Resistivity Surveying

Using the

OhmMapper

Capacitively Coupled Resistivity System (CCR)

from Geometrics



What is Resistivity Surveying?

- Method of measuring electrical current in the ground to image beneath the ground surface
- Detects many kinds of features
 - layering
 - folds, faults
 - bedrock
 - voids and cavities
- Widely understood and used by earth science community



What does the OhmMapper measurement tell us?

- Using resistivity measurements the OhmMapper detects changes in the content and structure of the earth's subsurface.
- changes in clay, water content, and mineralization
- weathering in faults and fractures

- depth of sediment to bedrock
- contaminant plumes
- geothermal activity
- shallow aquifers
- location of voids and cavities



How is earth resistance measured between the transmitter and receiver?



In conventional resistance, a specified current is injected into the ground using probes connected to a DC power source. The resulting measured voltage is used to calculate the ground's resistance to current flow by Ohm's Law,

$\mathbf{R} = \mathbf{V}/\mathbf{I},$

where **R** = resistance, **V** = voltage, and **I** = current.



How is resistivity ρ_a determined?

Resistance will vary depending on the distance and geometry between the probes so it is normalized with the addition of a *geometric factor* that converts the measurement to

resistivity, (expressed in ohm-meters)

eg

$$\rho_a = 2\pi a V/I$$

for equally spaced galvanic electrodes (Wenner array)

CCR: Principles of Operation

Similar to Galvanic (Direct Contact) Resistivity
 Geometric 'K' Factor used to Calculate ρ_α, s.t.

$$\rho_a = K\Delta V/I$$

Contact is made CAPACITIVELY at frequency of approximately 16 kHz.



CCR: Calculation of K Factor

from unpublished Russian paper on Timofeev's work on CCR, translated by G. Rozenberg, edited by J. Hunter

$$\frac{1}{K} = \frac{\Delta V}{\rho_{\omega}I} = \frac{1}{\pi} \int_{0}^{l_{1}} \int_{0}^{l_{2}} \frac{I(L_{1})}{I(L_{1}=0)} \frac{I(L_{2})}{I(L_{2}=0)} \frac{dL_{1}dL_{2}}{R^{3}}$$
$$K = \frac{l\pi}{\ln\left[\left(\frac{b^{2}}{b^{2}-1}\right)^{2b} \left(\frac{b^{2}+2b}{(b+1)^{2}}\right)^{(b+2)} \left(\frac{b^{2}-2b}{(b-1)^{2}}\right)^{(b-2)}\right]} \quad \text{where} \quad b = \frac{2R}{1}$$

Geometric factor for the equivalent galvanic measurement: K

$$=\left(\frac{4l^2}{R}-R\right)$$



Capacitively Coupled Resistivity

Traditional resistivity uses probes hammered into the ground



CCR uses antenna dragged along the ground





What is dipole-dipole resistivity?



Like some configurations of traditional galvanic resistivity, the OhmMapper uses a dipole array to measure resistivity





How are the dipole cables coupled to ground?

- Dipole electrodes are coaxial cables
- Coaxial shield acts as one plate of capacitor and is driven by 16.5 kHz AC signal.
- The earth acts as other plate of capacitor.
- Insulator acts as dielectric of capacitor
- AC signal passes from cable to earth via capacitance. DC signal is blocked.



How Capacitive Coupling Works



CCR: Field Deployment

OhmMapper
 console and
 antenna array





Resistivity: How it works

The earth can be considered an array of resistors





How does the receiver know what current the transmitter is generating?

The OhmMapper uses a patented modulation scheme, in which the transmitter's AC current is communicated by a lower-frequency signal. In this way the transmitter current is encoded in the transmitter signal itself.

At the receiver the measured voltage is demodulated to "decode" the transmitter signal and thus extract the current information.

What is a plan-view survey?

Making measurements on multiple lines with a constant transmitter-receiver separation will give a plan-view map of the site, but does not give depth information.

An estimate of the depth to which the targets can be detected in the plan-view mode is approximately half the transmitter-receiver spacing when N = 1.



5-Line Planviews of OhmMapper Data with N =0.25 and N = 0.5





How is a depth section made with traditional galvanically-coupled dipole-dipole resistivity?



Probes hammered into the ground at predetermined distances

Probes moved after each measurement

Occasionally a switch system used to select probes

Very time consuming!

How is a depth section done with the OhmMapper, capacitively-coupled resistivity measurement?



A series of measurements are made along a profile by towing the array with a constant transmitterreceiver separation. Then the transmitter-receiver distance is changed and the OhmMapper is again pulled over the same profile giving another series of readings, but corresponding to a greater depth.



How deep can you detect targets with the OhmMapper TR1?

Depth increased by larger Tx/Rx distance. Same as in DC resistivity.

- For n =1, depth = 0.416 x dipole length (a).
- For n = 3, depth = 1a.

n = separation between Tx and Rx dipoles/dipole length





Depth of Investigation

- Although the array geometry determines depth of investigation practical limits of depth of are determined by ground resistivity.
- Signal attenuated by 1/r³
- By Ohm's Law V=IR therefore high R gives high signal V. Receiver can detect transmitter at long Tx/Rx separation in resistive earth. Low R gives small V so transmitter must be near receiver in conductive earth.
- Can get more separation and therefore greater depth in resistive earth.



Repeatability comparison of two different OhmMapper pseudosections taken over same profile in opposite directions. (Reciprocally)

- Top pseudosection: All traverses from north to south.
- Bottom pseudosection: All traverses from south to north.
- Horizontal axis in distance along profile. Vertical axis in N-space.





OhmMapper depth section from data collected over weathered granite using 10meter dipoles and multiple separations

Data inverted with RES2DINV by Dr. M.H. Loke





Detection of Cavity in Karst

The following slides show a test in which an OhmMapper was dragged over a known cavity. The position of the cavity matches well with the high-resistivity target in the depth section.



WREDCO OhmMapper Survey, Line 0 East Cavity detection study in West Texas Photo courtesy of Jay Hanson





OhmMapper image over Line O East

Data taken by Jay Hanson of Wredco. Inversion by RES2DINV. With permission of Barr Engineering Co.



NETRICS

Cavity? Uncovered!

- This 1 meter wide cavity was located at the 31 m position on the transect. Its roof thickness is about 1 meter. The cavity's height is 2.5 meters and its length is 6-8 meters.
- Photo courtesy of Jay Hanson, WREDCO





Litigation survey for cavity under private house

The next slide shows the results of a survey done to determine the cause of damage to a home in Florida. The results from an OhmMapper survey was evidence that proved the damage was the result of a karst cavity under the house. See details in St. Petersburg Times article at web site www.sptimes.com and search on OhmMapper.



Results of OhmMapper survey over suspected karst cavity. The highly resistive area near surface is taken as proof of cavity. Study done by R.C. Kannan Assoc. of Largo, FL





Bedrock mapping

The following slide shows the results of an OhmMapper survey to map bedrock. The conductive (blue) top layer is taken to correspond to the sedimentary layer. This was confirmed by the observation that the areas on the depth section showing no sediments generally corresponded to rock outcropping.



Bedrock Mapping. Courtesy of Wredco Geophysical, Spooner, WI

WELL LOG - Line 300W @ -245 meters south



Agricultural soil mapping

The next slide shows the results of a US Dept. of Agriculture OhmMapper survey in an experimental corn field. Harvest productivity was compared to depth of top soil. Those areas that show very shallow top soil map well to low-productivity areas. Deep top soil, as mapped on the depth section, corresponded to higher productivity.



Mapping of bedrock in cornfield. Courtesy of USDA





Tracking fracture zones

The next slides shows the results of multiple profiles done with an OhmMapper. The contractor interpreted the continuation of similar resistivities from line to line as indicating the strike of geologic structures, perhaps indicating the presence and direction of fracture zones.



Bedrock mapping for ground water survey. Courtesy of Enviroscan of Lancaster, PA



Fracture zones #2

The following slide is another example of possible fracture zones shown in multiple OhmMapper resistivity profiles.



Weather Fractures from Groundwater survey. Enviroscan, Lancaster, PA



Test image of known culvert

The next two slides show a culvert detected with the OhmMapper using both a set of 5-meter dipoles and an experimental set of 1.5 meter dipoles.



Culvert imaged with OhmMapper using 5m dipoles.

The image below shows a resistive body centered at 72 meters, with a depth to its center of 2 meters. This is the red structure located half way between the 53 and 93 meter tick marks, and it corresponds exactly with the true location of a plastic-pipe culvert.





Culvert imaged with experimental 1.25 meter dipoles.

The image below shows a resistive body centered at 72 meters, with a depth to its center of 2 meters. This is the red structure located half way between the 53 and 93 meter tick marks, and it corresponds exactly with the true location of a plastic-pipe culvert.





Archeological Surveying

The next slide was taken over the location of a suspected Roman Amphitheater in England. The survey was run using multiple parallel lines with a single Tx/Rx separation in order to do a fast reconnaissance of the area. Although the site has not yet been excavated the circular feature shown in the planview map indicates the presence of the walls of the amphitheater.



Archeological Survey of Possible Roman Amphitheater in England. Planview map





Can the OhmMapper be used for a 3-D Survey?

The OhmMapper can be used to collect 3-D data sets. This is done by doing multiple passes with different Tx-Rx spacings on a single profile, then repeating this process for 2 or more profiles. 3-D data sets can be processed in non-Geometrics software.



3-D OhmMapper Survey

OhmMapper data inverted by RES3DINV and volumetrically imaged in Slicer/Dicer.





3-D OhmMapper data

Data inverted by RES3DINV and imaged in Slicer/Dicer





How are the OhmMapper measurements logged and stored?



The OhmMapper uses the same console as the Geometrics portable, cesium magnetometer, the G-858 MagMapper. The mapping console allows the operator to set up a survey grid with reference points that will allow positioning of data on a contour map.





CCR: Field System

Data Mapping Console and Instrument Module





What are the EM (electromagnetic) effects on a capacitively-coupled resistivity measurement?

The skin-depth effect is a limiting factor for depth of investigation in conductive environments. Accurate depth calculations cannot yet be made when the distance between the transmitter and receiver is greater than 1 skin depth. Skin depth is defined as the following:

$\delta = 500 \text{ SQRT } (\rho/f)$

where δ = skin depth, ρ = resistivity, f = frequency eg: f=8 kHz, ρ =20ohm-m, δ =25m

Applications for Capacitively-Coupled Resistivity

Monitoring dykes and levees for damage and leaks.

Shallow minerals exploration

Shallow ground-water exploration

Monitor environmental sites for leakage plumes

EM34 Profile Over Gravel Channel

EM-34 TRAVERSE T-12 EAST STOCKTON WATER DISTRICT SAN JOAQUIN COUNTY, CALIFORNIA



GEOCONSULTANTS, INC. G1148-01 4/98 FIGURE 14



OhmMapper Profile Over Gravel Channel,N = 2.5, Dipole = 10 m, 15 meters between ends of Tx and Rx





Comparison of galvanic dipole results with OhmMapper results

The data on the right was taken with the OhmMapper and inverted with software developed by KIGAM in Korea. The data set on the left was taken at the same place, but with a traditional galvanic, multi-electrode resistivity meter. The color scales are identical.



Comparison of OhmMapper TR1 survey with galvanic multi-electrode resistivity

OhmMapper TR1 dipole-dipole





Sting-Swift Dipole-Dipole

playgnd_5 (Field Data Pseudosection) AGI Sting-Swift Galvanic Dipole-Dipole



Data Courtesy of KIGAM (Korean Institute of Geology, Mining, and Materials)



Playgnd_5 (2-D Resistivity Structure) () <

playgnd_5 (Theoretical Data Pseudosection)



playgnd_5 (2-D Resistivity Structure)



Comparison of galvanic multielectrode measurements with OhmMapper #2.

This next slide compares an area of overlap of a multi-electrode, galvanic survey and an OhmMapper survey. The scales are the same. Although there is only about 40 meters where the two surveys overlapped the depth sections show close similarities. The color scales are identical.



Comparison of OhmMapper TR1(top image) with Sting-Swift(bottom image).

Iteration 5 RMS error = 9.6 % Depth 49.0 9.0 29.0 0.2 2.7 5.0 8.6 Inverse Model Resistivity Section 25.0 50.0 200 400 800 1600 3200 100 Resistivity in ohm.m Unit electrode spacing 1.3 m. Iteration 5 RMS error = 7.8 % Depth 0.0 10.0 20.0 30.0 40.0 0.4 3.7 7.4 Inverse Model Resistivity Section 25.050.0100 200 800 1600 3200 400 Resistivity in ohm.m Unit electrode spacing 2.5 m. WREDCO GeoSurveys - Spooner, WI (USA) ETRICS



Repeatability test of OhmMapper pseudosection in well-drained sandy soil. Top pseudosection all passes in north-south direction. Bottom pseudosection all passes in south-north direction.

10-meter dipoles. Separations of 2.5, 5, 10, 15, and 25 meters (N = 0.25, 0.5, 1, 1.5, 2, and 2.5)



Depth section from OhmMapper data taken on well-drained sandy soil. Inversion done with RES2DINV by Dr. M.H. Loke.

Dipole length = 10 meters. Dipole separations of 0.25, 0.5, 1, 1.5, 2, and 2.5





Summary of Signal and Data Flow

- Current generated in Tx OhmMapper Tr1 Signal and Data Flow
- Current flows in ground
- Rx measures voltage
- UV/mA sent to logger
- Data file transferred to P(
- MagMap2000 sections
- RES2DINV inversion





Dual-Receiver OhmMapper TR2





Comparison of TR2 and TR1 results

The pseudosections on the right were generated with a TR2. Those on the left were generated with TR1 data taken over the same profile lines.



TR2 (left) vs TR1 (right) Comparison





Advantages of Capacitively-Coupled Resistivity

- Fast data can be collected at a walking pace
- Portable one man operation
- Automatic can be vehicle towed
- Flexible can be used for profiling and sounding
- Versatile used an accessory for G-858 cesium magnetometer
- Low power works in very high resistivity environments without supplemental power



MetalMapper

- Mapping metal detectorSee shallow non-ferrous targets.
- Good for UXO work
- Add-on to G-858 magnetometer.
 - Inexpensive geophysical metal detector.







Metal Mapper sample data from Stanford Test Site showing underground pipeline and shallow buried targets.





Designed for magnetic and conductive soils

Unique dual-pulse technique allows the affect from magnetic soils to be balanced out of the target response. Giving superior performance to any metal detector in volcanic or other magnetic soils.

