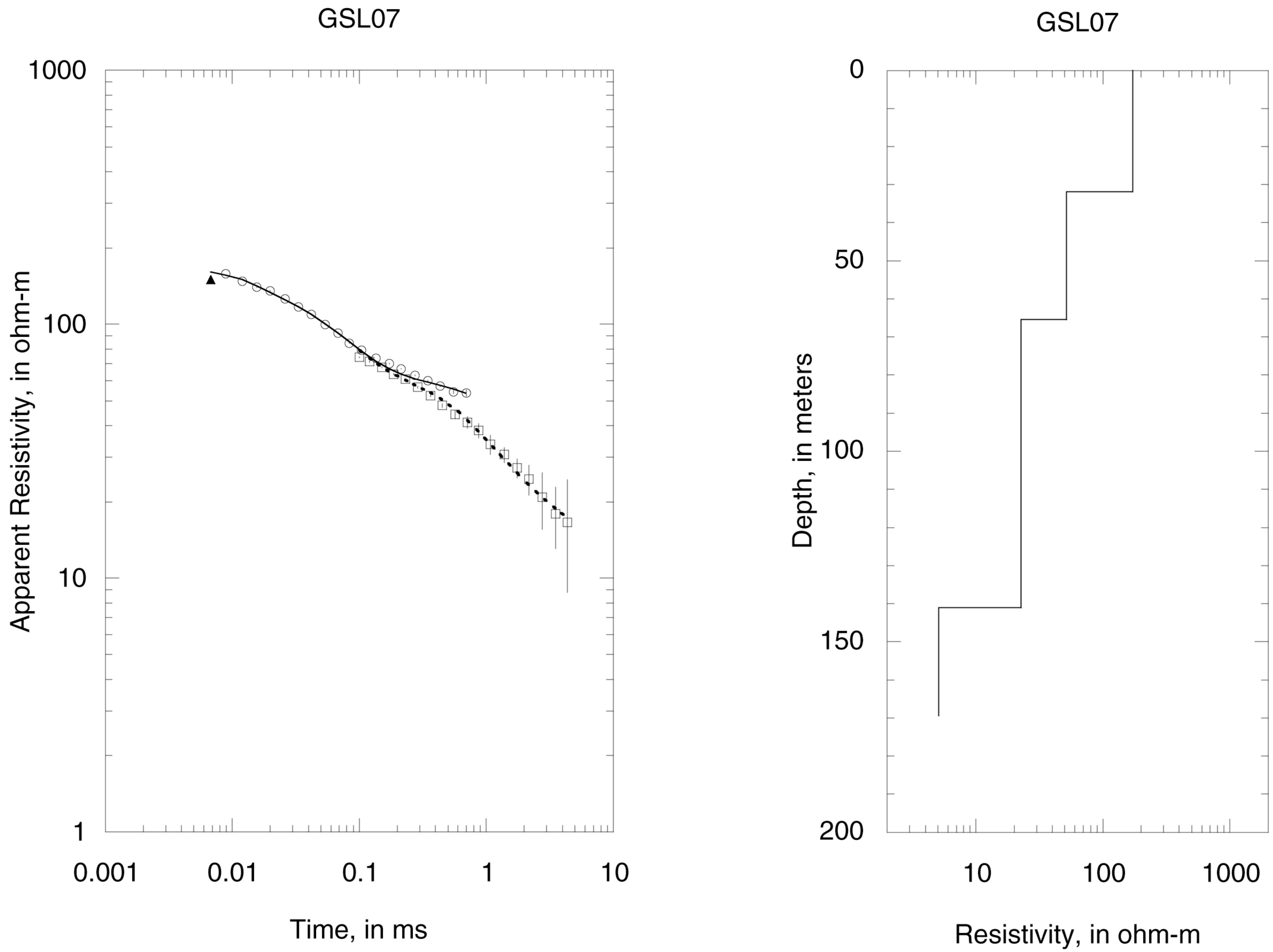


Figure E–7. Sounding GSD07 (GSL07)

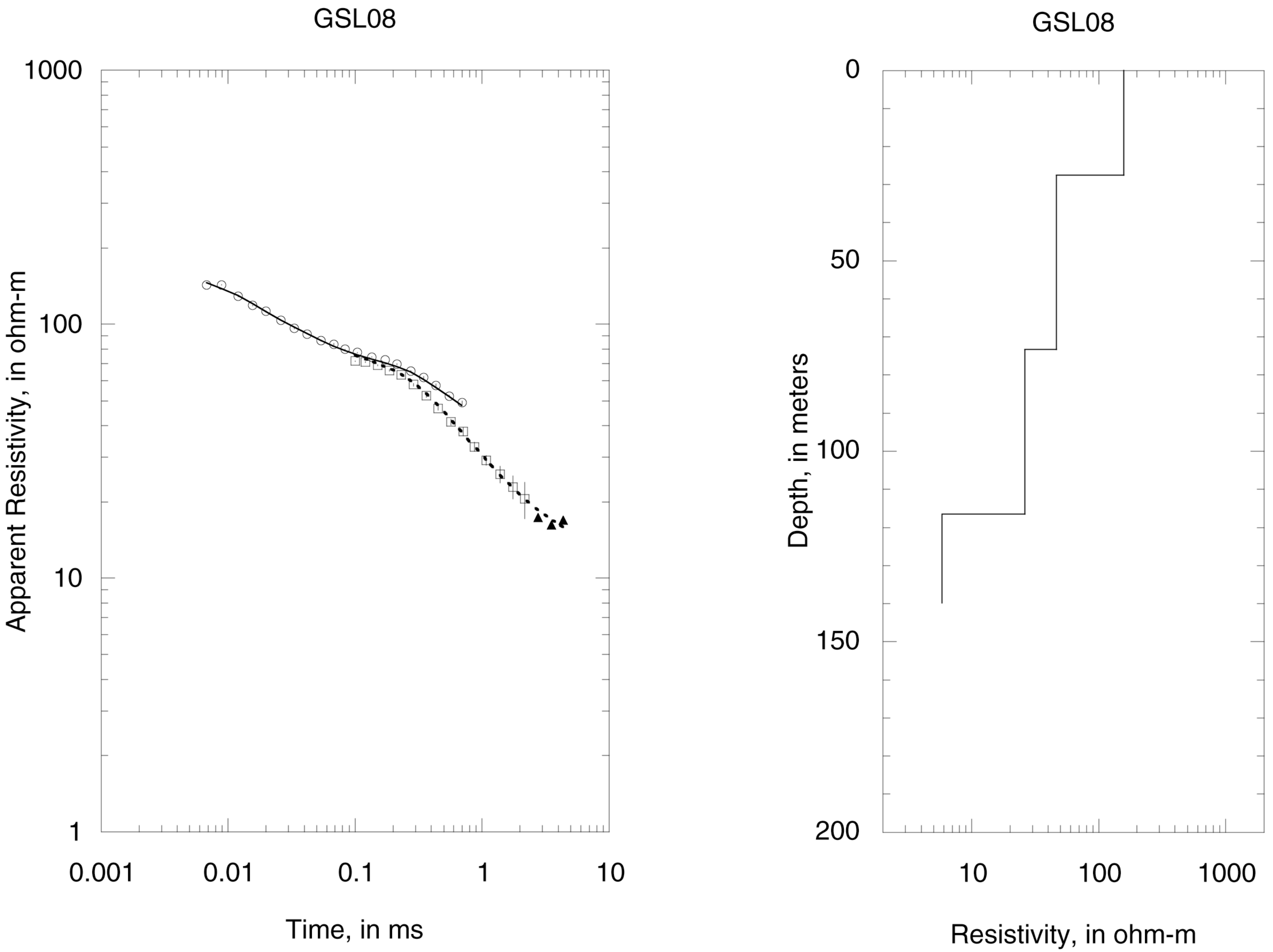


Figure E–8. Sounding GSD08 (GSL08)

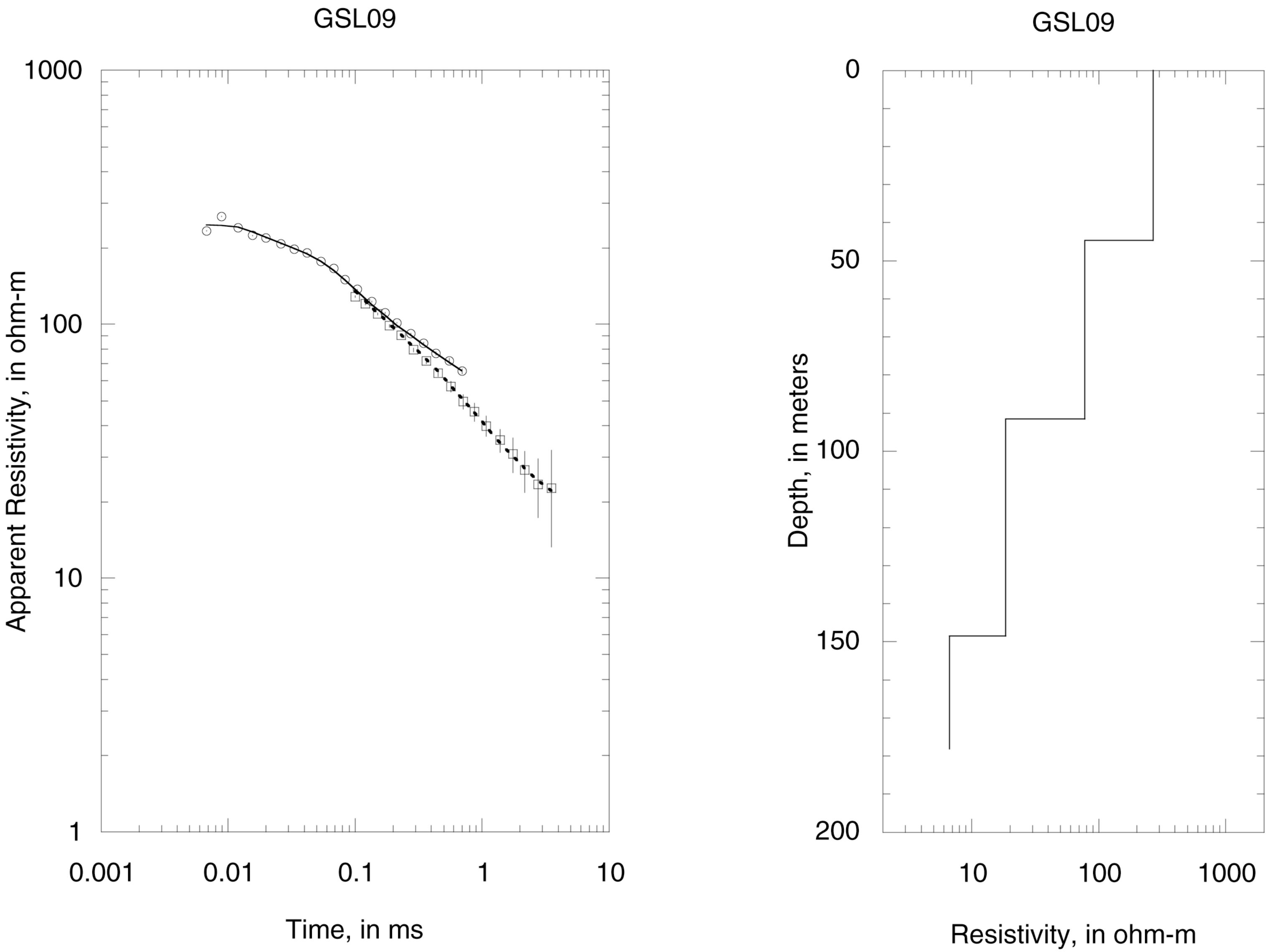


Figure E–9. Sounding GSD09 (GSL09)

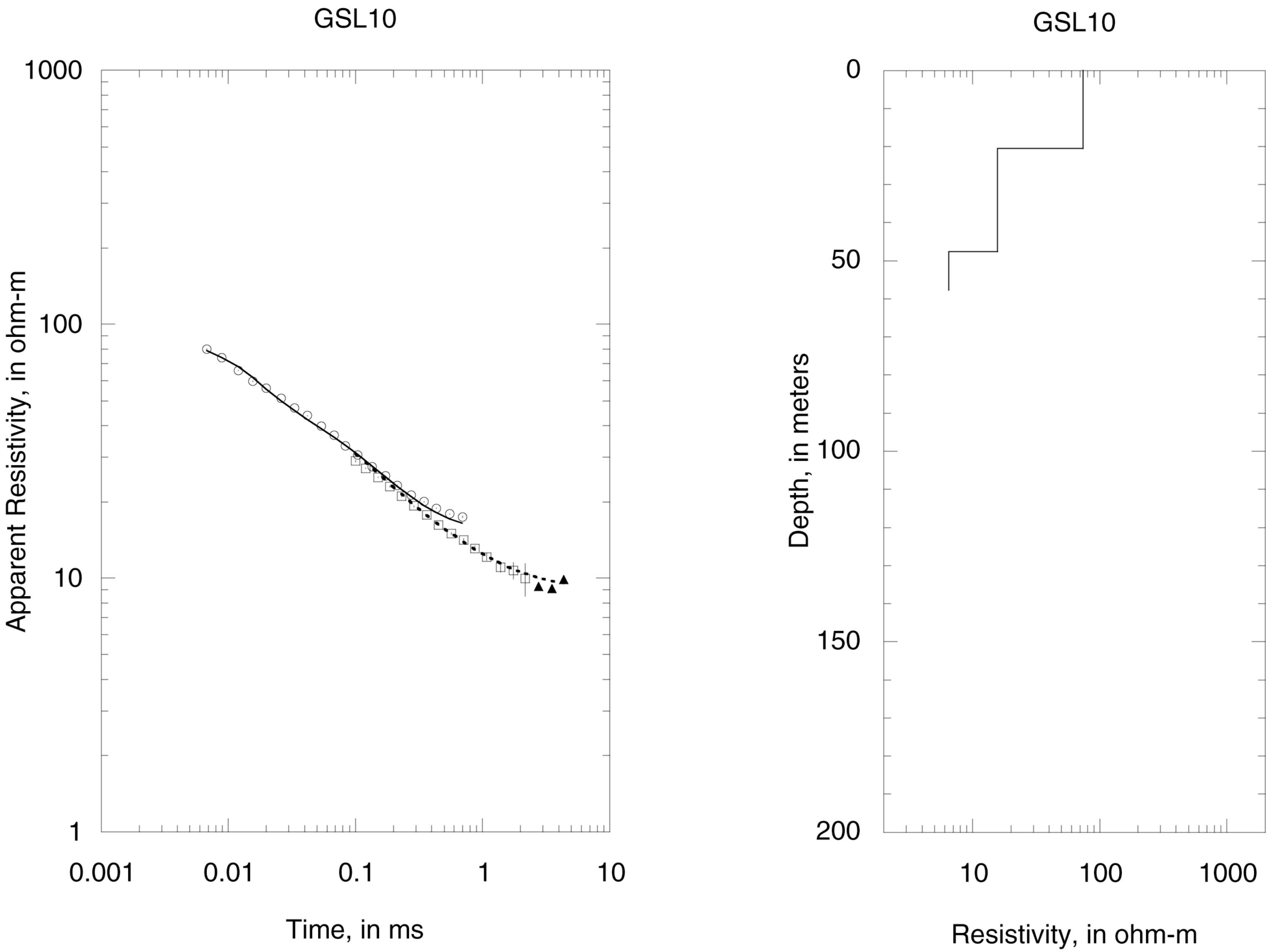
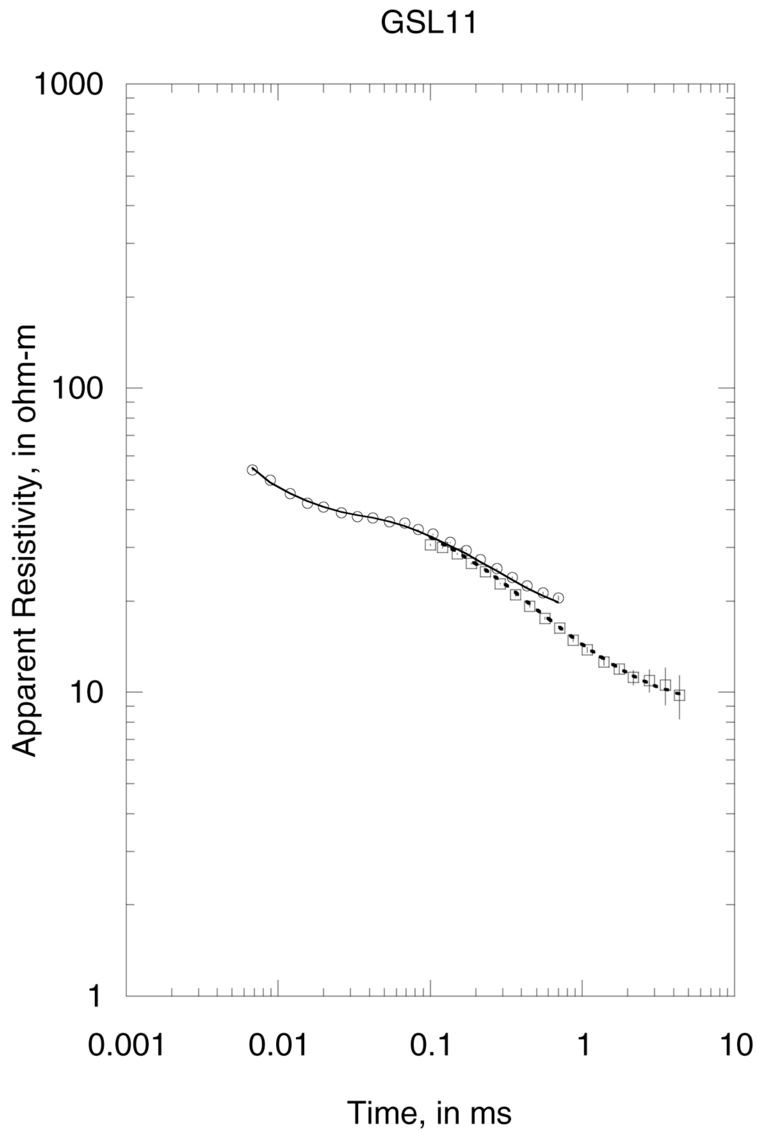


Figure E–10. Sounding GSD10 (GSL10)



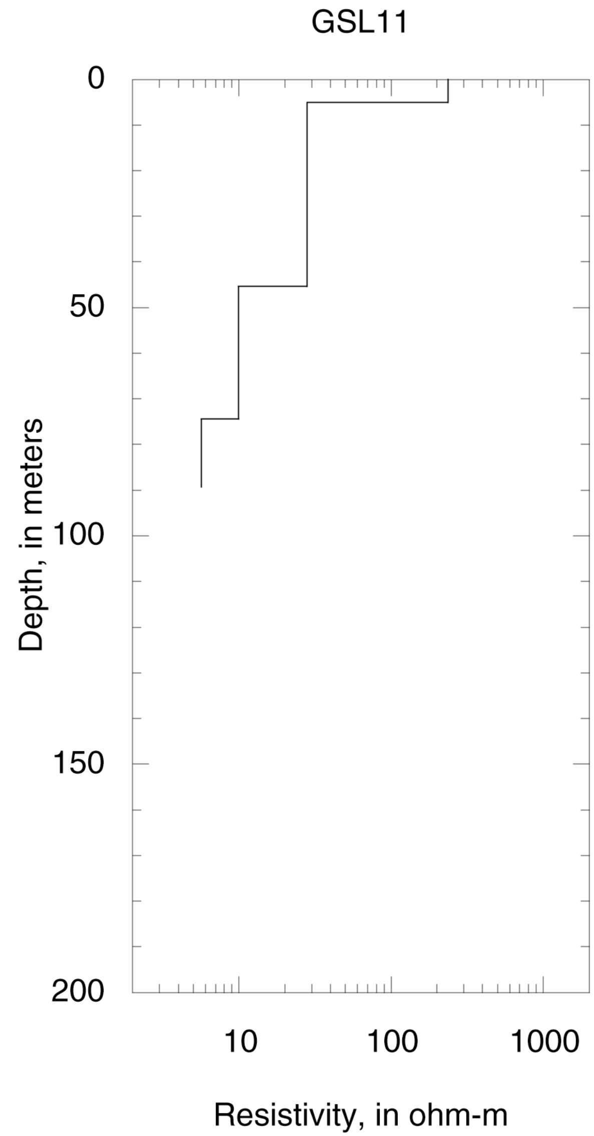
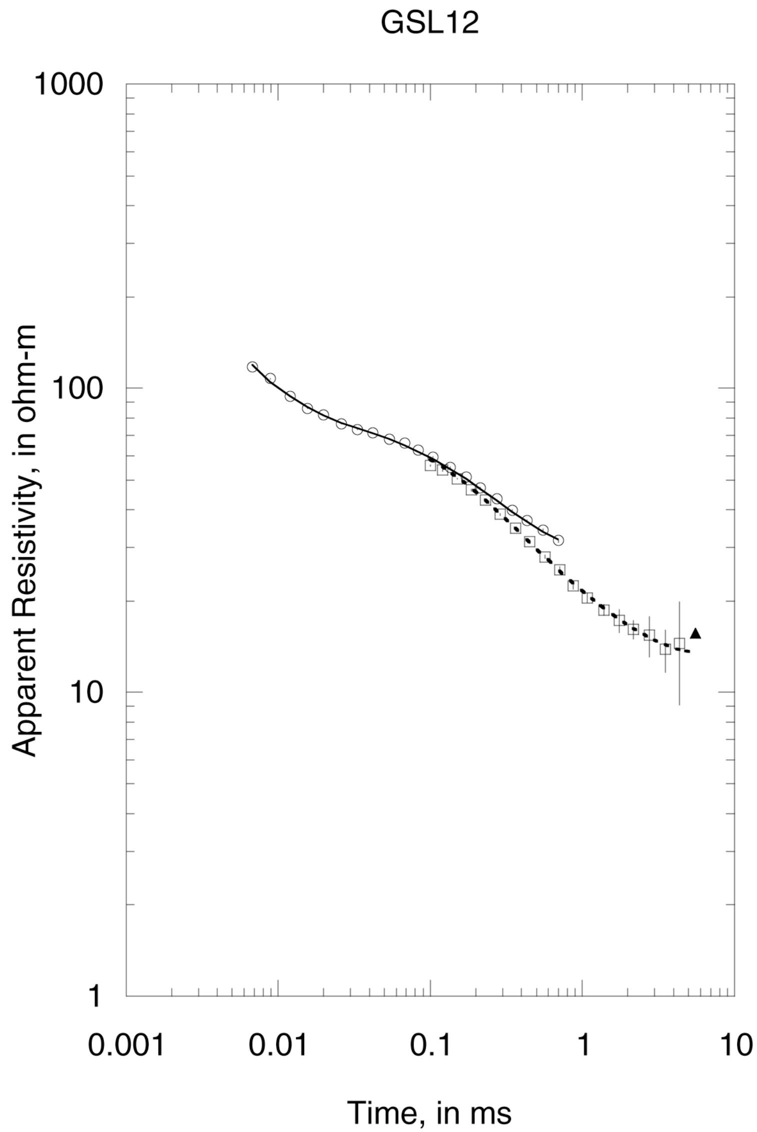


Figure E–11. Sounding GSD11 (GSL11)



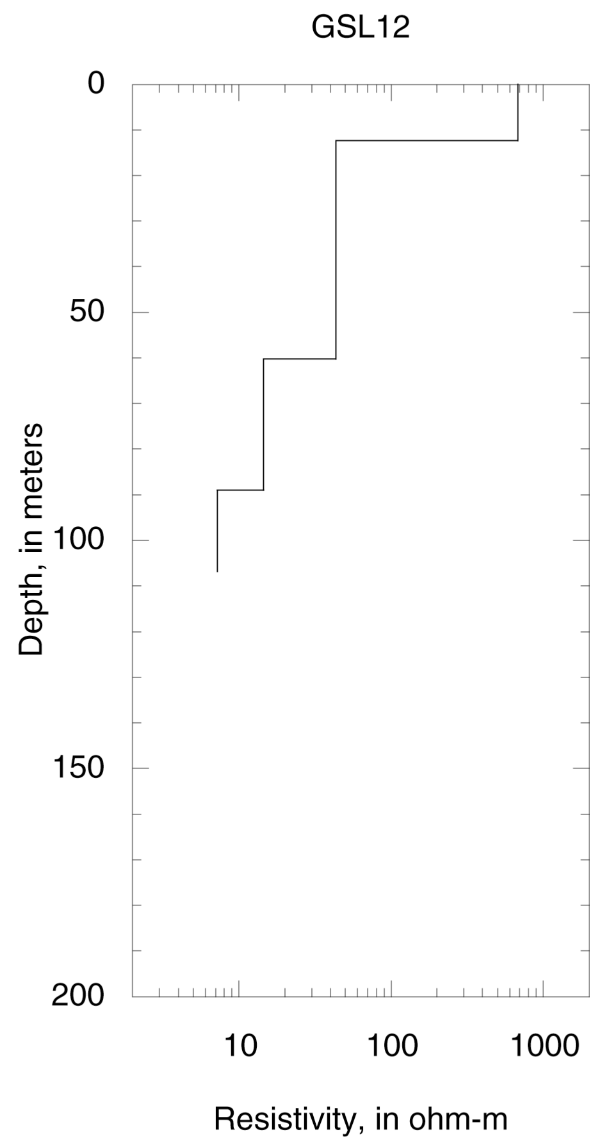


Figure E–12. Sounding GSD12 (GSL12)

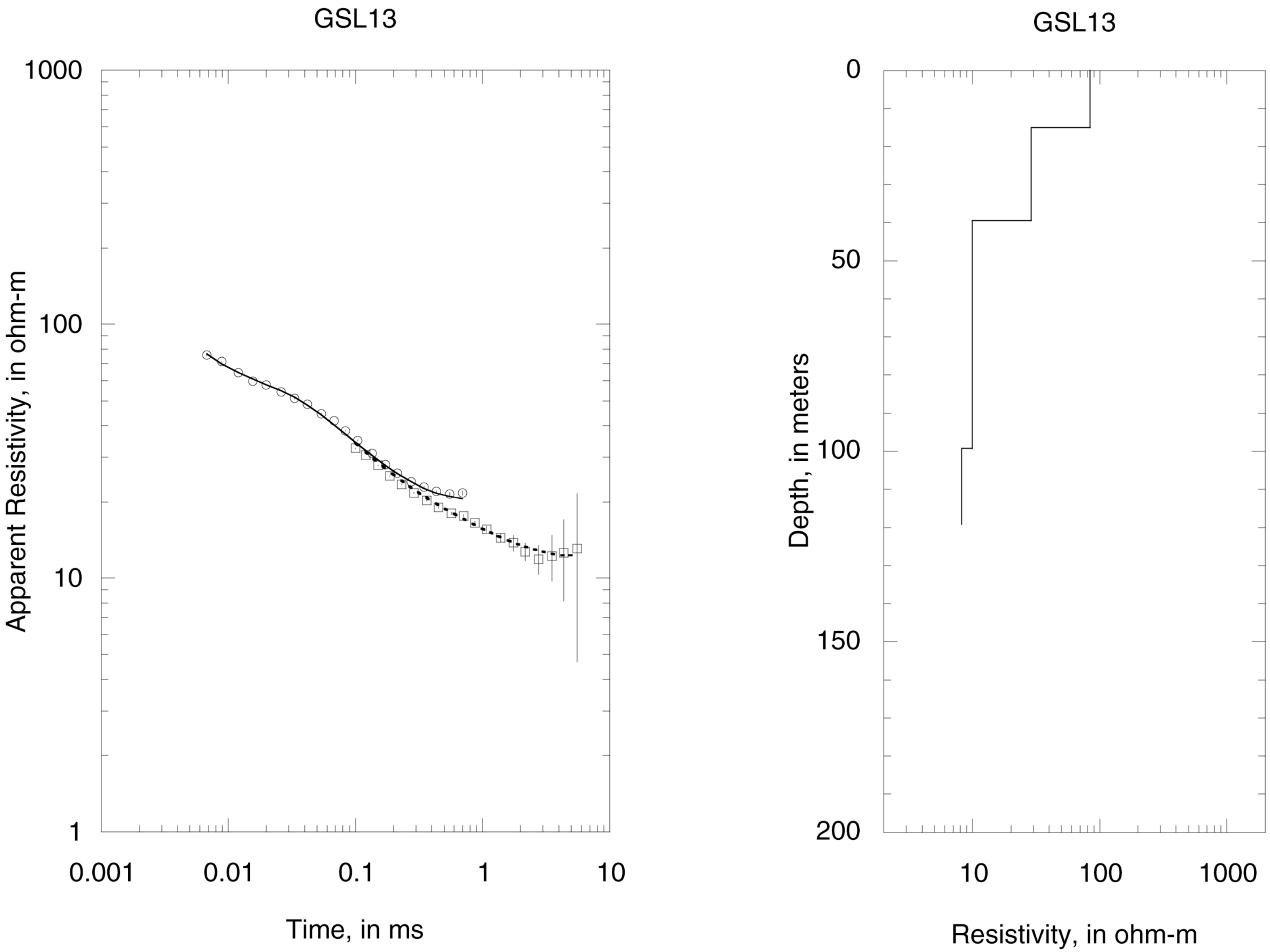


Figure E–13. Sounding GSD13 (GSL13)

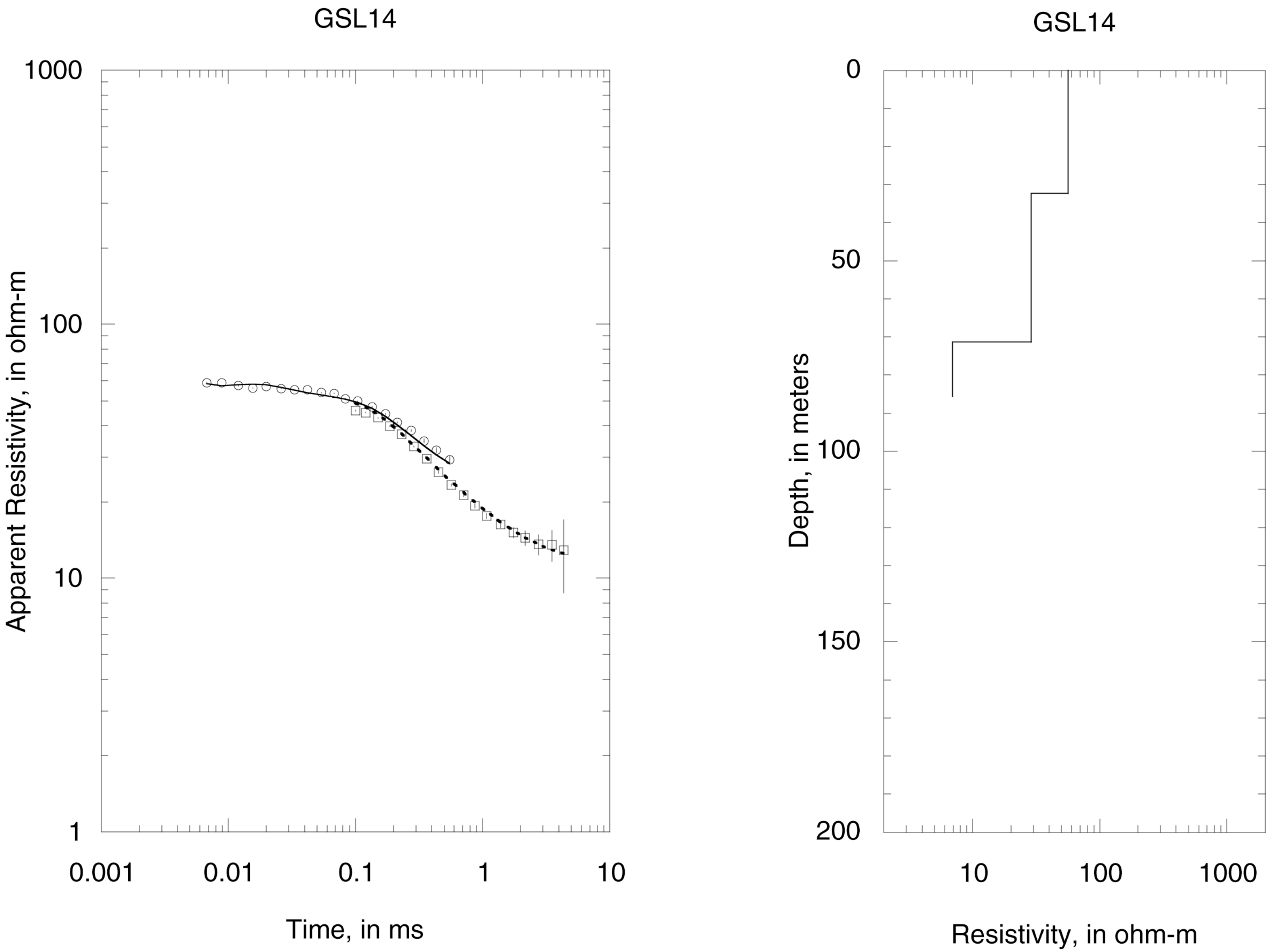


Figure E–14. Sounding GSD14 (GSL14)

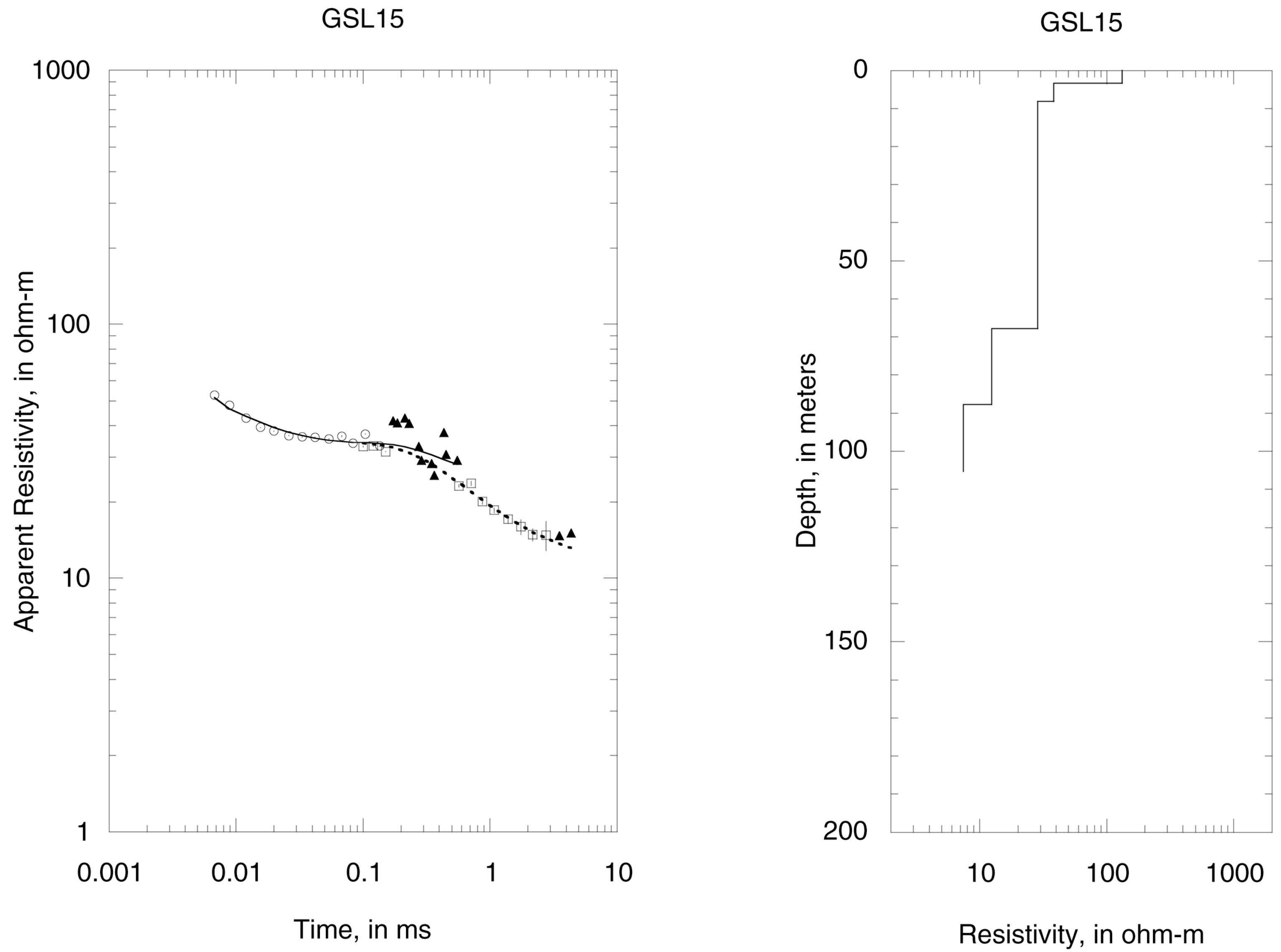
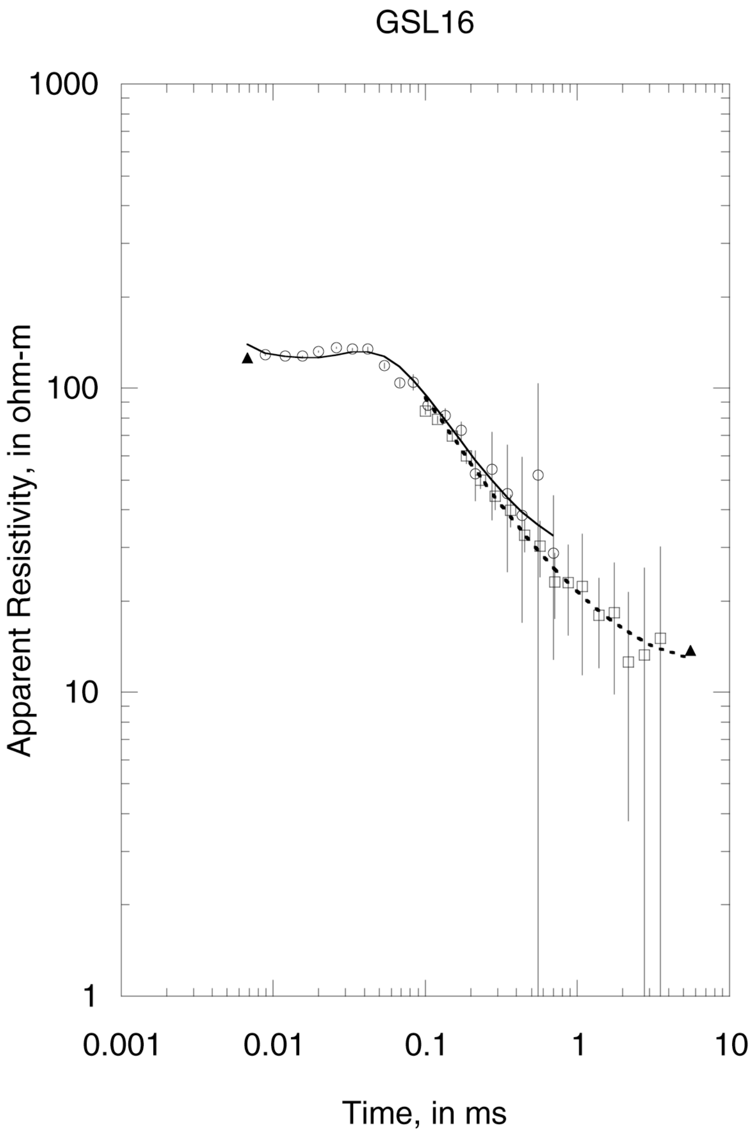


Figure E–15. Sounding GSD15 (GSL15)



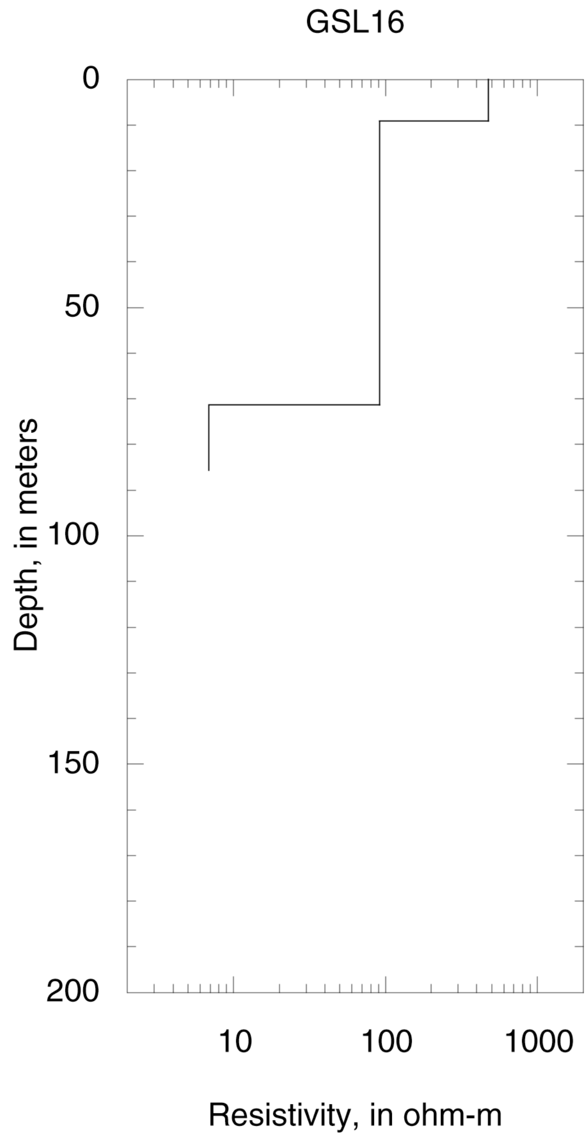


Figure E–16. Sounding GSD16 (GSL16)

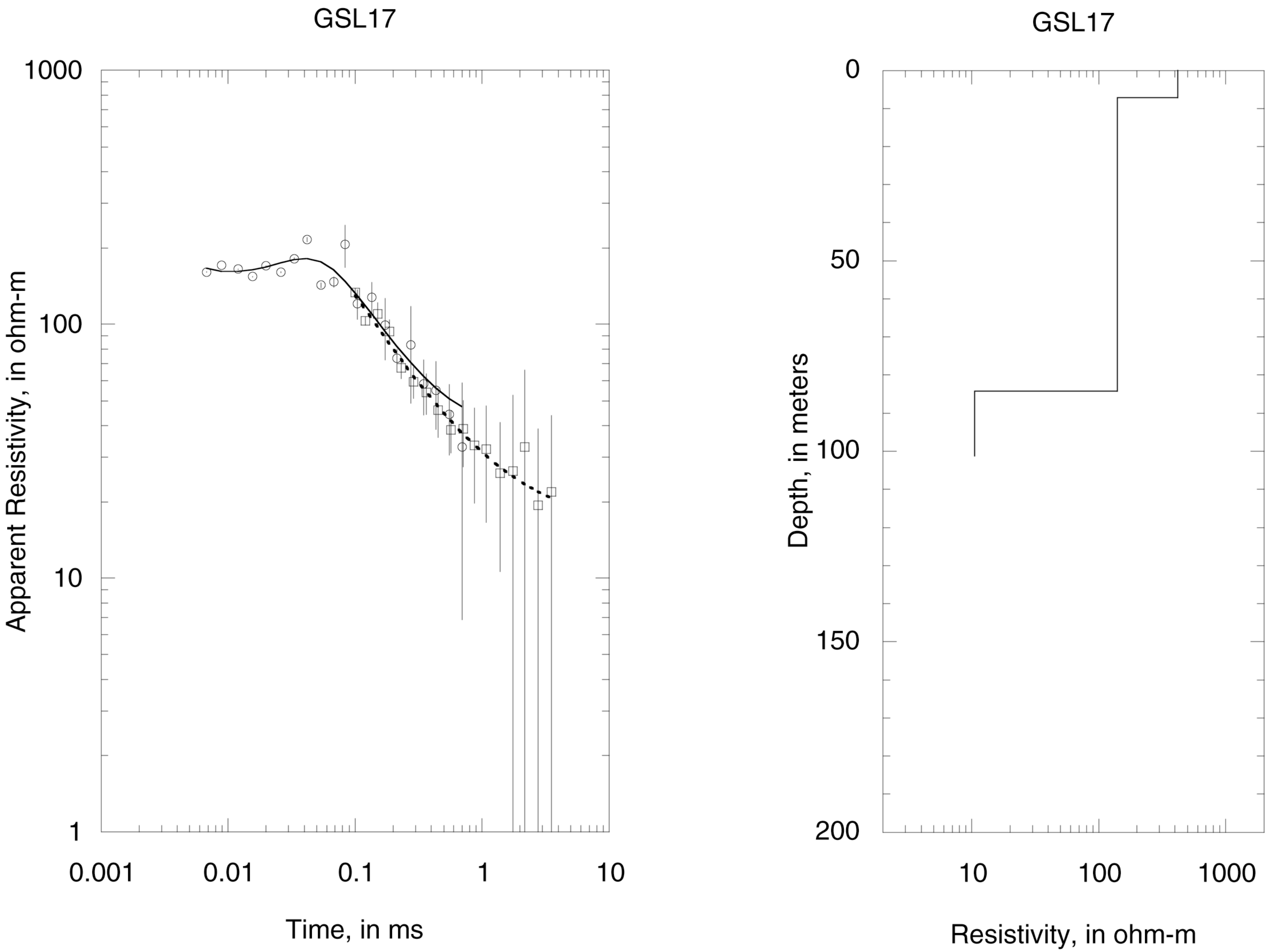


Figure E–17. Sounding GSD17 (GSL17)