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DC Resistivity Profiling in Mortandad, Ten Site and DP Canyons Los Alamos National Laboratory Los Alamos, NM

Geophex Job No. 1247

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Digital Data CD

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List of Acronyms

AGI ..... Advanced Geosciences, Inc.
bgs ..... Below ground surface
DC ..... Direct Current
DOE ..... U.S. Dept. of Energy
ERT ..... Electrical Resistance Tomography
ft ..... Feet
GPS ..... Global Positioning System
LANL ..... Los Alamos National Laboratory
RES ..... Two dimensional DC resistivity
RMS ..... Root Mean Square

List of Definitions[1]

conductivity: The ability of a material to conduct electrical current. In isotropic material, the reciprocal of resistivity. Sometimes called **specific conductance**. Units are siemens per meter.

dipole-dipole array: Inline electrode array used in induced polarization, electrical, and electromagnetic surveying, where both current and potential-measuring electrodes are closely spaced.

ohm-meter: A unit of resistivity, also written ohm-meter2/meter; the resistance of a meter cube to the flow of current between opposite faces. Reciprocal of mho/m

Permeability: A measure of the ease with which a fluid can pass through the pore spaces of a formation.

Porosity; Pore volume per unit gross volume. Effective porosity is the porosity available to free fluids, excluding unconnected porosity and space occupied by bound water and disseminated clay.

RMS Error: The square root of the average of the squares of the differences between a series of n measurements m and their mean. Also called the standard deviation.

[1] Sheriff, Robert E. *Encyclopedic Dictionary of Applied Geophysics.* Tulsa, Oklahoma : Society of Exploration Geophysicists, 2002.

Executive Summary
From December 5, 2003 to December12, 2003, Geophex performed DC resistivity surveys within Upper Mortandad, Ten Site, and DP Canyons at the Los Alamos National Laboratory, New Mexico. The purpose of these surveys was to assist in efforts to characterize the groundwater conditions at LANL and provide potential sites for future monitoring wells.

Combined with 2002 resistivity data collected in Mortandad Canyon, these profiles identify "moist" zones in the alluvium and upper Bandelier Tuff. Further, areas were interpreted to be "wet" or clay-rich fracture zones that may provide pathways for groundwater to reach depth. Six more areas are identified in the 2003 Mortandad Canyon resistivity data. DP Canyon resistivity data highlight the *in situ* porosity/permeability state where shallow groundwater is present. The DP Canyon profiles confirmed areas of known saturation and showed some potential variations in physical properties in the upper bedrock unit underlying alluvium.

Included in this deliverable is a letter report and data package containing both electronic and hard copies of the geophysical data collected at the site.

1.0 Introduction

From December 5th through December 12th, Geophex personnel performed DC resistivity profiling within upper Mortandad, Ten site and DP Canyons at Los Alamos National Laboratory, NM. The purpose of this survey was to add to 2002 resistivity data collected in lower Mortandad Canyon. In the 2002 survey, resistivity data provided images of the porosity state and interpretations of potential permeability pathways within the upper 200 feet. In 2003, the upper Mortandad survey surrounds the source of laboratory effluent and attempts to illuminate the porosity and/or permeability resulting from this outflow to the start of the 2002 survey. All these data will be combined with data from planned borehole studies to understand how the conductivity data relates to moisture and porosity distributions. Resistivity data in Ten Site Canyon intersect the 2002 data from lower Mortandad and add to this earlier survey. Although DP Canyon is not directly connected to the Mortandad Canyon system, these data were collected to assist in an active remediation project by providing information about the subsurface porosity/permeability state between known boreholes. In total, data collection consisted of 9976 linear feet (1.9 miles) of resistivity data from two survey lines in upper Mortandad Canyon, two survey lines in Ten Site Canyon, and three survey lines within DP Canyon. Both resistivity profiles acquired in Mortandad Canyon were acquired down the axis of the canyon. In Ten Site Canyon, one profile was collected down the axis of the canyon and the other was a cross-canyon profile. DP Canyon data consisted of one axial profile with two intersecting cross-canyon profiles.

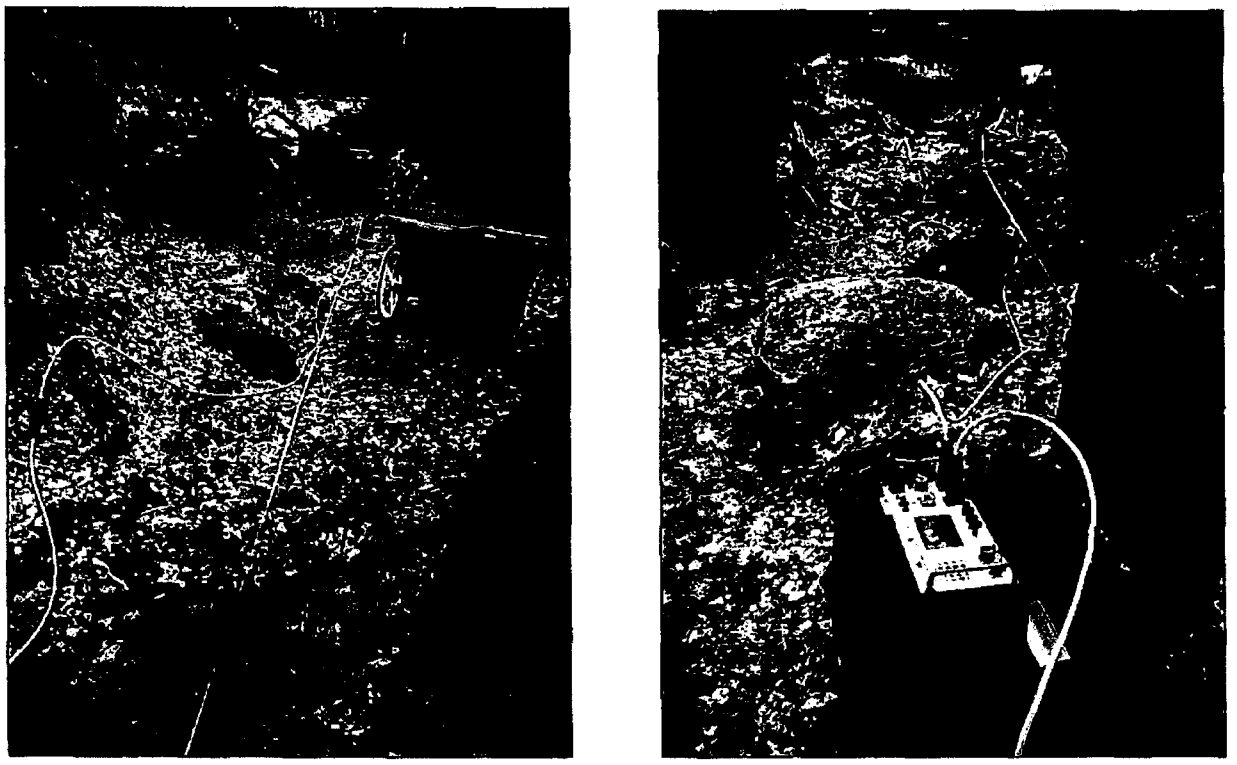


Figure 1. Views of resistivity profiling within upper Mortandad Canyon 2003

Table 1 provides a summary of the geophysical survey line designations and locations shown in Figure 2 and Plate 1.

Table 1 Resistivity Profiles in Mortandad, Ten Site, and DP Canyons

Profile Name	Acq Direction	# of Deployments/Type	Start Location*	End Location*	Total distance (ft)	Raw Data Files
Line MC03-1	West-East	1-56 electrodes-4m/13.1ft	N-1770188.0	N-1770159.9	721.6	MC03R1
		Dipole-dipole	E-1625469.0	E-1626170.1		
Line MC03-2	West-East	9-56 electrodes-5m/16.4ft	N-1770223.0	N-1769714.3	5904.0	MC03R2A
		Dipole-dipole	E-1626527.3	E-1631953.7		MC03R2B
						MC03R2C
						MC03R2D
						MC03R2E
						MC03R2F
						MC03R2G
						MC03R2H
						MC03R2I
Line TS-1	West-East	2-56 electrodes-5m/16.4ft	N-1768561.1	N-1768597.6	1558.0	TS03R1A
		Dipole-dipole	E-1632770.8	E-1634247.1		TS03R1B
Line TS-2	South-North	1-56 electrodes-3.5m/11.5ft	N-1768370.4	N-1768994.4	631.4	TS03R2
		Dipole-dipole	E-1633657.1	E-1633709.7		
Line DP-1	West-East	3-56 electrodes-2m/6.6ft	N-1774870.0	N-1774689.1	806.9	DP03R1A
		Dipole-dipole	E-1633335.2	E-1634108.8		DP03R1B
						DP03R1C
Line DP-2	South-North	1-28 electrodes-2m/6.6ft	N-1774648.8	N-1774821.4	177.1	DP03R2
		Dipole-dipole	E-1633958.7	E-1633985.9		
Line DP-3	South-North	1-28 electrodes-2m/6.6ft	N-1774710.2	N-1774886.8	177.1	DP03R3
		Dipole-dipole	E-1633592.6	E-1633592.3		

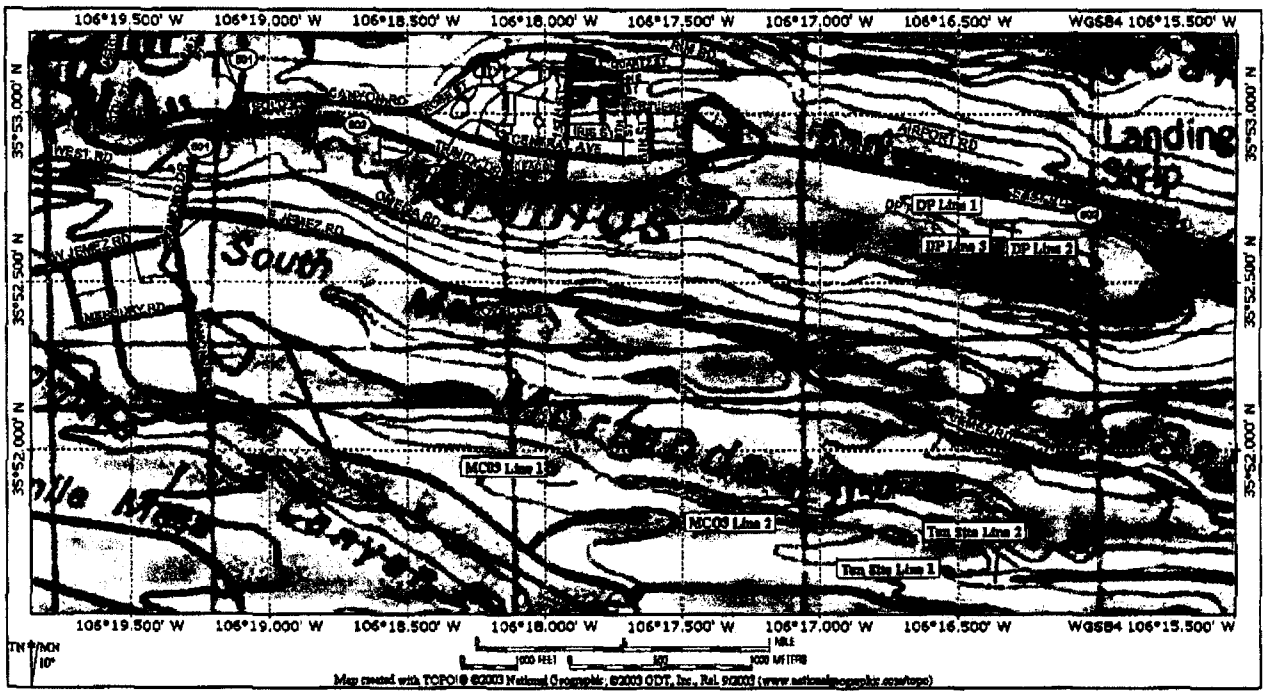


Figure 2. Generalized site map for 2003 LANL DC resistivity surveying

2.0 Methods

2.1 Resistivity

Resistivity (RES) data were collected using an AGI SuperSting R8 IP Earth Resistivity/IP Meter, with a 56-electrode cable (Figure 3). Electrodes were connected to a stainless steel stake with a rubber band and planted in the ground (Figure 4). Prior to acquiring data, a contact resistance check was conducted to verify each electrode was ready to acquire data. To reduce contact resistances, electrodes were treated with salt water prior to the resistance test and data acquisition. All data were acquired using dipole-dipole geometry.

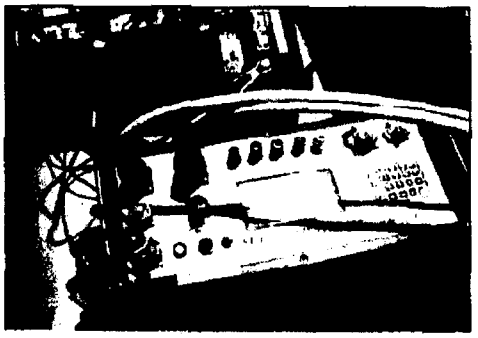


Figure 3. AGI SuperSting R8IP Resistivity Meter

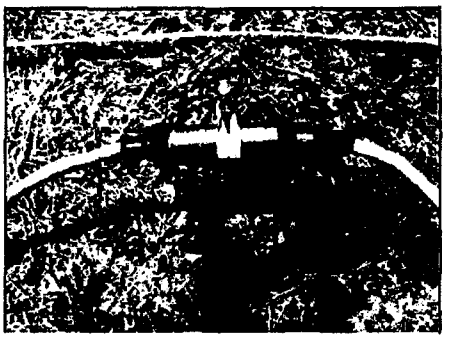


Figure 4. SuperSting electrode attached to stake

Resistivity data map variations in subsurface electrical resistivity. The electrical resistivity of any portion of the earth is related to various geologic parameters such as mineralogy, fluid content, and degree of water saturation. In environmental surveys with relatively shallow water tables, resistivity values are governed primarily by soil water content. Low electrical resistivity values correspond to high *in situ* bulk porosity and permeability, rather than to lithology directly. For example, a dry (above the water table), well-sorted sand will be highly resistive while the same sand below the water table will have a high bulk porosity and may represent a permeability pathway (if conditions allow) and have a low or very low resistivity.

Data were transferred from the SuperSting to a PC off site. Each profile was edited and processed with RES2DINV© software (Geoelectric Imaging, Inc.). Data processing consists of: 1) entering the elevations, 2) editing of any outlying data points, 3) combining individual acquisition deployments for long profile lines, 4) a final inversion with RES2DINV©, 5) inversion results are transferred to ASCII "XYZ" files, and 6) these files are imported into Oasis Montaj© software (Geosoft, Inc.) for gridding and display.

Processed Resistivity profiles are shown in Appendices A-C.

2.2 Surveying/Locations

All geophysical survey grids and profiles were surveyed using a Trimble Pro XR Global Positioning System (GPS). GPS data were post processed using Trimble Pathfinder Office (v. 2.90). All data was rectified to New Mexico State Plane (Central) Coordinates (NAD 1983, Conus). Relative elevations along resistivity lines were recorded in the field using a hand level. These elevations were corrected to sea level using ground surface elevations from existing monitoring wells, provided by LANL.

3.0 Results

Due to the similarity of the resistivity data collected in 2003, the results of the resistivity data from 2002 are reiterated below. The general findings in the 2002 Mortandad Canyon survey were also observed in the 2003 data of Mortandad and Ten Site Canyons. To aid all observations in Mortandad and Ten Site Canyon, the same color scale used to present the 2002 data was chosen for the 2003 data. Due to the shallow groundwater and monitoring information available in DP Canyon near the surface, these data are sufficiently different than Mortandad & Ten Site Canyons and are discussed separately.

3.1 2002 Mortandad Canyon Resistivity Results

The following are the resistivity results stated in 2002. The generalities of these data correlate to the 2003 Mortandad and Ten Site Canyons data sets.

- Various zones are inferred to be "moist". It is interpreted that these zones are partially saturated and appear as low resistivity (blue colors) in Appendix A, and Plates 2 and 4.
- These "moist" zones (i.e., low resistivity) correspond to moisture weight percent data that is superimposed on the profile. Therefore, resistivity is interpreted to be mapping current sediment moisture. However, it is assumed that these zones would indicate the preferential groundwater flow pathways during any recharge event.
- High resistivities (red/pink colors) are inferred to be either "dry" unconsolidated sediments or "dry" bedrock (i.e., upper portions of the Tshirege Member of the Bandelier Tuff). Gamma logs were placed on the resistivity data to aid in the determination between the two. It is presumed that high resistivity zones in the deeper parts of the profiles (> 50 ft. bsl) represent bedrock. The transition from red to pink colors indicates zones decreasing moisture content (i.e. "dry" zones) within that volume of bedrock.
- "Dry" bedrock is not uniform in elevation or across the deeper parts of the profiles. Vertical zones of low resistivity extend to depth in certain areas. These are interpreted to be either "moist" or clay-rich fracture zones within the bedrock or effects of the resistivity line being too close (< 30 ft.) from a cased monitoring well with bentonite grout. The later can be eliminated in many cases by referring to an attached spreadsheet listing Mortandad Canyon wells and their offsets from the resistivity profiles (Appendix D).
- On Line 1, the majority of low resistivity zones at depth occur between the intersections of Line 4 and 8.
- Cross canyon profiles (Lines 3-9) highlight low resistivity on the southern edge of the canyon. The "moist" zone tends to begin shallow and progressively go deeper towards the center of the canyon.

3.2 2003 Upper Mortandad Canyon Resistivity Results

As in 2002, the low resistivity zones that extend to depth are of interest as possible indications of vertical pathways for meteoric water. 2003 Mortandad Canyon Line 1 (MCO3-1) was collected above and adjacent to the effluent pipe for the Laboratory's radioactive liquid waste treatment facility at TA-50. In this line, two areas display low resistivity zones that extend greater than 50 ft bgs (i.e. between 225-260 ft and 540-580 ft). The bedrock tuff is shallow and generally found above 650 ohm-m. The gap between MCO3-1 and 2003 Mortandad Canyon Line 2 (MCO3-2) is ~360 ft due to the rough terrain present downstream of the effluent pipe. In MCO3-2, more zones of low resistivity at depth are observed. On this figure (Appendix A), the locations of these areas are identified in NM Central state plane coordinates. Generally, the number of these anomalies and the nature of the surrounding bedrock is different between 0-3500 ft and 3500-5900 ft (as measured along the profile). From 0-3500 ft, two zones of low resistivity are identified within a more uniform high resistivity bedrock. From 3500-5900 ft, six zones of low resistivity are identified within a bedrock that is more variable laterally. This characteristic continues further down Mortandad Canyon as seen in Line 1 of the 2002 data and the 2003 data of Ten Site Canyon. Therefore, it is interpreted that a change in the nature or character of the bedrock occurs at the 3500 ft. location.

3.3 2003 Ten Site Canyon Resistivity Results

The character of resistivity data collected on the two profiles of Ten Site Canyon is similar to that observed in the eastern half of the 2003 Mortandad Canyon as previously discussed. With respect to zones of low resistivities extending to depth, three areas are observed on Ten Site Line 1 (TS03-1). The first area (~ 225-280ft) lies within Ten Site Canyon proper. The other two areas (~ 1000-1050 ft and 1125-1275 ft) lie east of the mouth of Ten Site Canyon within Mortandad Canyon near MCWB 6.5D, MCWB 6.6D and MCOBT-4.4. On TS03-1, the mouth of Ten Site Canyon highlights high resistivity near the surface. Along this profile, it appears that near surface groundwater connectivity would be difficult. It is noteworthy that TS03-1 (800-1550 ft along profile) is comparable to 2002 Mortandad Line 1 from ~1800-2600 ft. since they both lie within Mortandad Canyon. Ten Site Line 2 (TS03-2) is oriented south to north across the mouth of Ten Site Canyon and intersects TS03-1, 2002-Line4, and 2002-Line 1 within Mortandad Canyon. Since the electrode spacing is 5 ft less than other profiles, the total depth of the image is less than TS03-1 but slightly greater than 2002-Line 4. As with the 2002 cross-canyon lines, TS03-2 displays low resistivity in the Ten Site Canyon that appears unable to connect to similar zones to the north. The center of TS03-2 represents a zone that has lower resistivities at depth. In 2002, this area was the beginning of a large section of Mortandad Canyon that was observed to have low resistivity at depth. It is interpreted that the center of TS03-2 is reflecting that section.

3.4 2003 DP Canyon Resistivity Results

The purpose of the resistivity survey in DP Canyon was to assist in the characterization of the groundwater conditions and assessment of groundwater flow paths at the site. DP Canyon is different than Mortandad and Ten Site Canyon in two important ways: 1) the groundwater level is close to the surface, and 2) the bedrock surface is very close to the surface.

The DP Canyon axial profile Line 1 (DP-1) illustrates low resistivity near surface (< 100 ohm-m) that quickly grades to high resistivities > 800 ohm-m. The color scale utilized in these data was adjusted compared to Mortandad and Ten Site Canyon due to groundwater elevation information taken in December 2003 and weathered tuff elevations from monitoring wells within 20 feet of the resistivity line. These wells and the relevant elevations are displayed on the profile figures in Appendix C. Due to the scales of the figures, this information is easiest seen on the figures for DP Canyon Lines 2 and 3 (DP-2 and DP-3). At DPPN-7.7, DPPN-4.5N and DPW-4.6D, the depth between the groundwater elevation and the top of the weathered tuff precisely delineates the lowest resistivities observed in the data set (< 60 ohm-m). It is interesting to note that Line 2 was acquired during a hard rain but the stream channel was dry. At the start and throughout the entire acquisition of Line 3, a flash flood event filled the stream channel. Interestingly, no significant differences are observed in the data between the two profiles. In these data, it is interpreted that the low resistivities (< 60 ohm-m) represent saturated zones with high bulk porosity and areas of high permeability (e.g. below the stream channel). Conversely, the high resistivities (> 500 ohm-m) are interpreted to represent low bulk porosity, low permeability zones within the bedrock tuff and groundwater is unlikely to be found. Resistivities that range from 80-200 ohm-m are zones in the weathered tuff and bedrock that bulk porosity is high and the material either contains a higher moisture weight percentage (as in Mortandad or Ten Site Canyon) or may be partially saturated and represent permeability pathways that are intermittently utilized.

In light of the aforementioned data characteristics, the specific observations for each line are itemized below.

DP-1:

- The depth of the transition from low to high resistivity is relatively constant until 325-350 ft and 475- 775 ft (i.e. the end of the line) across the profile. *In situ* monitoring data indicates that the top of this zone (≥ 80 ohm-m –transition from blue to green) corresponds to the top of the weathered tuff. Variations in the thickness of the zone defined between 80-500 ohm-m (green-red color) are interpreted as saturation changes in the weathered/near surface bedrock.

- At 325-350 ft, low resistivities (< 80 ohm-m) are present. At this location, an interpreted high porosity and high permeability zone is observed. A water utility line crosses the profile at this location and is interpreted to be the cause for this anomaly. The observed trench for this utility appears to be 17 ft wide and extend to ~55 ft bgs. Since the anomaly is so dramatically larger than should be observed, it is important to note that this low resistivity response is not simply the result of a metal utility pipe near the surface. A more plausible explanation for the low resistivity extending to depth is if the water line is leaking into the surrounding trench and this water moves into the uppermost tuffs through fractures induced or enhanced during the utility trenching. Regardless of the exact cause, the anomaly ends ~55 ft bgs implying that these induced or enhanced fractures associated with the trench do not extend very deep nor extend laterally very far.

- From 475-775 ft, the transition zone (80-500 ohm-m) undulates and is interpreted to reflect thickness/saturation variability in weathered/near surface tuff. Regardless, no areas of this section indicate any deep vertical groundwater movement or access.

DP-2:

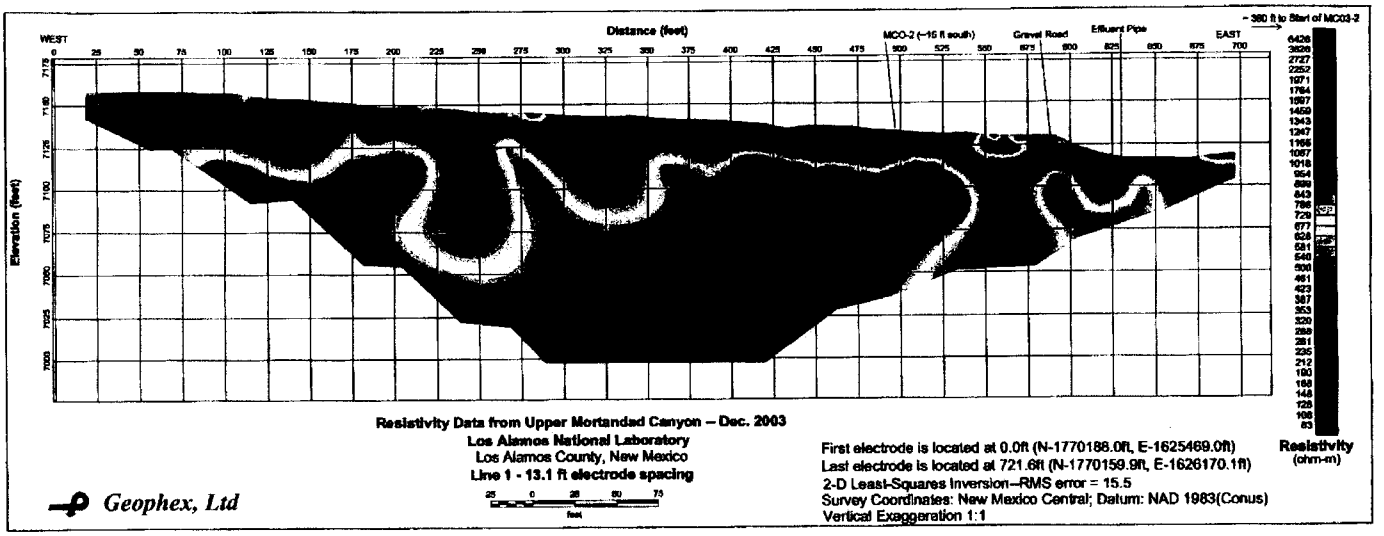
- Near surface groundwater is prevalent from 40-140 ft. with the majority south of the channel.
- A zone that could be interpreted as a vertical permeability pathway (resistivity between 80-200 ohm-m – green color) in the bedrock exists from 110-130 ft (i.e. north of the stream channel).
- Surface recharge is interpreted from the start of the profile (southern side of the canyon) to the groundwater detected at 40 ft.

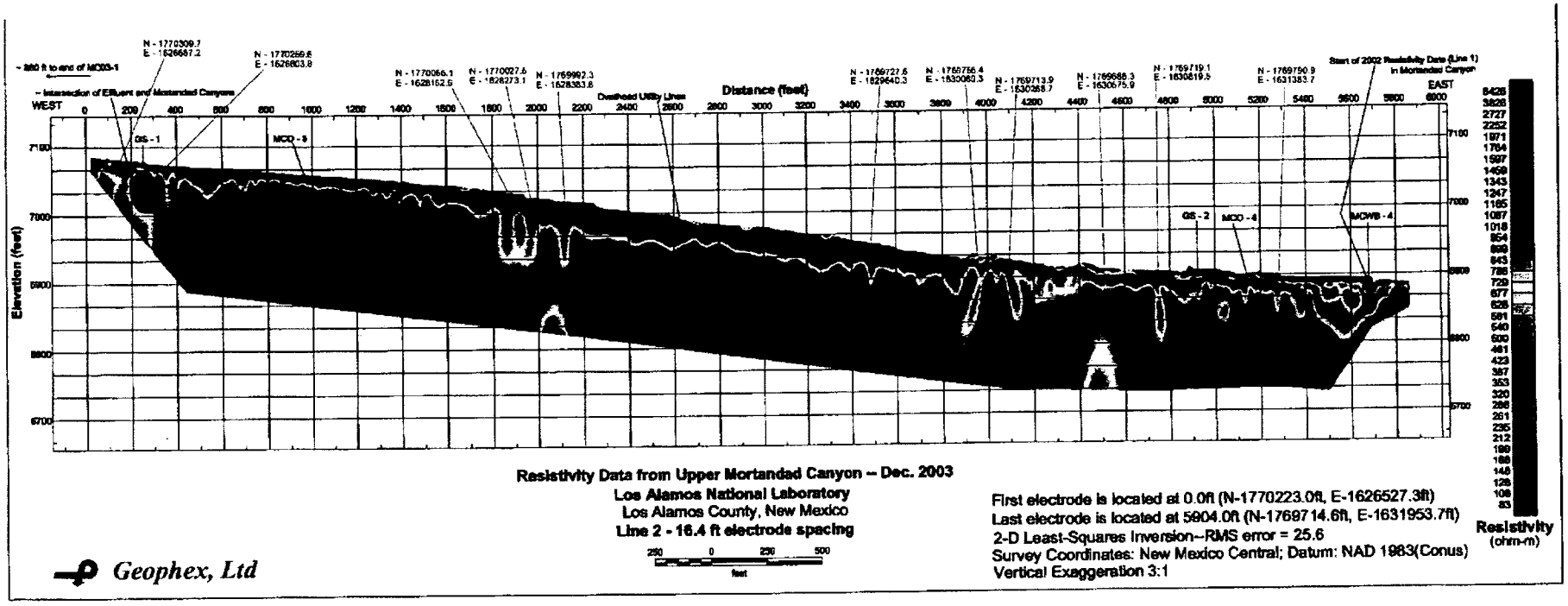
DP-3:

- Near surface groundwater is prevalent from 40-140 ft. The observed geometry is different between DP-2 and DP-3.
- As with DP-2, a possible vertical pathway (green color) in the bedrock is interpreted from 110-140 ft.
- From 50-70 ft, intermediate resistivities (80-200 ohm-m—green color) are observed at ~ 30 ft bgs. However, it does not appear to connect to near surface directly at this location.

Appendix A

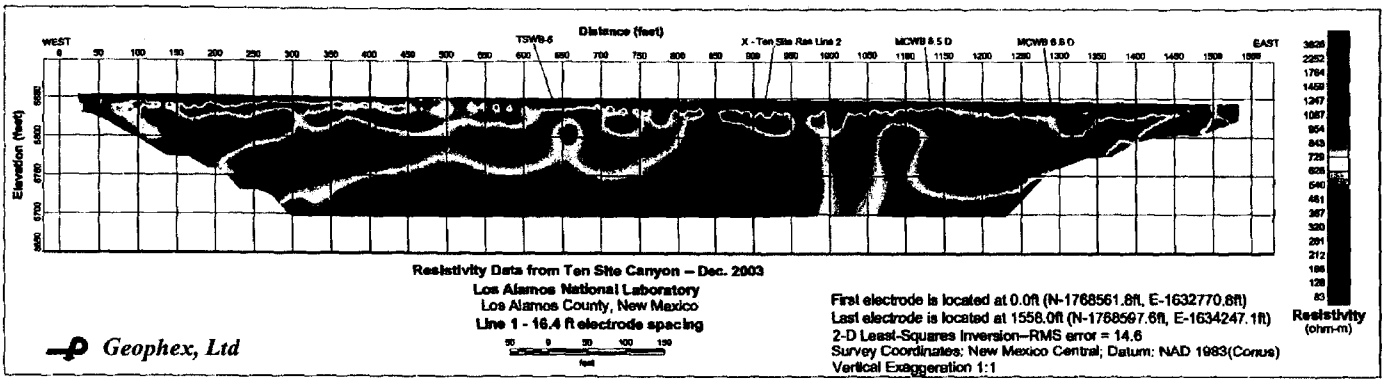
Resistivity Profiles in Mortandad Canyon

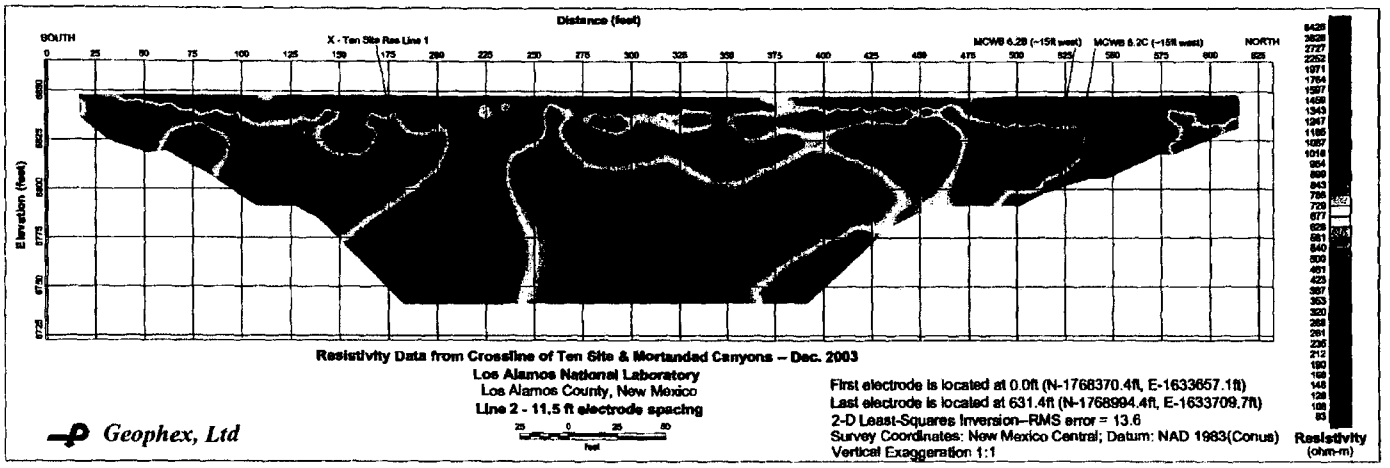

WEST
Distance (feet)
MCO-2 (~15 ft south)
Gravel Road
Effluent Pipe
EAST
~ 380 ft to Start of MCO3-2
Elevation (feet)
Resistivity
(ohm-m)
Resistivity Data from Upper Mortandad Canyon – Dec. 2003
Los Alamos National Laboratory
Los Alamos County, New Mexico
Line 1 - 13.1 ft electrode spacing
Geophex, Ltd
First electrode is located at 0.0ft (N-1770188.0ft, E-1625469.0ft)
Last electrode is located at 721.6ft (N-1770159.9ft, E-1626170.1ft)
2-D Least-Squares Inversion--RMS error = 15.5
Survey Coordinates: New Mexico Central; Datum: NAD 1983(Conus)
Vertical Exaggeration 1:1


Distance (feet)
Elevation (feet)
WEST
EAST
Overhead Utility Lines
GS - 1
MCO - 9
GS - 2
MCO - 4
MCWB - 4
Resistivity
(ohm-m)
Resistivity Data from Upper Mortandad Canyon -- Dec. 2003
Los Alamos National Laboratory
Los Alamos County, New Mexico
Line 2 - 16.4 ft electrode spacing
Geophex, Ltd
First electrode is located at 0.0ft (N-1770223.0ft, E-1626527.3ft)
Last electrode is located at 5904.0ft (N-1769714.6ft, E-1631953.7ft)
2-D Least-Squares Inversion--RMS error = 25.6
Survey Coordinates: New Mexico Central; Datum: NAD 1983(Conus)
Vertical Exaggeration 3:1

Appendix B

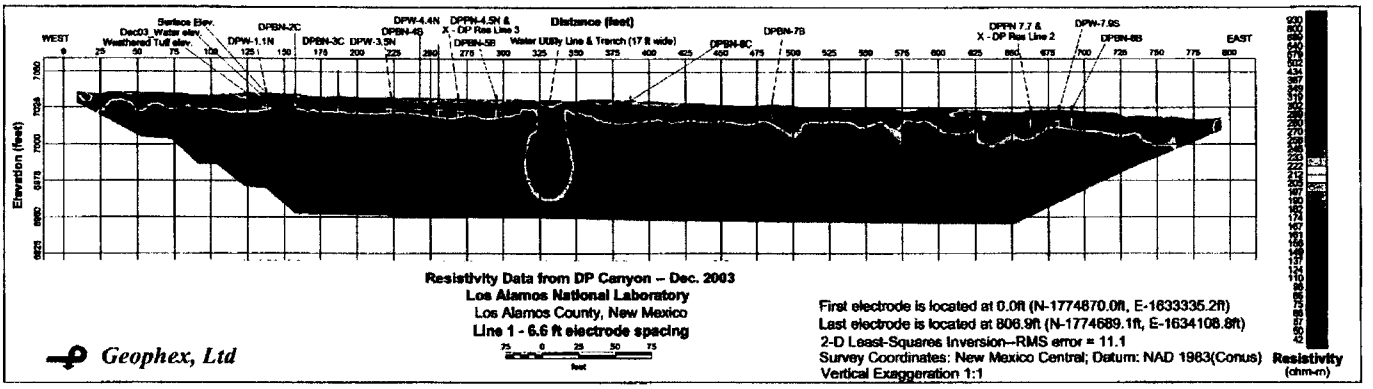
Resistivity Profiles in Ten Site Canyon

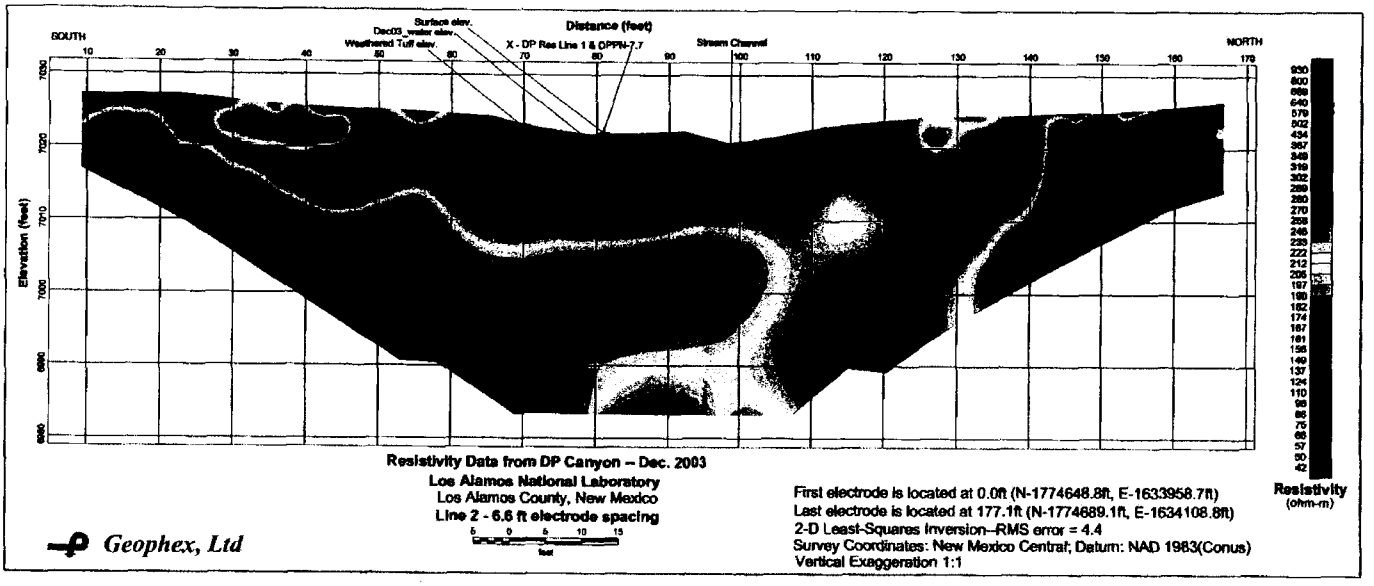

WEST
EAST
Distance (feet)
TSWB-5
X - Ten Site Res Line 2
MCWB 5 D
MCWB 6 S D
Elevation (feet)
Resistivity Data from Ten Site Canyon – Dec. 2003
Los Alamos National Laboratory
Los Alamos County, New Mexico
Line 1 - 16.4 ft electrode spacing
Geophex, Ltd
First electrode is located at 0.0ft (N-1768561.8ft, E-1632770.6ft)
Last electrode is located at 1558.0ft (N-1768597.6ft, E-1634247.1ft)
2-D Least-Squares Inversion--RMS error = 14.6
Survey Coordinates: New Mexico Central; Datum: NAD 1983(Conus)
Vertical Exaggeration 1:1
Resistivity
(ohm-m)


Distance (feet)
SOUTH
NORTH
X - Ten Site Res Line 1
MCWB 6.2B (~15ft west)
MCWB 6.2C (~15ft west)
Elevation (feet)
Resistivity Data from Crossline of Ten Site & Mortandad Canyons – Dec. 2003
Los Alamos National Laboratory
Los Alamos County, New Mexico
Line 2 - 11.5 ft electrode spacing
Geophex, Ltd
First electrode is located at 0.0ft (N-1768370.4ft, E-1633657.1ft)
Last electrode is located at 631.4ft (N-1768994.4ft, E-1633709.7ft)
2-D Least-Squares Inversion--RMS error = 13.6
Survey Coordinates: New Mexico Central; Datum: NAD 1983(Conus)
Vertical Exaggeration 1:1
Resistivity
(ohm-m)

Appendix C

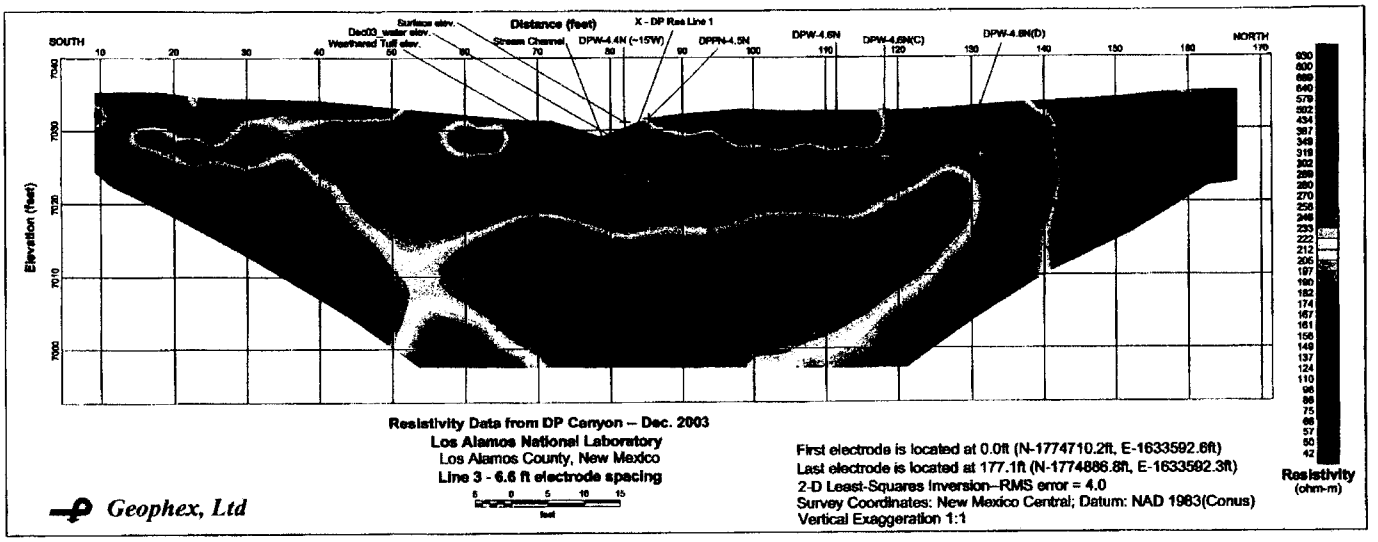
Resistivity Profiles in DP Canyon


WEST
EAST
Distance (feet)
Elevation (feet)
Surface Elev.
Dec03 Water elev.
Weathered Tuff elev.
DPBN-2C
DPW-1.1N
DPBN-3C
DPW-3.5N
DPW-4.4N
DPBN-4B
DPPN-4.5N &
X - DP Res Line 3
DPBN-5B
Water Utility Line & Trench (17 ft wide)
DPBN-6C
DPBN-7B
DPPN 7.7 &
X - DP Res Line 2
DPW-7.9S
DPBN-8B
Resistivity Data from DP Canyon – Dec. 2003
Los Alamos National Laboratory
Los Alamos County, New Mexico
Line 1 - 6.6 ft electrode spacing
Geophex, Ltd
First electrode is located at 0.0ft (N-1774870.0ft, E-1633335.2ft)
Last electrode is located at 806.9ft (N-1774689.1ft, E-1634108.8ft)
2-D Least-Squares Inversion--RMS error = 11.1
Survey Coordinates: New Mexico Central; Datum: NAD 1983(Conus)
Vertical Exaggeration 1:1
Resistivity
(ohm-m)



Resistivity Data from DP Canyon -- Dec. 2003
Los Alamos National Laboratory
Los Alamos County, New Mexico
Line 2 - 6.6 ft electrode spacing

First electrode is located at 0.0ft (N-1774648.8ft, E-1633958.7ft)
Last electrode is located at 177.1ft (N-1774689.1ft, E-1634108.8ft)
2-D Least-Squares Inversion--RMS error = 4.4
Survey Coordinates: New Mexico Central; Datum: NAD 1983(Conus)
Vertical Exaggeration 1:1


SOUTH
NORTH
Distance (feet)
Surface elev.
Dec03_water elev.
Weathered Tuff elev.
Stream Channel
DPW-4.4N (~15W)
X - DP Res Line 1
DPPN-4.5N
DPW-4.6N
DPW-4.6N(C)
DPW-4.6N(D)
Elevation (feet)
Resistivity
(ohm-m)
Resistivity Data from DP Canyon – Dec. 2003
Los Alamos National Laboratory
Los Alamos County, New Mexico
Line 3 - 6.6 ft electrode spacing
feet
Geophex, Ltd
First electrode is located at 0.0ft (N-1774710.2ft, E-1633592.6ft)
Last electrode is located at 177.1ft (N-1774886.8ft, E-1633592.3ft)
2-D Least-Squares Inversion--RMS error = 4.0
Survey Coordinates: New Mexico Central; Datum: NAD 1983(Conus)
Vertical Exaggeration 1:1

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ER ID # 84540

RECORD TYPE: Map / Plate:

DATE: December 2003

SYMBOL: Geophex Job # 1247 Plate 1

SUBJECT: DOE OLA90 2003 Geophysical Data Acquisition Mortandad & Ten Site Canyons, LANL

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ER ID # 84540

RECORD TYPE: Map

DATE: December 2003

SYMBOL: Plate 2 Geophex Job 1247

SUBJECT: DOE OLASO 2003 Geophysical Data Acquisition, DP Canyon, LANL

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ER ID # 84540

RECORD TYPE: MAP

DATE: FEBRUARY 2004

SYMBOL:

SUBJECT:
US DOE LAAO, DC RESISTIVITY PROFILES
OF MORTANDAD AND EFFLUENT CANYON
LANL, FEBRUARY 2004