Electrical Resistivity Imaging

A Presentation
by
Mats Lagmanson
Advanced Geosciences, Inc.

San Antonio, October 24, 2005

Geophysical Electrical Resistivity Surveying

- An electric current is injected into the ground through two electrodes

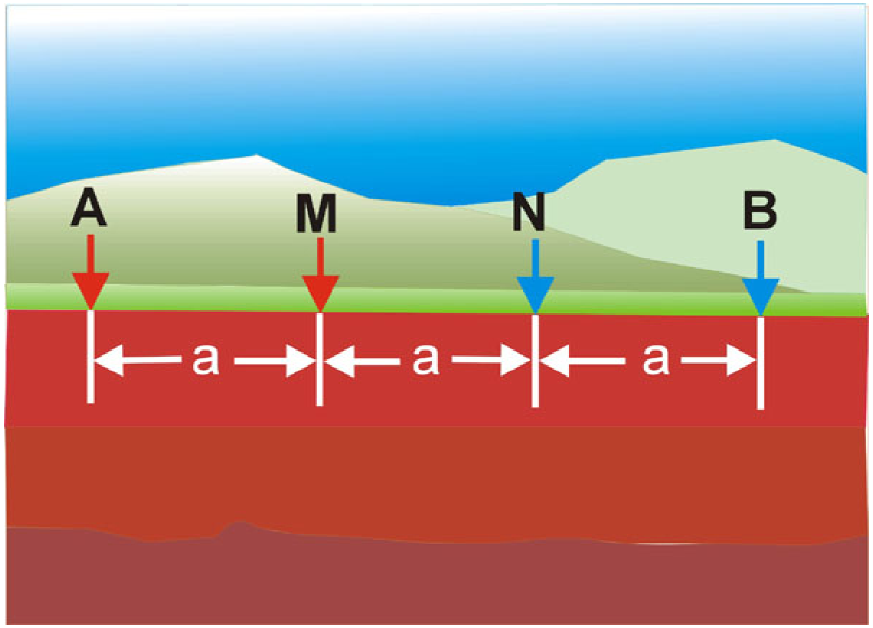
- The resulting potential is measured between two other electrodes

- Injected current and resulting voltage (potential) is measured and "**apparent resistivity**" is calculated.

Apparent resistivity can be seen as a weighted average of the different resistivities under the four electrodes. If the ground is homogeneous the apparent resistivity equals the true resistivity

Apparent resistivity

Apparent resistivity is a weighted average of the resistivities under the four electrodes. If the ground is homogenous, the apparent resistivity equals the true resistivity



Our EarthImager software is used to invert the apparent resistivity data to “true” resistivity.

Resistivity Imaging

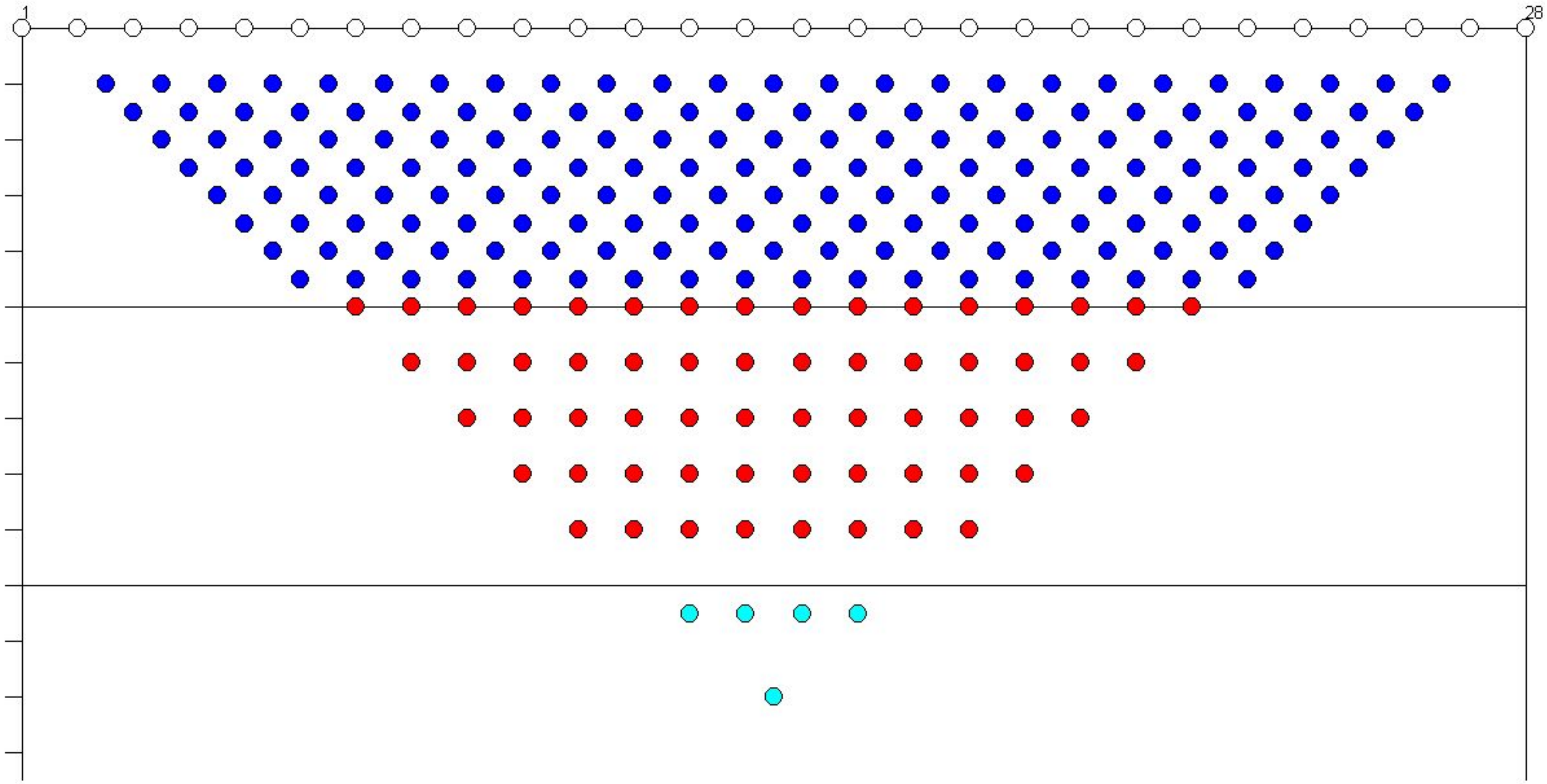
- The goal is to create an image of the ground in terms of electrical resistivity.

- Because of the large amounts of data needed, the survey is performed by an automatic system.

- Our SuperSting R1 or R8 instruments are specially designed for automatic resistivity imaging surveys.

- The field data is inverted from apparent resistivity to “true” resistivity by the EarthImager software.

Multi-electrode System

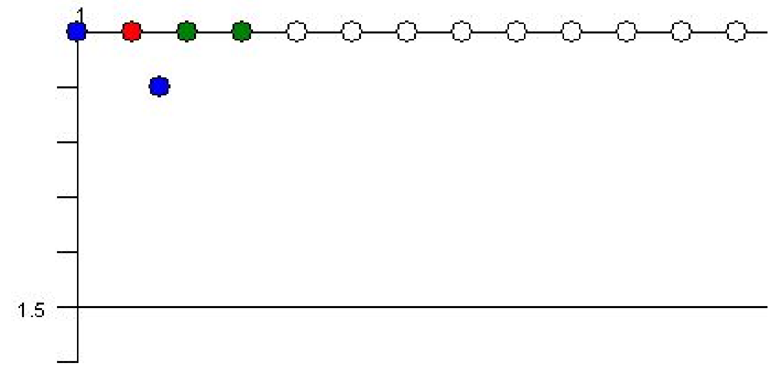


Multi-electrode system is a system where a large number of electrodes are attached to the instrument.

Single vs. Multi-channel System

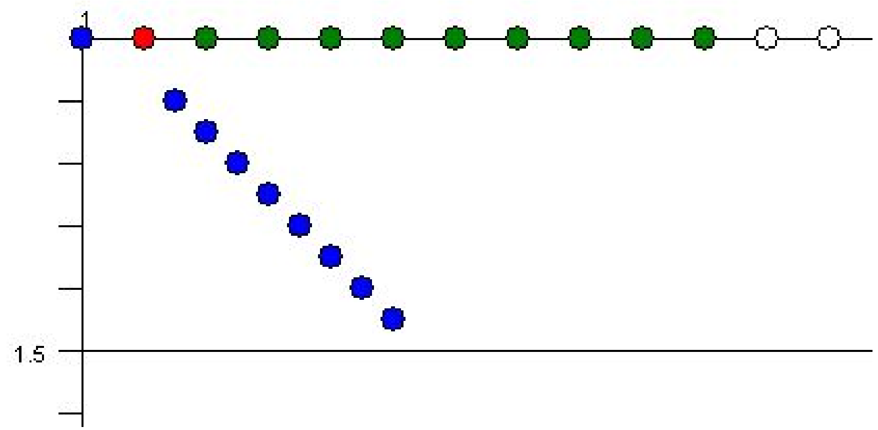
- Single channel instrument

  SuperSting R1



- 8-channel instrument

  SuperSting R8

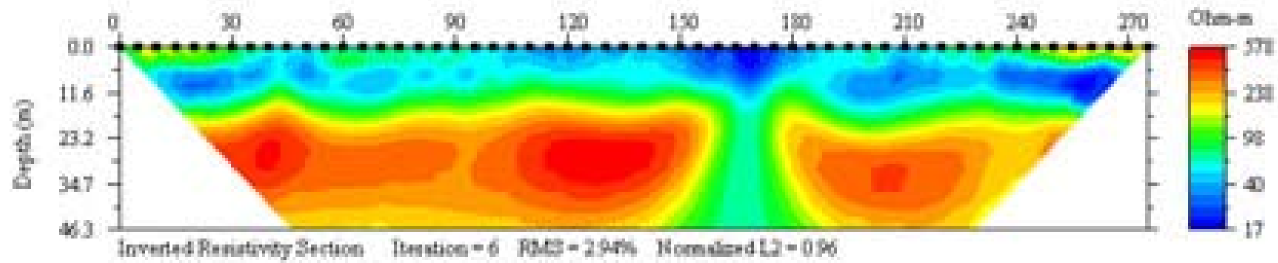


A multi-channel instrument is much faster in the field than a single channel instrument. However the final result will be the same.

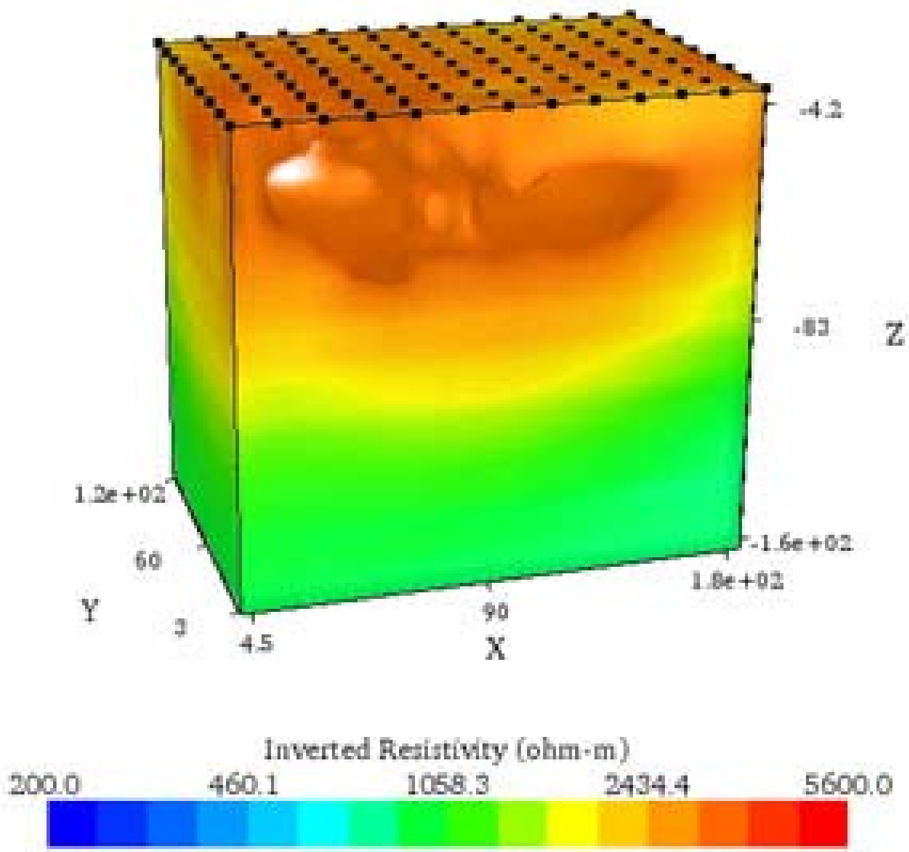
Software from AGI

AGI Advanced Geosciences, Inc.

EarthImager 2D



EarthImager 3D



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Typical Ranges of Resistivity for Some Materials

Rock/material type	Resistivity range (Ωm)
Igneous	100 - 1000000
Limestone	100 - 10000
Sandstone	100 - 1000
Sand and gravel	600 - 10000
Clay	10 - 100
Unconsolidated wet clay	20
Soil	1 - 10
Fresh water	3 - 100
Drill mud, hydraul-EZ	4.5
Sea water	0.2 - 1
Copper (native)	0.0000002

Some properties which affect the resistivity of soil and rock

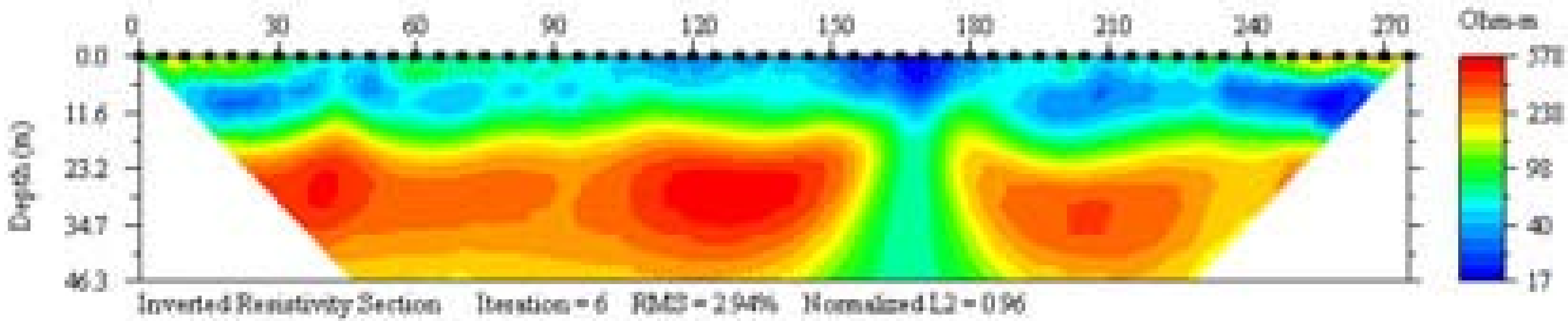
- Porosity, shape of pores, size of pores and connection of pores
- Moisture (water) content
- Dissolved electrolytes
- Temperature of pore water (resistivity decreases with increasing temperature)
- Conductivity of minerals

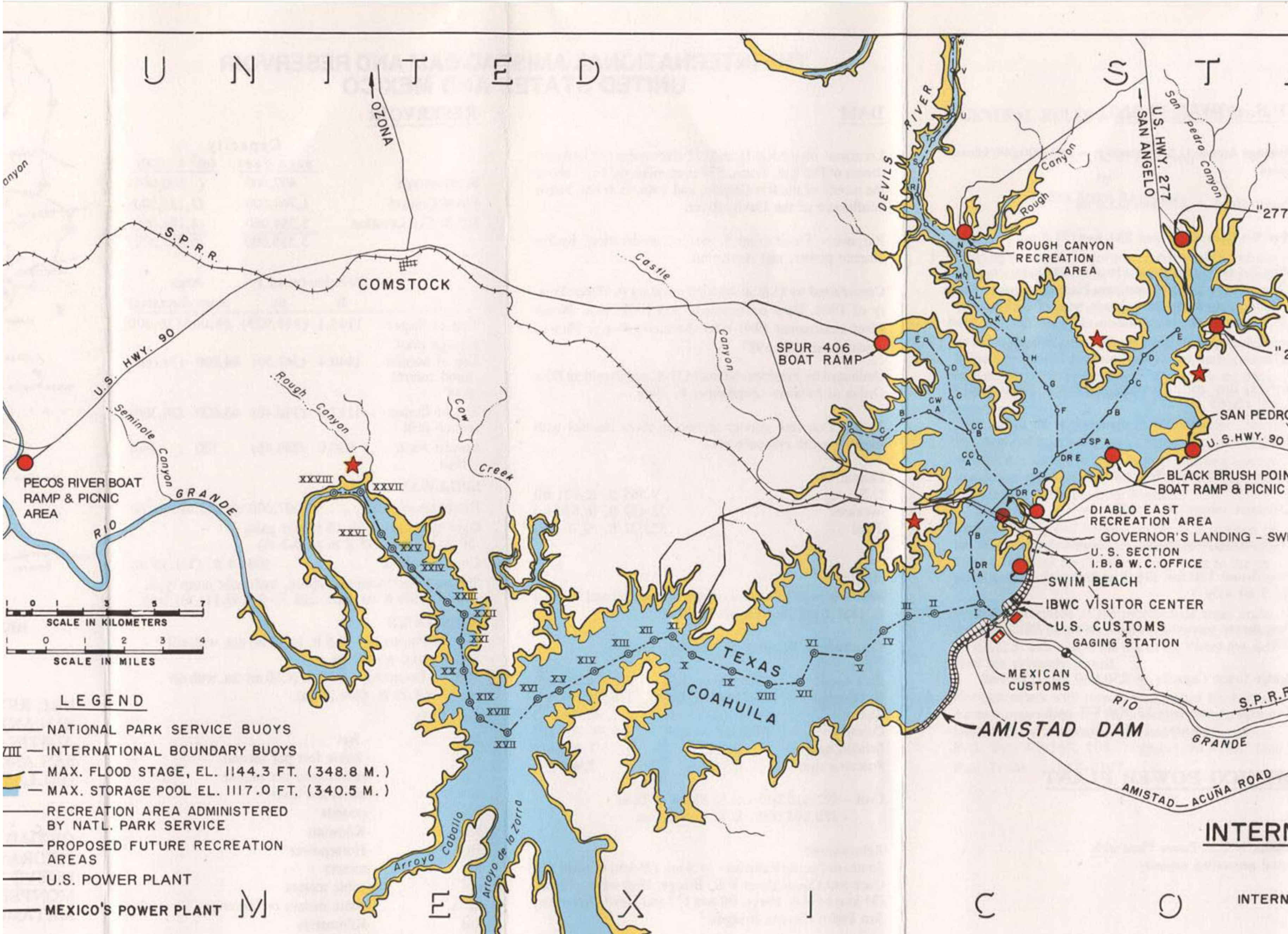
Types of Electrical Resistivity & IP Surveys

2D Resistivity Imaging.

- 3D Resistivity Imaging.
- Bore hole to bore hole survey (ERT).
- Resistivity monitoring (time lapse surveys).
- Aquatic surveys in marine or fresh water environment.

- EarthImager 2D




UNITED STA
MEXICO
OZONA
S.P.R.R.
COMSTOCK
U.S. HWY. 90
Castle Canyon
Rough Canyon
Seminole Canyon
Cow Creek
RIO GRANDE
PECOS RIVER BOAT RAMP & PICNIC AREA
DEVILS RIVER
Rough Canyon
ROUGH CANYON RECREATION AREA
SPUR 406 BOAT RAMP
U.S. HWY. 277 — SAN ANGELO
San Pedro Canyon
"277"
SAN PEDRO
U.S. HWY. 90
BLACK BRUSH POINT
BOAT RAMP & PICNIC A
DIABLO EAST RECREATION AREA
GOVERNOR'S LANDING - SWIM
U.S. SECTION I.B. & W.C. OFFICE
SWIM BEACH
IBWC VISITOR CENTER
U.S. CUSTOMS
GAGING STATION
MEXICAN CUSTOMS
AMISTAD DAM
RIO GRANDE
S.P.R.R.
AMISTAD — ACUÑA ROAD
TEXAS
COAHUILA
Arroyo Caballo
Arroyo de la Zorra
SCALE IN KILOMETERS
SCALE IN MILES
LEGEND
NATIONAL PARK SERVICE BUOYS
INTERNATIONAL BOUNDARY BUOYS
MAX. FLOOD STAGE, EL. 1144.3 FT. (348.8 M.)
MAX. STORAGE POOL EL. 1117.0 FT. (340.5 M.)
RECREATION AREA ADMINISTERED BY NATL. PARK SERVICE
PROPOSED FUTURE RECREATION AREAS
U.S. POWER PLANT
MEXICO'S POWER PLANT
INTERN
INTERNA

Resistivity survey at the Amistad Dam

One of more than 15 concrete plugged holes, where water leaked out

The Amistad dam was leaking under the embankment in the karstic limestone.

The survey was performed along the embankment on the bottom of the almost dry dam

Dam Leakage

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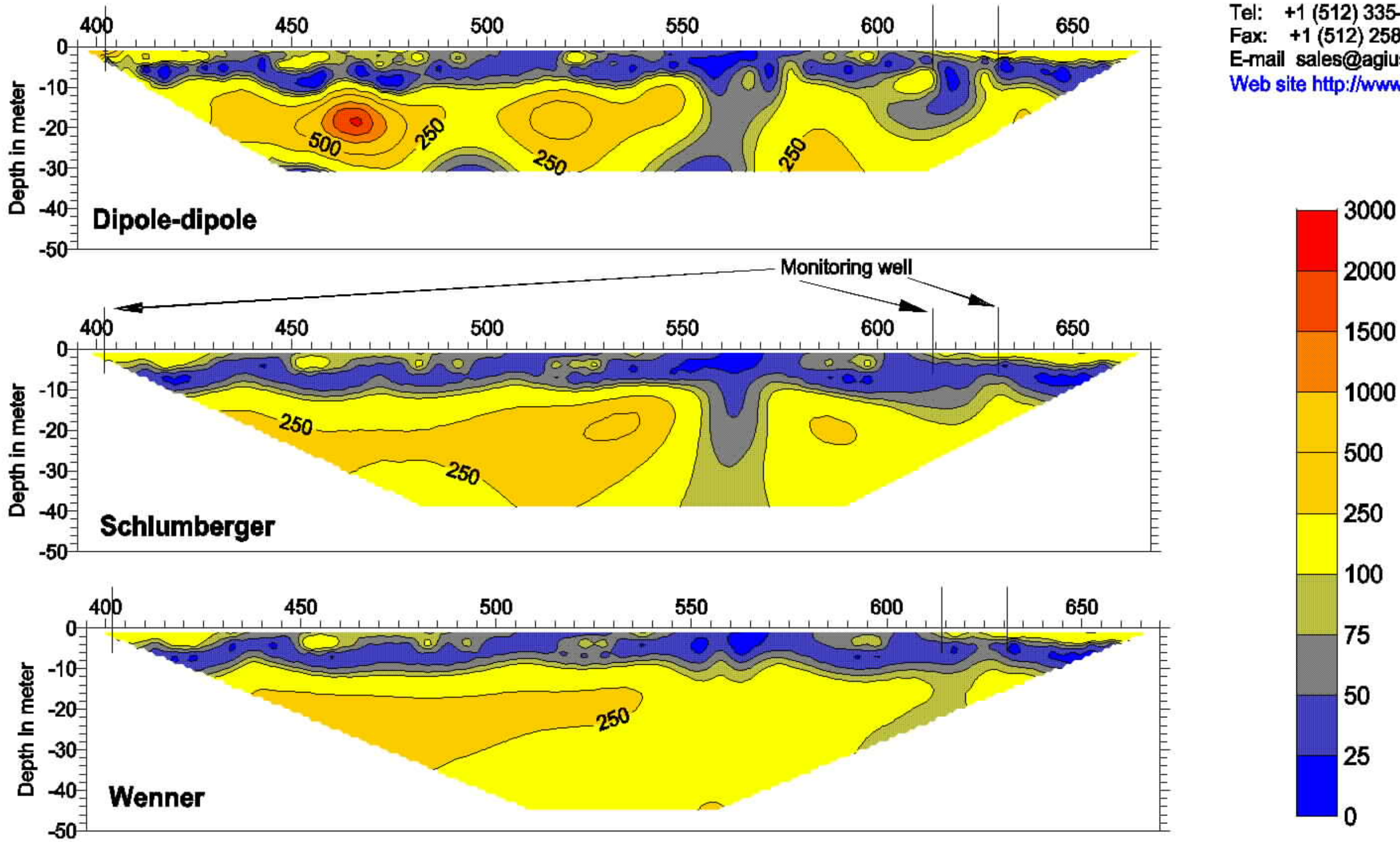


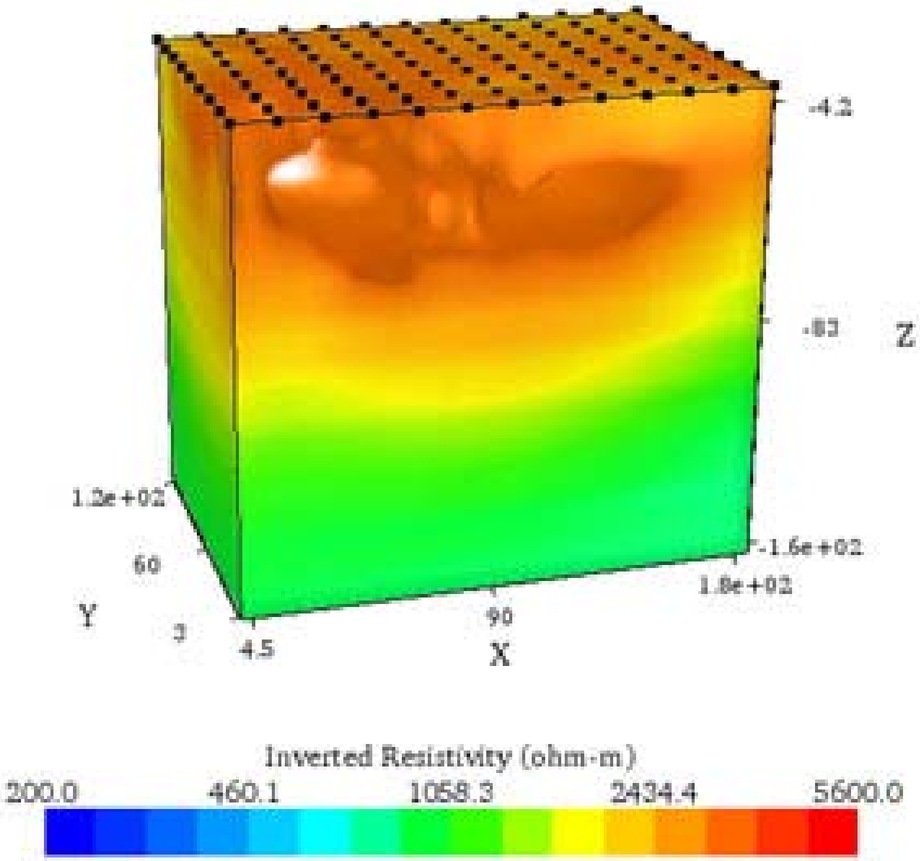
Objective: Compare electrode arrays to determine best method to detect leakage through the karstic limestone bottom of the dam
Survey date: October 10, 1996
Survey site: On the bottom of the Amistad dam just inside the wall
Instrument: Sting/Swift, 56 electrodes at 5 meter spacing, same electrode lay-out for all three surveys.
Units: Meter and Ohmmeter

Amistad Dam Revisited February 1999

The anomalies centered around coordinates 565 and 620 has now been drilled and grouted. The anomaly around 565 is a fracture zone with associated cave and the anomaly at 620 is a cavity. The two systems had been injection grouted using 703 cubic meters of a mixture consisting of 50% water, 14% cement and 36% sand. The water in the dam is reported to be raising.

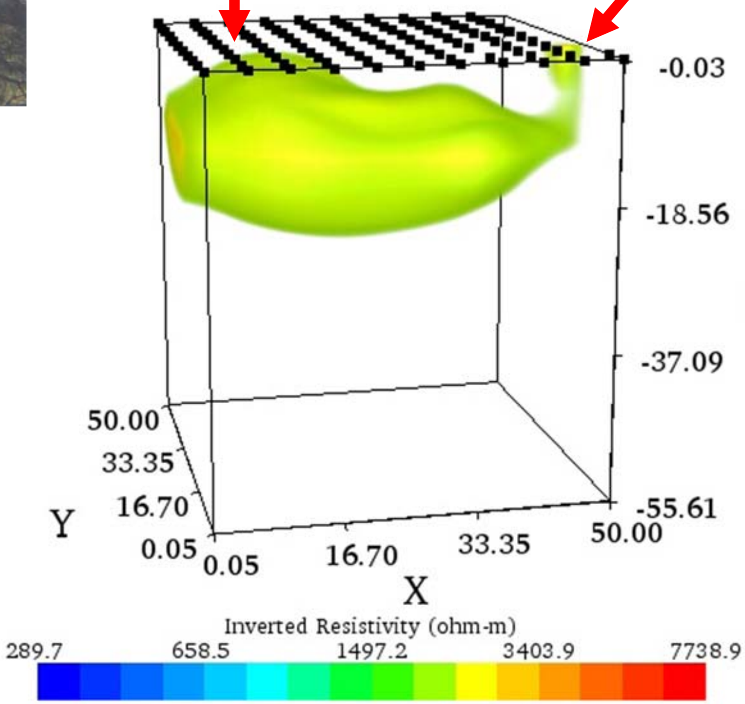
Courtesy of Comision Federal de Electricidad, Mexico

• EarthImager 3D



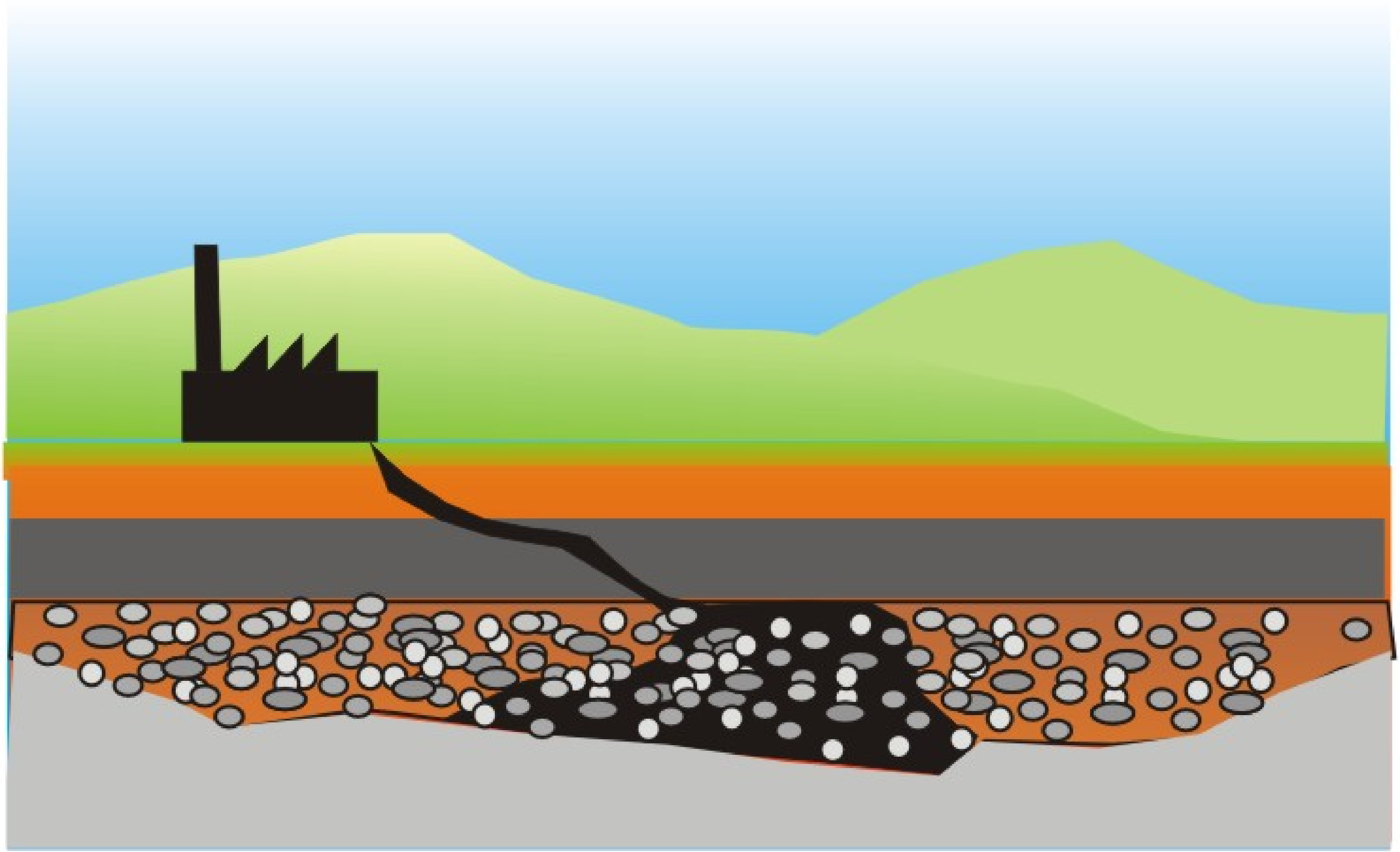
Processing with EarthImager 3D

By removing all resistivities below 2700 Ohmmeter, the approximate extent of the gypsum body could be displayed and the volume calculated.

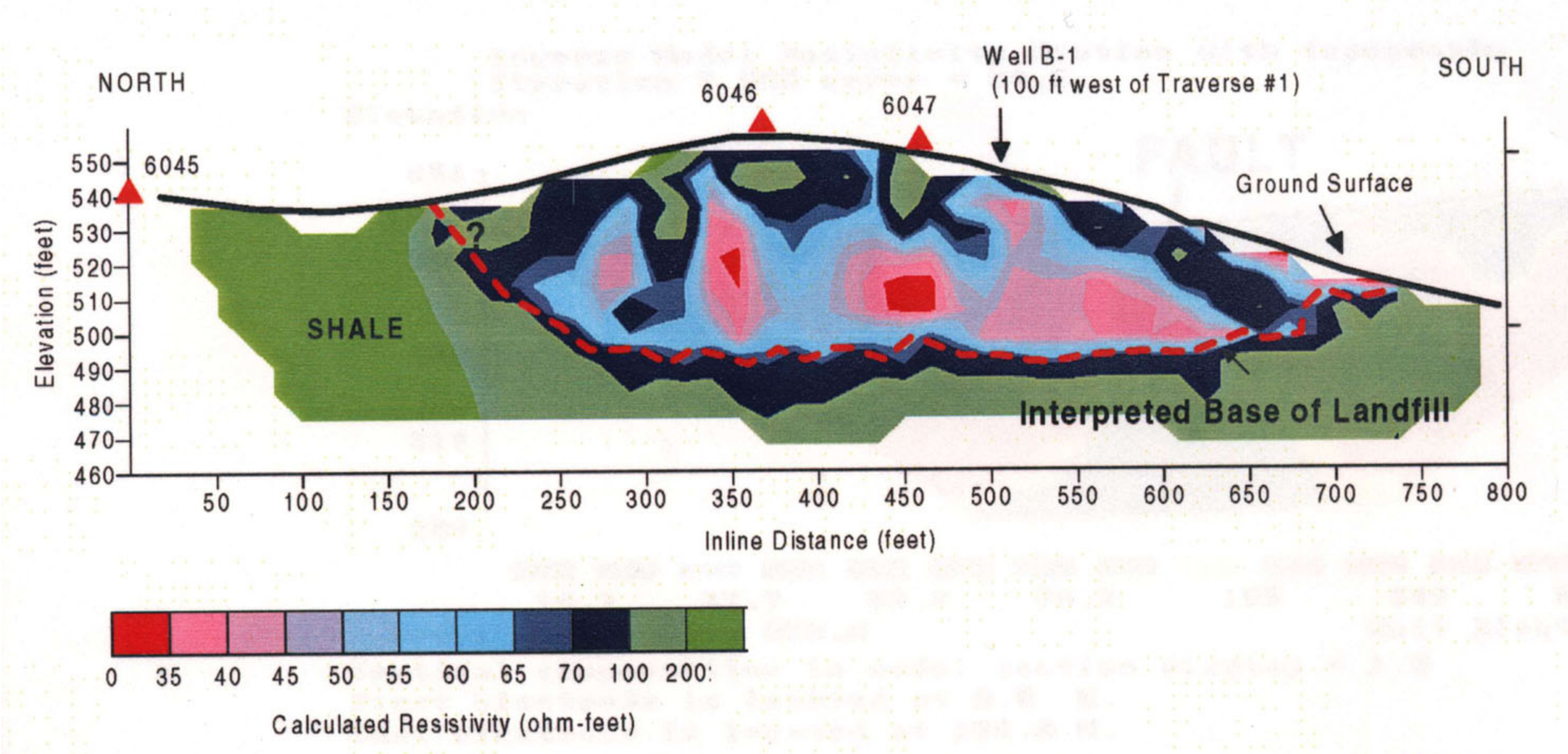



SuperSting
3D Resistivity
Imaging
System
SUPER STING
Advanced Geosciences, Inc. USA

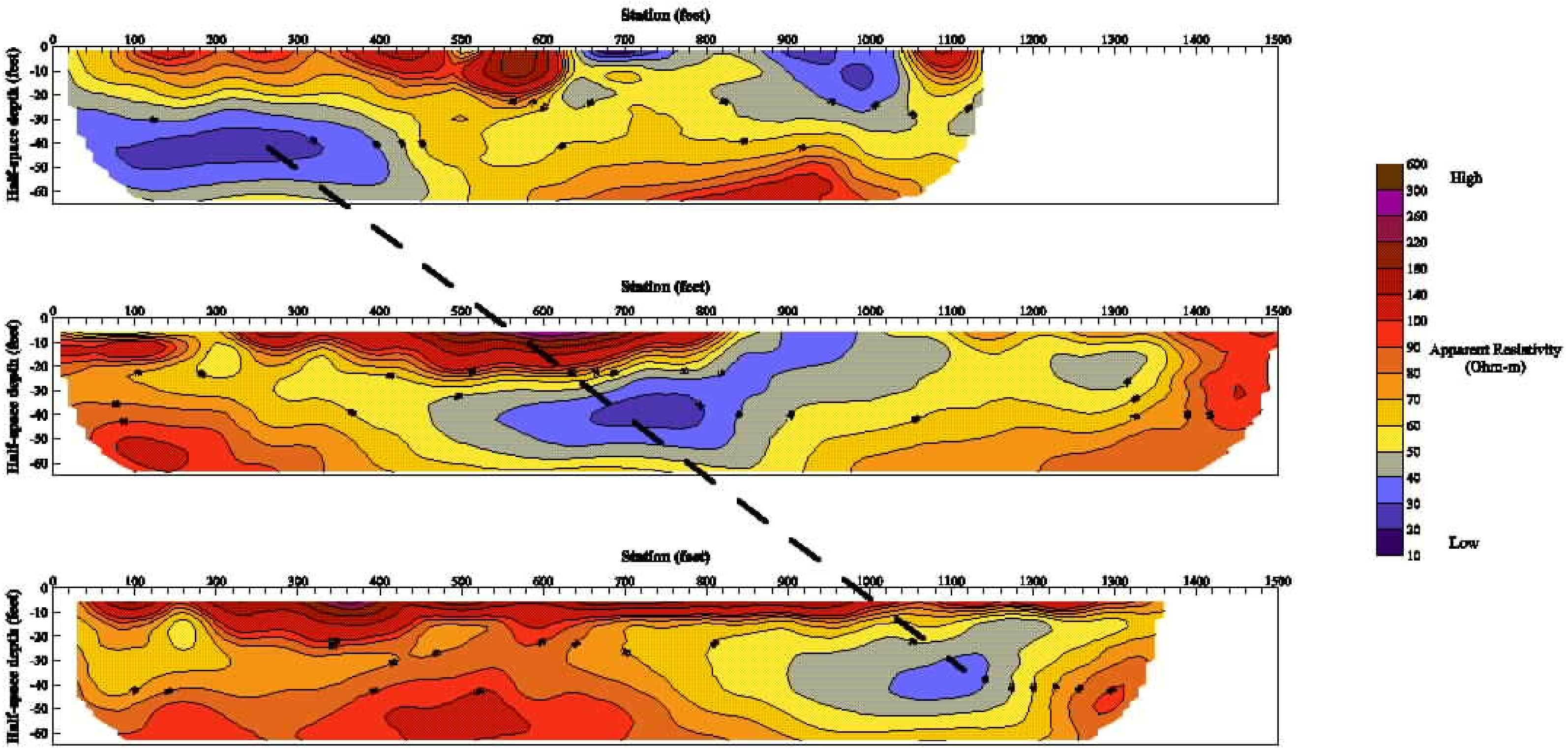
Environmental Surveys



Landfill Survey using the Sting/Swift automatic resistivity system, courtesy of SAIC, Middletown Pennsylvania



Plume Mapping Using High Resolution Resistivity



Objective: The objective was to map the extent of a pollution plume
Survey date: 1996
Instrument: Sting R1 using manual cables
Method: Pole-pole array
Spacing: 5 - 200 feet
Units: Feet and Ohmmeter

Vertical Exaggeration: 3:1
0 50 100 150 200 250 (feet)

Courtesy of
hydroGEOPHYSICS, Inc.
Tucson, Arizona

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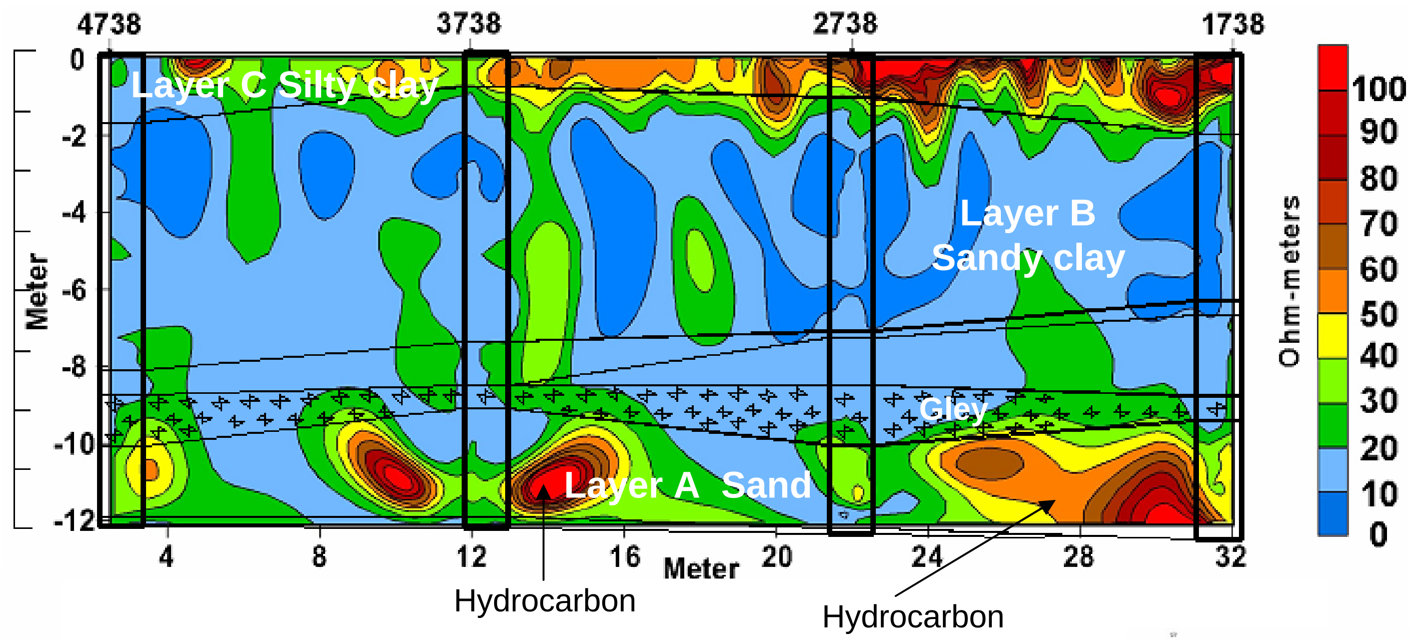
Direct Push Electrical Resistivity Tomography (ERT) to Delineate an LNAPL Plume



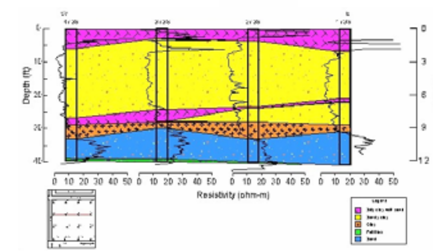
Study Site: Enid, Oklahoma

Objective: To define the geological controls on the distribution and location of LNAPL (hydrocarbon) in Enid, OK using electrical resistivity tomography (ERT) with the aid of sedimentological analysis

Conclusions: Data shows that there is a structural dome in the subsurface at the top of layer A along the western side of the site. This structural high corresponds with the LNAPL. LNAPL is normally thought to be a single plume; however, it was found in 1 to 2 meter amorphous 'blobs' shown on geoelectrical cross-sections. An overlay of a sedimentological cross-section labeled west to east is shown on top of one geoelectrical cross-section passing through the area of the dome. Drilling in the areas shown to have LNAPL 'blobs' revealed that there was indeed LNAPL at that location. ERT with the aid of sedimentological analysis delineated the LNAPL 'blobs.'

Instrument: SuperSting R8 with borehole cables

Date: August, 2002



Supporting data from direct push borehole logging system.

Picture shows the study site and gas station where LNAPL escaped.

Courtesy of OSU Oklahoma State University

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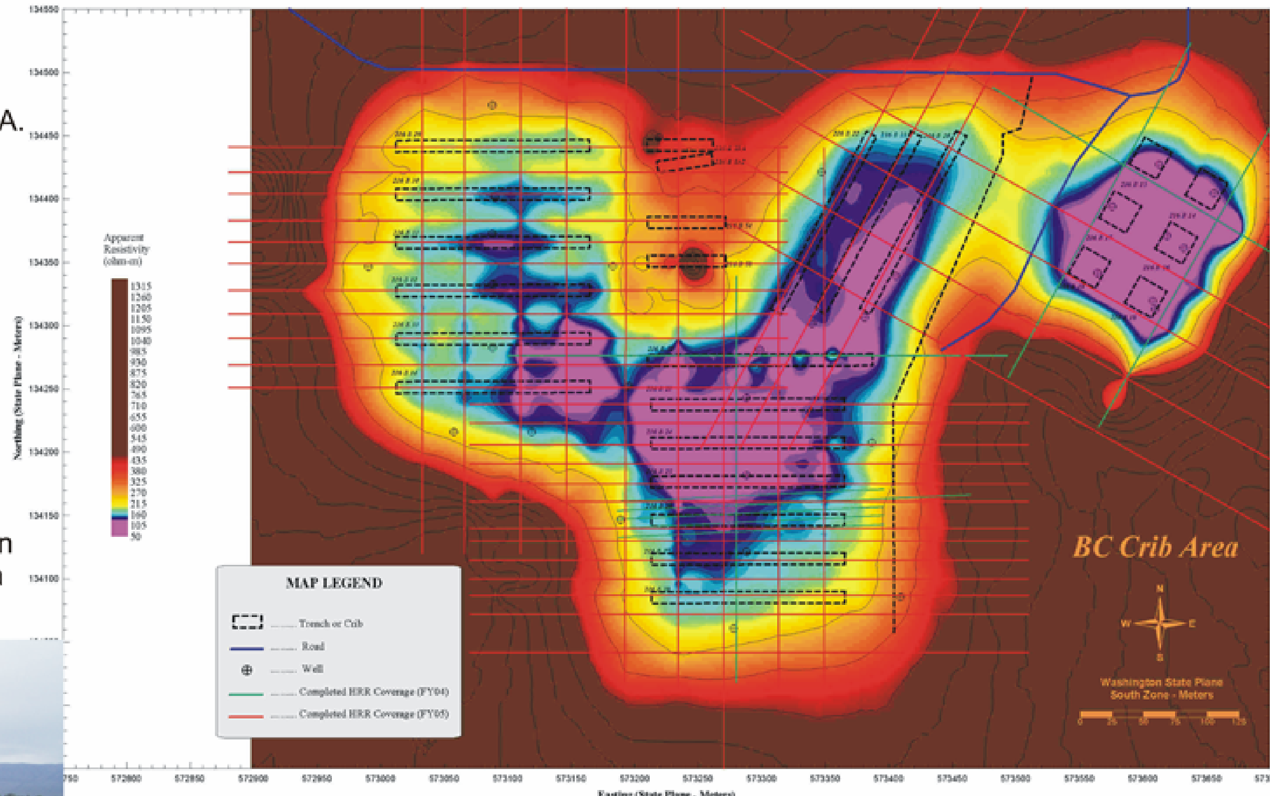
Resistivity Survey at the Hanford Site, Richland, Washington

As part of a geophysical survey, the SuperSting R8 instrument was used to record 19 line kilometers of electrical high resolution resistivity (HRR) data at the Hanford Site in Richland, Washington, USA.

The purpose of the investigation was to delineate the edges of a plume containing radiological and heavy metal constituents beneath disposal trenches and cribs, where liquid radioactive mixed waste from the processing of uranium had been disposed of.

The plume's electrical signature, on the order of 50 - 250 Ω-meter, was shown to spread laterally beyond the edges of the trenches or cribs and vertically to rest upon a hydraulically resistive silty clay layer at a depth of 42 meters below ground surface.



The map shows the apparent resistivity at a depth of 32 meter (105 ft).

The SuperSting at work at the desolate Hanford site

Data, courtesy of
Pacific Northwest National Laboratory
and
hydroGEOPHYSICS, Inc.
Tucson, Arizona, USA

Objective: To delineate a plume containing radiological and heavy metal constituents
Survey date: 2004 - 2005
Survey site: The Hanford Site, Richland, Washington, USA
Instrument: SuperSting R8/IP with 72 electrodes at 2 meter spacing
Method: Pole-pole electrode array using roll-along with 12 electrodes at a time
Processing: HGIPro proprietary software developed by HGI

SuperSting 8-channel Resistivity Instrument
by

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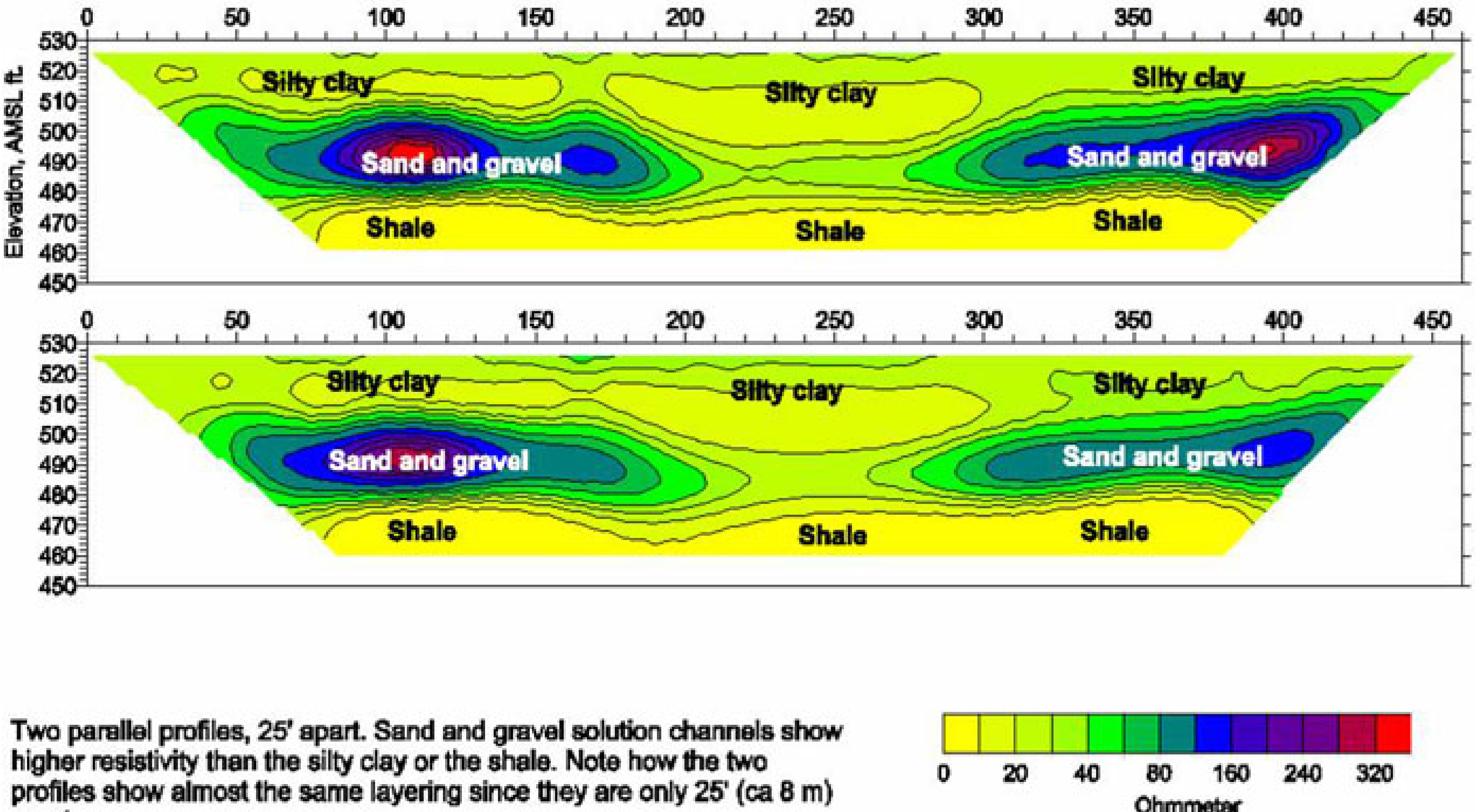
Mapping of stratigraphy, sand and gravel lenses in clay and shale environment



Two parallel profiles, 25' apart. Sand and gravel solution channels show higher resistivity than the silty clay or the shale. Note how the two profiles show almost the same layering since they are only 25' (ca 8 m) apart.

Instrument: Sting/Swift, 47 electrodes at 10' (3 meter) spacing
Method: Earth resistivity survey using the dipole-dipole electrode array
Units: Feet and Ohmmeter

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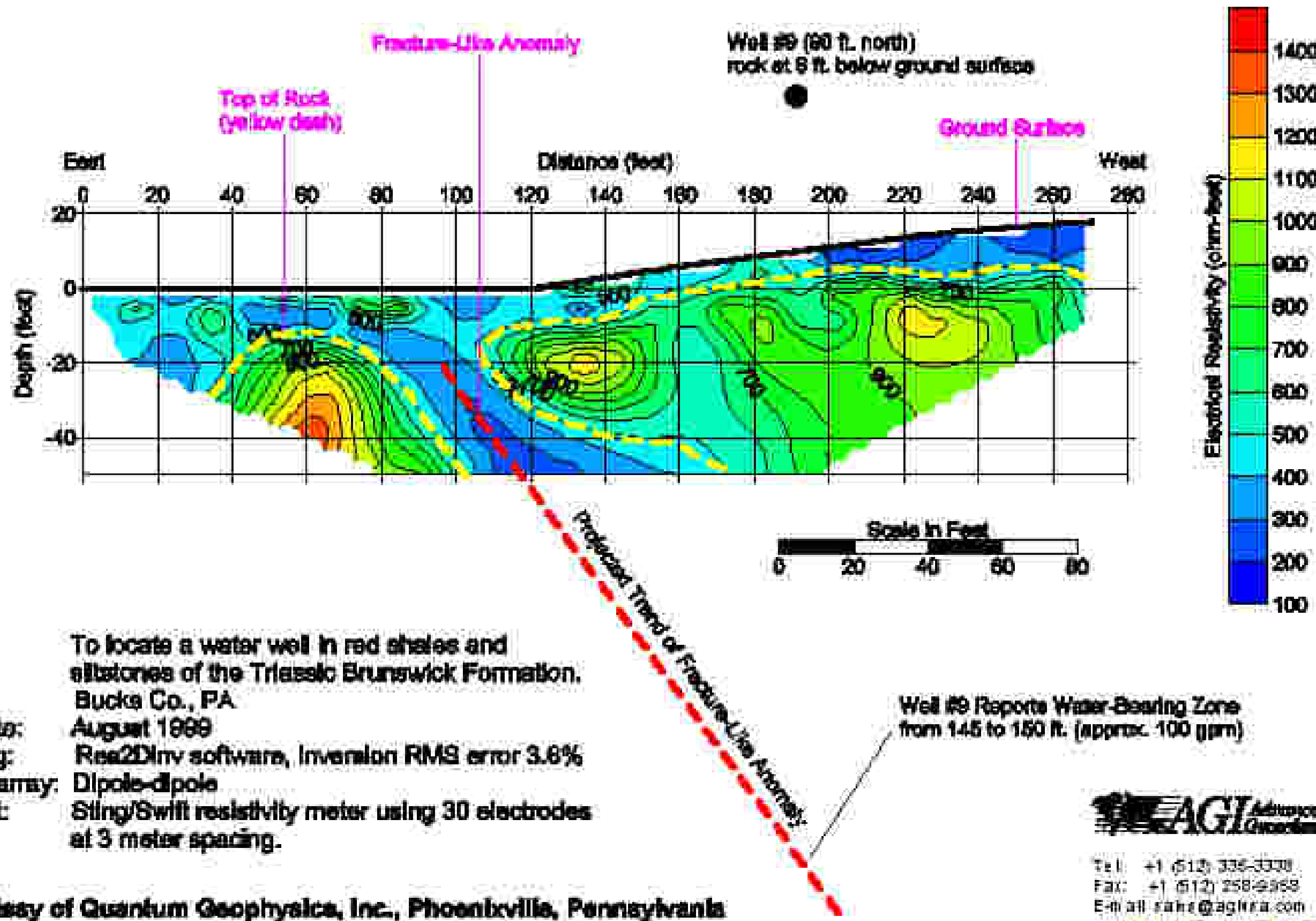
Locating Water Bearing Fracture Zones In Bedrock



Objective: To locate a water well in red shales and siltstones of the Triassic Brunswick Formation.
Location: Bucks Co., PA
Survey date: August 1999
Processing: Res2Dinv software, Inversion RMS error 3.6%
Electrode array: Dipole-dipole
Equipment: Sting/Swift resistivity meter using 30 electrodes at 3 meter spacing.

Courtesy of Quantum Geophysics, Inc., Phoenixville, Pennsylvania

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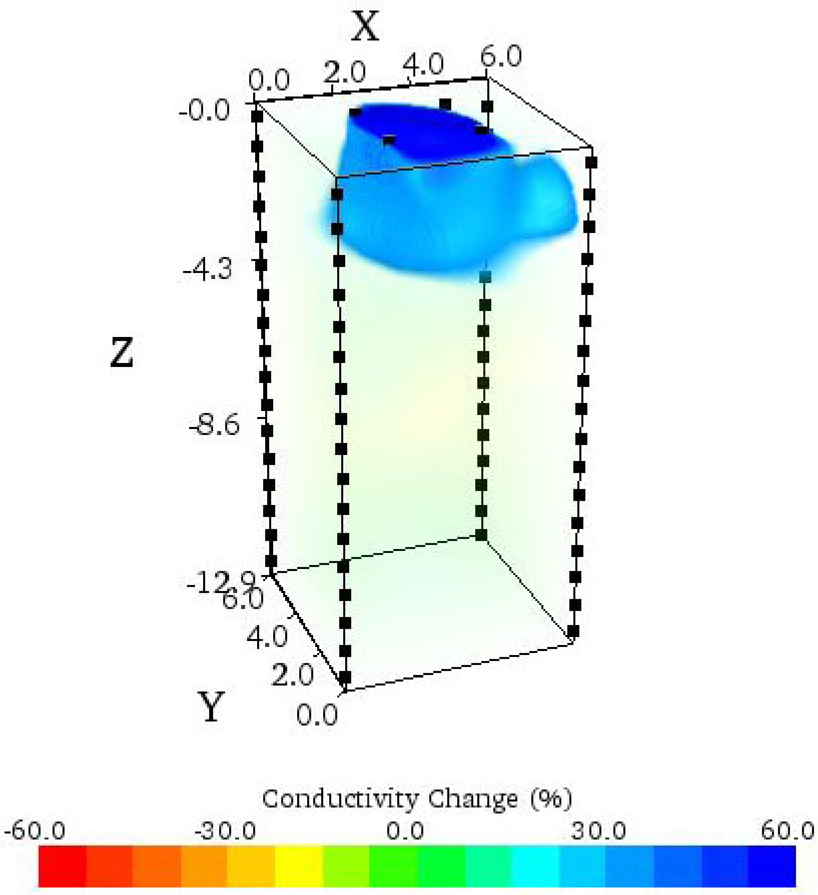
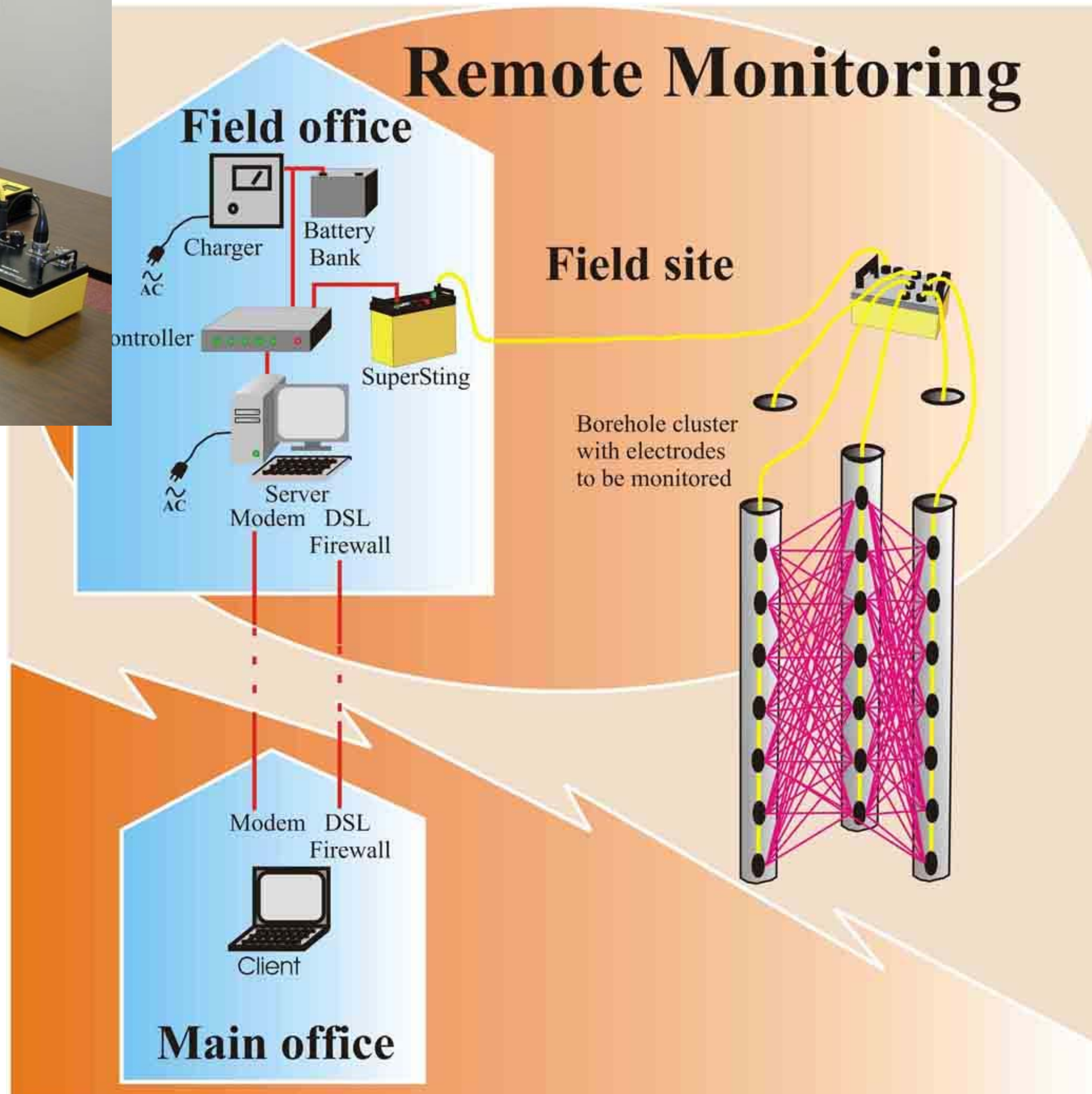
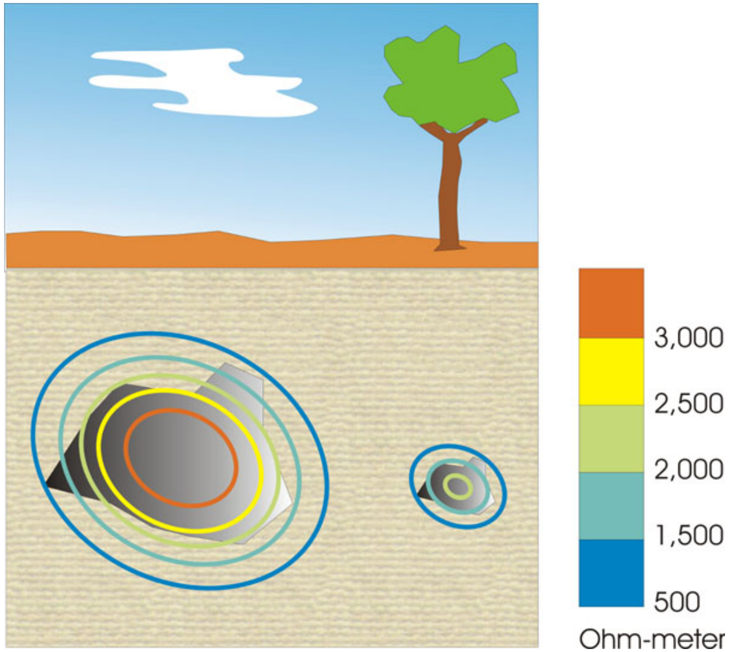
Resistivity Monitoring



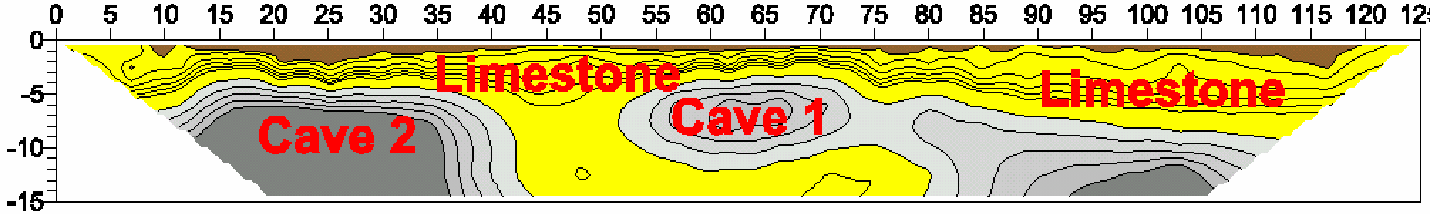


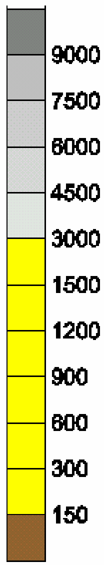
Remote Monitoring
Field office
Charger
AC
Battery Bank
ontroller
SuperSting
AC
Server
Modem
DSL Firewall
Field site
Borehole cluster with electrodes to be monitored
Modem
DSL Firewall
Client
Main office

Cave and Tunnel Detection



The Sting Cave





Cave 2, the Sting cave, was detected during a test measurement over a previously known cave, Cave 1. This cave shows lower resistivity than the Sting cave as Cave 1 has floor to ceiling columns which act as current conduits. The Sting cave does not have any columns. Both caves were confirmed by drilling large diameter, 24 inch, entrance holes. Depth to ceiling for Cave 1 is 1.8 m, for Cave 2 is 7.3 m,

The resistivity section above was calculated from the apparent resistivity data using the RES2DINV automatic inversion software. The graphical presentation was made using the Surfer for Windows software.

Survey date:	October 29, 1994
Method:	Dipole-dipole resistivity (dipole 4.6 m, n=8)
Unit:	Meter and ohmmeter
Instrument:	Sting/Swift, 28 electrodes at 4.6 m spacing
Survey time:	Set-up and take down 1 hour (2 man crew)
	Data acquisition 40 min

Courtesy of Gasch & Associates, Sacramento California

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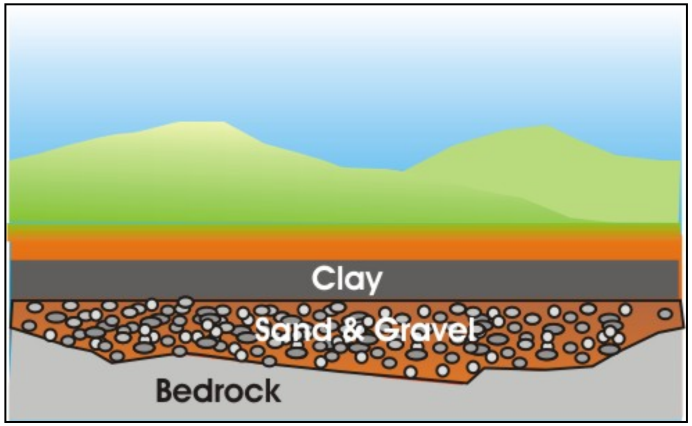
Cave 1 is a previously known cave.
The Sting Cave (Cave 2) was detected during a demonstration survey over Cave 1

Cave detection

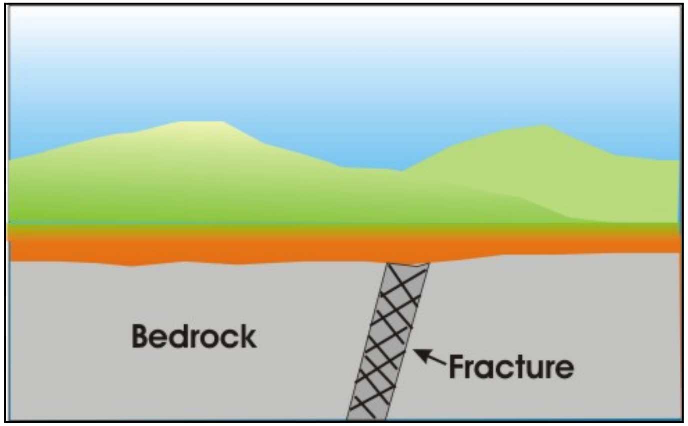
A previously unknown cave, the Sting Cave, was detected with the Sting/Swift system

Engineering Geology

- Mapping Bedrock



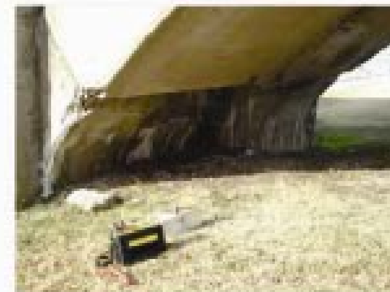
- Fracture detection



Electrical Resistivity Side Scanning Using the AGI SuperSting Resistivity Meter

Location of Field Test

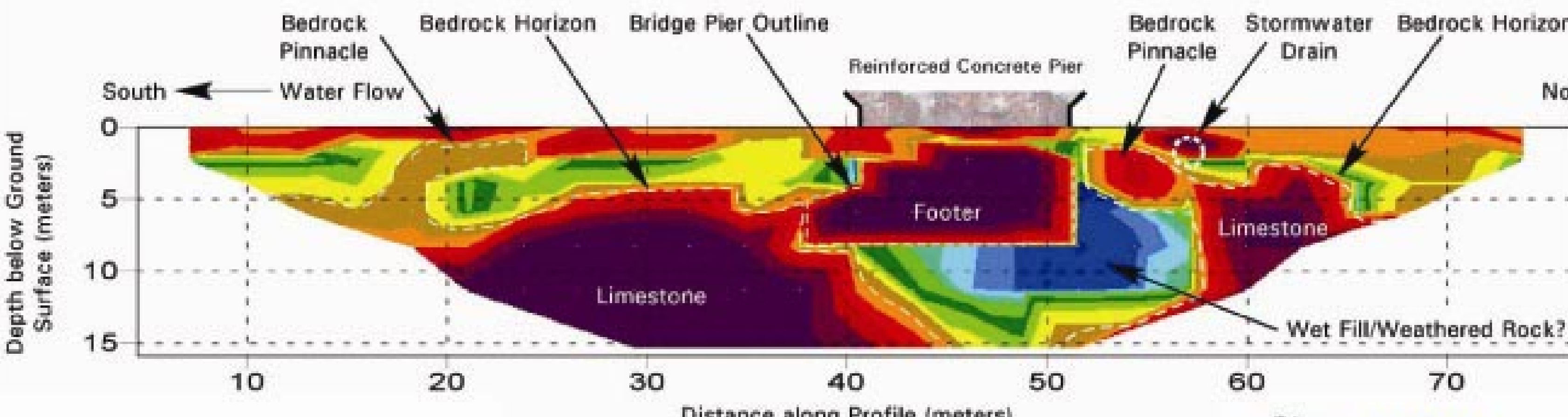
A 28-electrode AGI SuperSting Array with a 3-meter electrode spacing was oriented parallel to the bridge pier and water flow and approximately 2 meters from the pier. Modeling results indicate that adjacent subsurface structures can be mapped using electrical resistivity to image the size, depth and orientation of the target structure and surrounding earth materials.



Inactive Railroad Bridge Over the Susquehanna River, Harrisburg, Pennsylvania

Note that the bridge pier is not detected until the depth of sensing has approximately equaled the distance that the array was positioned from the structure. This is consistent with theoretical models.

Resistivity/Depth Cross-Section



Courtesy of

GTS TECHNOLOGIES

Harrisburg, Pennsylvania

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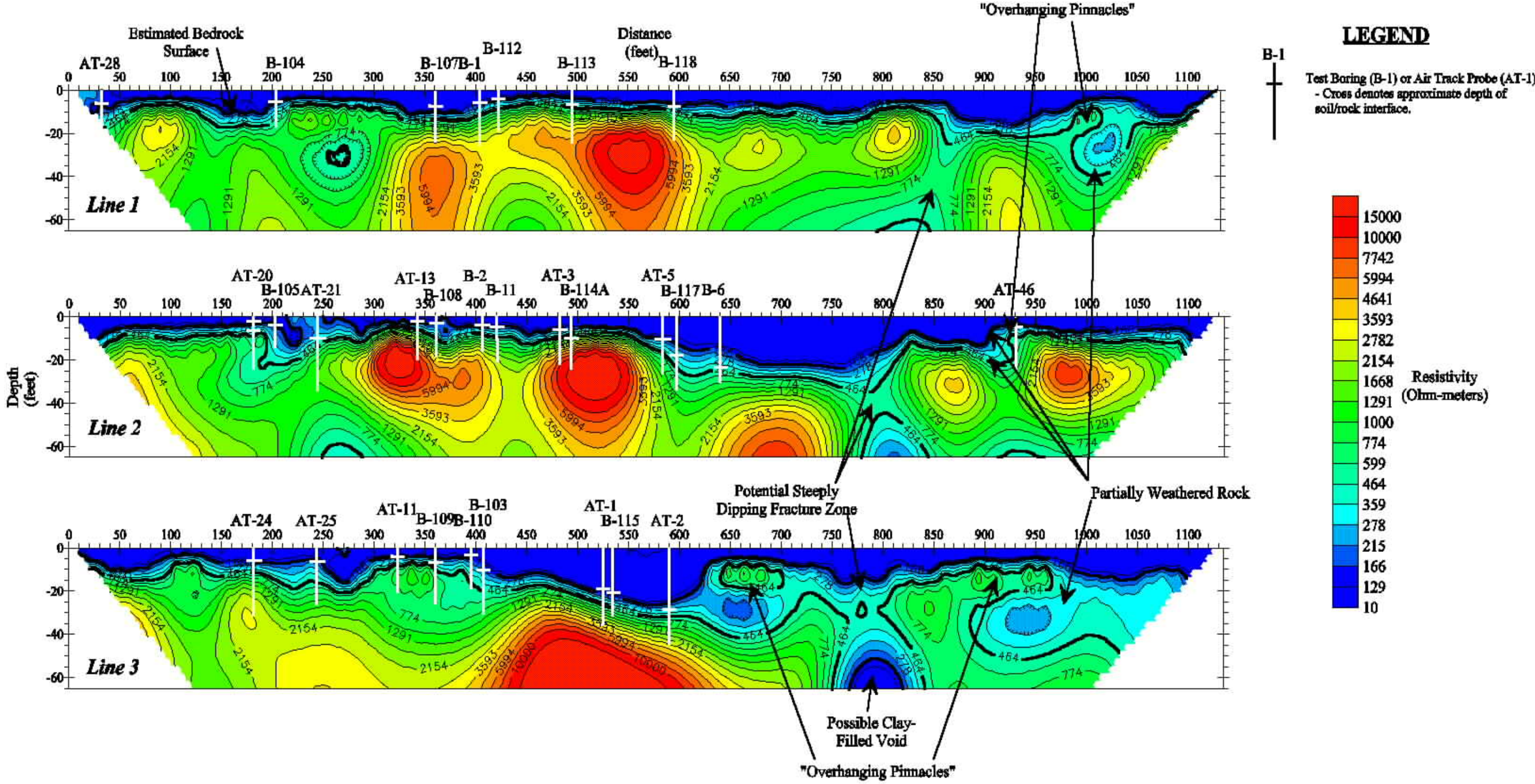
Bedrock Mapping in Karst Terrain



- Boring lines show approximate locations and depths. Most borings were not located directly over the resistivity traverse and therefore some variation from the resistivity profile should be expected.
- Resistivity measurements were obtained at discrete electrode spacings.
- Resistivity contours were interpolated from the data points.
- Data was recorded in a dipole-dipole electrode array, using a Sting/Swift automatic resistivity system, with electrodes at 5 meter intervals.

- The three two-dimensional resistivity profiles presented show correlation between test borings and air track probes and the estimated bedrock surface from resistivity data in karst terrain. The thickened contours show estimated disintegrated rock and bedrock surfaces, respectively. Areas of very high resistivity were probed and determined to be dry, competent limestone.

SCALE:

Horizontal: 1" = 100'
Vertical: 1" = 50'

Courtesy of

Schnabel Engineering

Web site http://www.schnabel-eng.com

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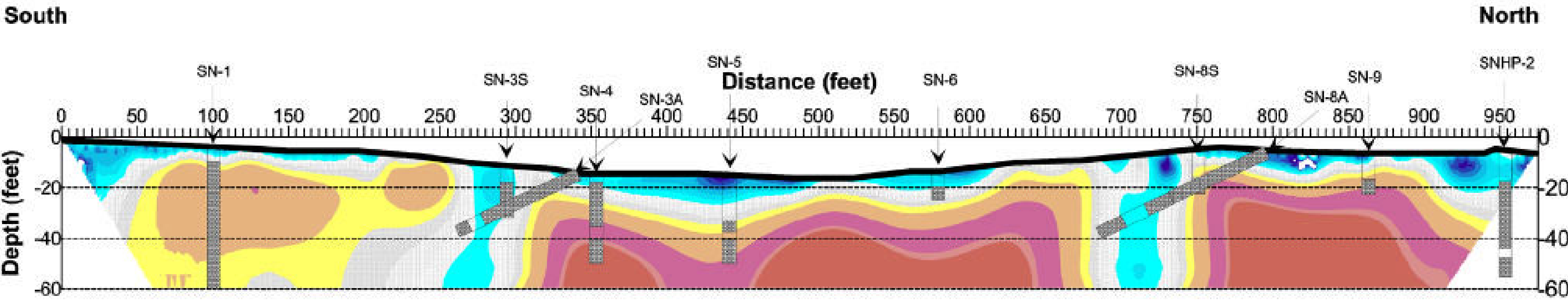
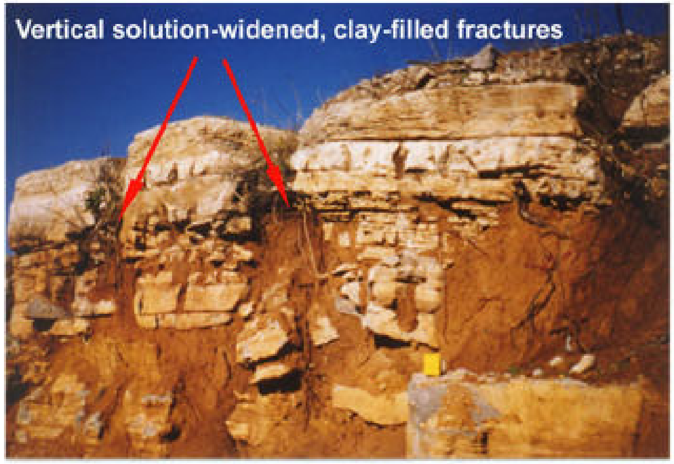
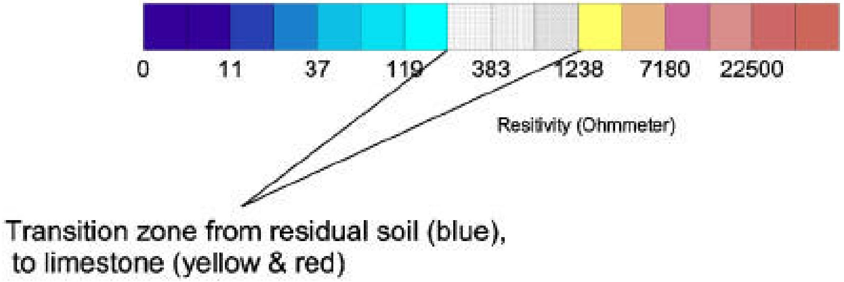
Karst Investigation



Electrical Resistivity Profile Showing Borehole Locations and the Presence of Bedrock



Vertical solution-widened clay-filled fractures, seen at a road cut in the area.



Objective: To map the bedrock and its vertical solution-widened fractures.
Survey date: June 2000.
Location: Nashville, Tennessee.
Survey site: The site is underlain by Carters Limestone of Ordovician age. Vertical solution-widened fractures are of the main concern for the site development.
Instrument: Sting/Swift, 56 electrodes at 5 ft spacing, with 9 roll-alongs (moving 14 electrodes each time).
Units: Feet and Ohmmeter.

The Sting/Swift system

Courtesy of

PELA TENNESSEE OFFICE
Geologists, Hydrogeologists & Geophysicists Specializing in Karst
P.E. LaMoreaux & Associates, Inc.

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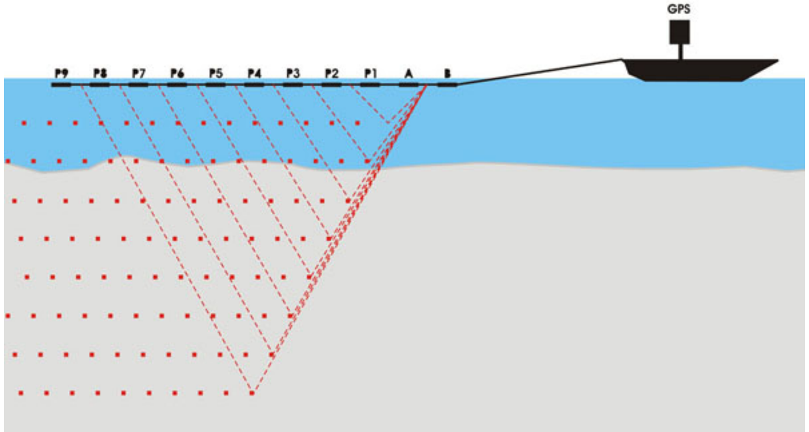
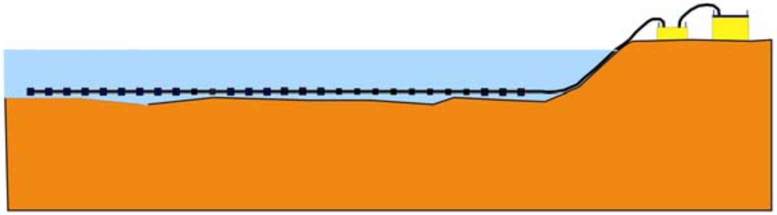
Aquatic Resistivity Imaging

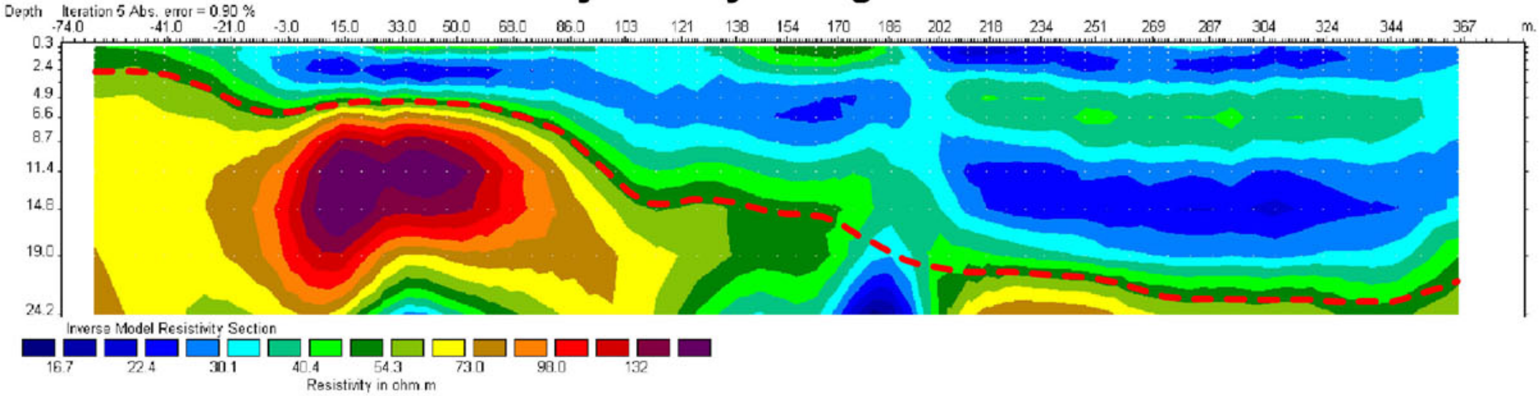
- Towing an electrode streamer behind a boat



- Electrodes placed on the bottom



Lake Resistivity Survey Using Towed Elecrodes



The water depth (dashed red line) has been estimated from a depth map. The lake bottom consists of limestone. Resistivity changes within the water column possibly depends on water temperature.

The SuperSting with towed electrode array. The electrode cable is connected in the top left corner of the front panel, the power (12 V DC) is connected at the lower left corner and the GPS is connected at the top to the right.
The SuperSting is an 8-channel instrument, meaning that it records 8 readings for each time it injects current. By having the receiving electrodes at different spacing from the current electrodes, 8 depth readings is measured for each current injection.

The sea electrode is made of graphite (patent pending), the advantage is that it does not corrode as current is passed through it. The towing cable has a kevlar member and water block.

The Marine Module of the Administrator software is used to plot the survey line. The black line shows the total path run, the red line shows the extracted resistivity profile in the resistivity image above.

Objective: Test of towed electrode array
Survey date: January 10, 2002
Survey site: Lake Travis, Austin, Texas
Instrument: SuperSting with 11 electrodes at 10 meter spacing towed at the surface behind a boat
Array type: Dipole-dipole
Units: Meter and Ohmmeter

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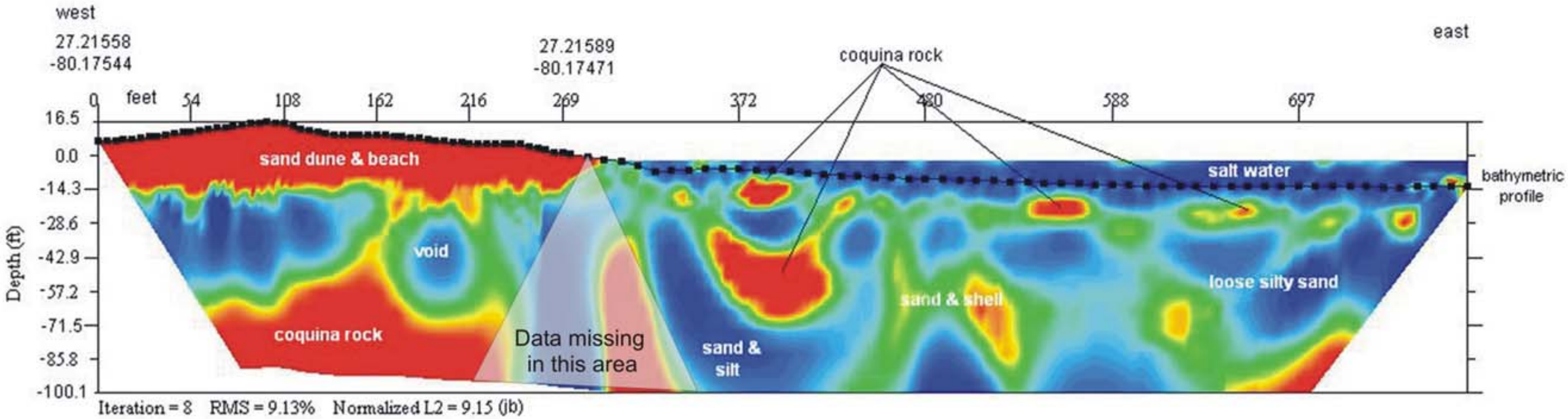
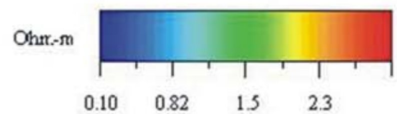
Florida Oceanographic Society's Marine Park Water Intake





Coquina rock is a soft porous limestone composed of broken shells, corals and other organic debris.

A resistivity imaging survey was performed by N.S. Nettles & Associates, to be used for design of two horizontal water well intakes for the Florida Oceanographic Society's marine park. The well screen is to be placed in the zone of the greatest shell content, as depicted by the increased resistivity compared to the surrounding sands.

Data for a land to sea resistivity imaging profile was aquired using the AGI SuperSting R8/IP resistivity imaging system. Data was processed using the EarthImager software. The electrodes at sea were simply placed at the bottom, no other connection was needed. The EarthImager software provided the terrain correction both under and above water.

Survey date: February 22, 2005
Electrode array: Dipole-dipole
Units: Feet and Ohmmeter
Instrument: SuperSting R8/IP
Processing: EarthImager 2D software

AGI EarthImager 2D

SuperSting instrument and EarthImager software by

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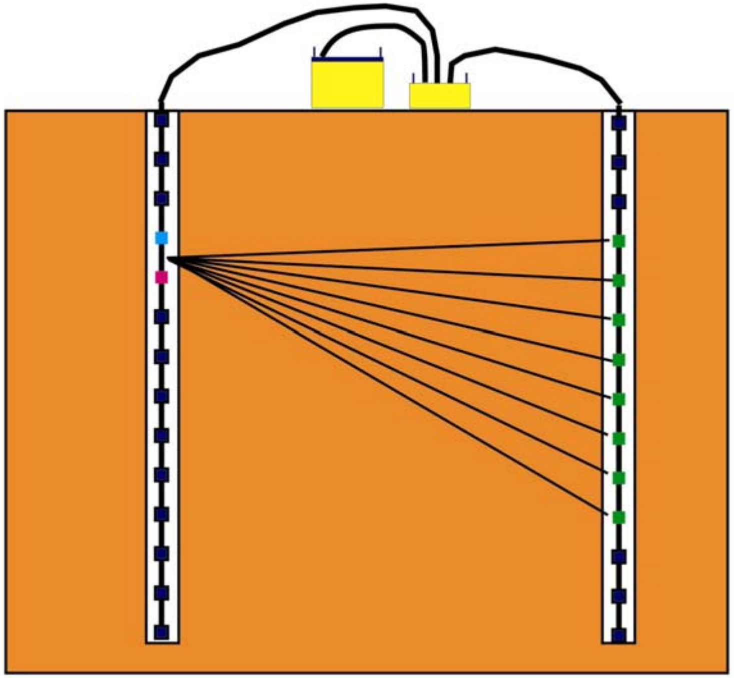
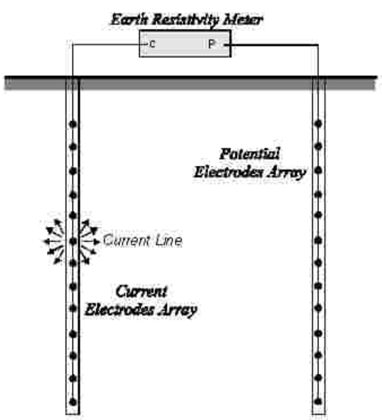
Data courtesy of
N.S. Nettles & Associates, Inc.
Palm Harbour, Florida, USA

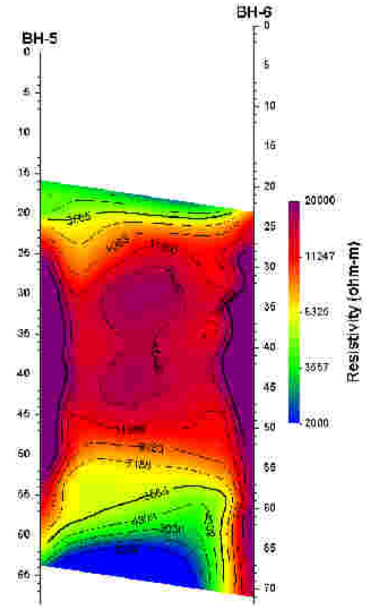
Electrical Resistivity Tomography



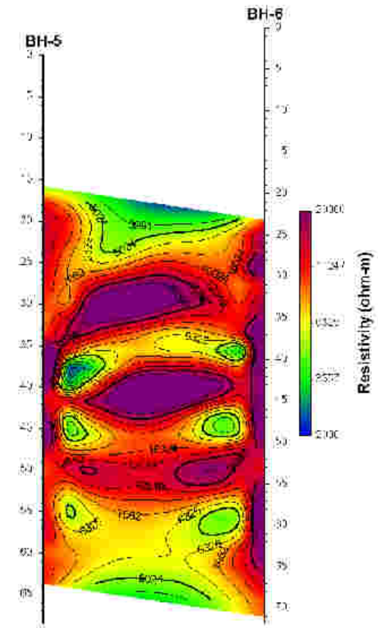
Using Electrical Resistivity Tomography (ERT) to Monitor Brine Movement



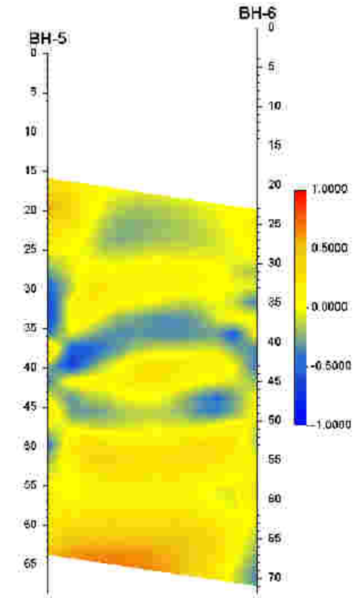
Typical field set-up for a bore hole tomography survey.



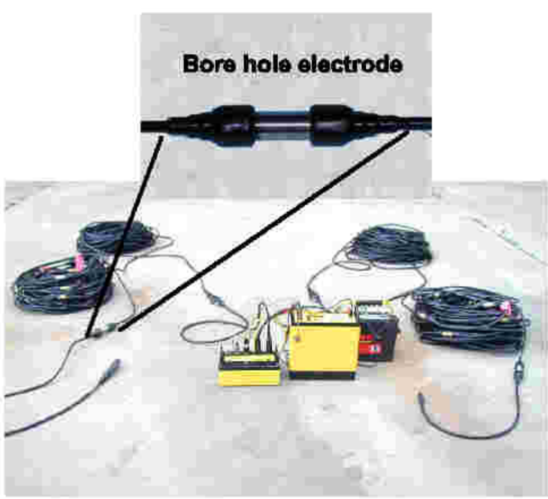
The resulting electrical resistivity tomogram before brine injection.



The resulting electrical resistivity tomogram after brine injection.



The difference between the "before" and "after" tomograms displayed as the logarithm of the ratio of the two resistivities.



The AGI Sting/Swift borehole equipment.

Hyundai Institute of Construction Technology in cooperation with Korea Institute of Geology, Mining & Materials (KIGAM) performed a cross-borehole resistivity survey using the Sting /Swift system with bore hole cables. The survey was performed between two bore holes approximately 80 meter deep and 26.7 meter apart. Data was recorded both in-line (current and potential electrodes placed in the same bore hole) and cross-bore hole using the pole-dipole electrode array. The first data set was recorded prior to injecting a brine solution. A 0.05 ohm-m brine was then injected at 33 meter in BH-5. The injection lasted two days; 100 liters the first day and 200 liters the second day. A second resistivity cross-bore hole survey was performed 10 days after the brine injection. To visualize the difference between the two tomograms the logarithm of the ratio of the two resistivities was calculated and plotted. In the index, +1 indicates a 10-fold increase in resistivity and -1 a 10-fold decrease. The zones of reduced resistivities could be interpreted as the ground water preferential flow paths between the two borings.

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Courtesy of Hyundai Institute of Construction Technology and Korea Institute of Geology, Mining & Materials

Instrument prices

Number of electrodes	SuperSting R1/IP Single channel	SuperSting R8/IP 8-channel
28 electrodes	$22,484.00	$30,184.00
56 electrodes	$30,328.00	$38,228.00
84 electrodes	$38,292.00	$46,692.00
112 electrodes	$49,296.00	$58,156.00

Prices includes: Instrument, electrode cables, stakes and utility program. EarthImager software is extra.

EarthImager 2D is $2,800

EarthImager 3D is $3,400

EarthImager 2D & 3D combo (both programs on one dongle) is $4,000

If you would like to get more information on the electrical resistivity imaging technique or our SuperSting, automatic Resistivity & IP imaging instrument you can contact me at:

Mats Lagmanson

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