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Marine Resistivity Survey on the Lagoon of Venice, Italy.

Introduction

During the week of May 5-11, 2003, the DelTech International Workshop was held in Venice, Italy. The workshop was organized by technical seminars, equipment demonstrations and a field trip.

As part of the equipment demonstrations, Advanced Geosciences, Inc. (AGI) participated with it's SuperSting Marine, towed resistivity imaging system.

A preparation survey was performed on May 5 and a final survey, of predetermined lines 1-4, was performed on May 8.

Figure 1 shows the total available resistivity data from the workshop. This report only treats resistivity data collected along lines 1 – 4 (see Figure 2.) Contact AGI for any other data collected during the workshop.

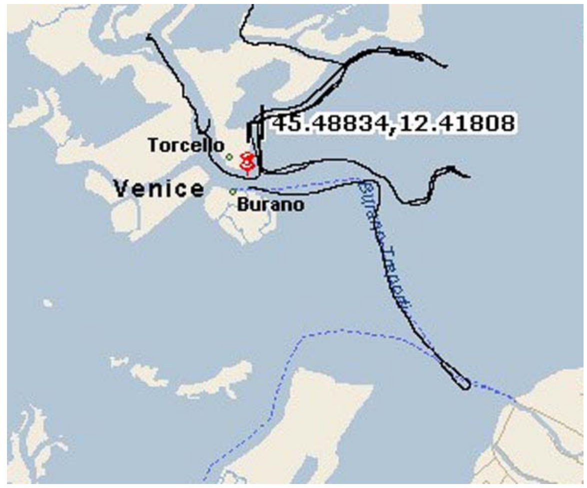

Figure 1 The black lines show GPS track of the boat. Resistivity data was collected on most of these lines and are available from AGI upon request.

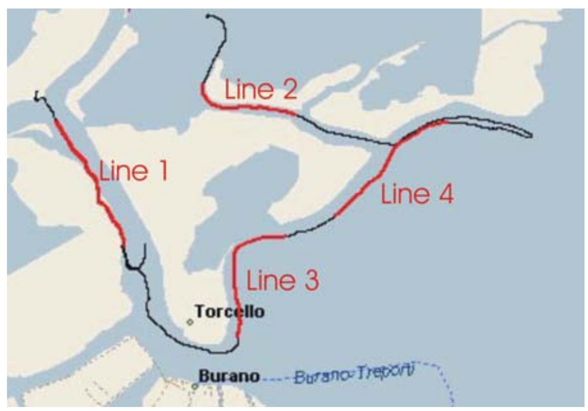

Figure 2 Location of lines 1 - 4.

Instrumentation and survey design

The survey was undertaken using the AGI SuperSting Marine system and a streamer with 11 electrodes at 3 meter intervals.

The SuperSting instrument has 8 receivers and a transmitter, making it possible to record eight readings simultaneously as the current is injected through the two current electrodes.

The streamer was towed at the surface of the water in such a way that the electrodes were totally submerged below the surface at all times. The two electrodes nearest the boat were used for current injection and the other nine electrodes were used for potential measurements.

An electric current was injected into the water approximately every 3 seconds through the two current electrodes. The resulting eight potential differences, between the following 9 electrodes, were simultaneously measured and recorded. The survey array could be considered a moving dipole-dipole electrode array.

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The boat was moving forward at about 1 – 2 m/sec. and a measurement consisting of eight readings was performed approximately every 3 seconds. The actual measurement time was 920 msec, therefore each reading reflects measurement over a distance of 0.9 – 1.8 meter.

The distance between the transmitter (the two current electrodes) and each receiver (each pair of potential electrodes) determines the depth of penetration. If the water is shallow enough, the measurement will penetrate into the bottom. Typically with this array, the method will see 25% of the electrode spread length, into the water and bottom. Using 11 electrodes at 3 meter spacing gives a maximum electrode spread length of 30 meters. The expected depth of investigation, with this electrode arrangement, was therefore 7.5 meter from the surface and down. In order to see into the bottom, this arrangement is not suitable for water depths of much more than 2-3 meter.

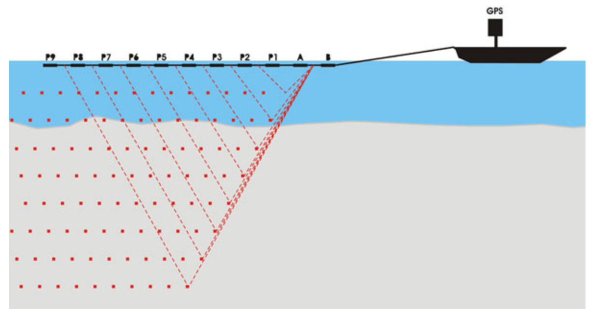

Figure 3 Current is injected into the water every 3 seconds and 8 potential differences is measeured simultaneously as the boat moves forward.

A longer streamer with 6 meter electrode spacing and an expected depth penetration of 15 meter was available, but could not be used because of the heavy boat traffic on the Venice lagoon. This cable was only used at some limited areas of the lagoon and was not used at all on the survey lines 1 – 4.

A GPS receiver was placed on the boat and the SuperSting was time synchronized with the GPS, making it possible to later on, calculate the location of each electrode, assuming that the electrode cable trailed the boat track.

Figure 4 The SuperSting Marine instrument

A fathometer was time synchronized with the GPS and used for entering a priori information about water depth during the inversion modeling. The fathometer also had a sensor which records the near surface water temperatures.

Result

The SuperSting records injected currents and induced voltages, which are converted into apparent resistivity based on the electrode geometry. To process the data, the electrode locations, depth, and temperature data are projected onto the boat track in the AGI Marine Log Manager software. The AGI EarthImager modeling software with the Continuous Resistivity Profiler (CRP) module is then used to construct a continuous

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resistivity cross section below the electrodes. The EarthImager with the CRP module is capable of inverting kilometers of marine resistivity data in minutes on a regular PC.

The processed results of lines 1-4 are included in this report. The position of the lines and number of data points are listed in the Table 1 below.

Table 1 Location and length of lines 1-4.

	Start Lat.	Start Long.	End Lat.	End Long.	Number of data points	Survey direction	Distance Meter
Line 1	45.49858	12.40797	45.49284	12.41247	1,831	NW to SE	760
Line 2	45.49873	12.42290	45.50003	12.41686	846	E to W	549
Line 3	45.48853	12.41939	45.49341	12.42198	1,092	S to N	718
Line 4	45.49419	12.42457	45.49872	12.43135	1,182	SW to NE	758

The result of the survey is an image in terms of electrical resistivity. Figures 5 – 8 shows the result along lines 1 – 4. Note that the resistivity cross sections in these figures have a vertical exaggeration. A jpg-file where each line is presented with approximately the same depth and length scale is attached with this report. There is also an X, Y and Z ASCII file attached for each of the lines 1 – 4.

All cross sections are presented with the same resistivity color scale in figures 5 – 8. A white line indicates the bottom as measured with the fathometer. The start and end latitude and longitude for the profiles are given in the figures. The surface water temperature along the line is plotted in a separate diagram below the resistivity cross section.

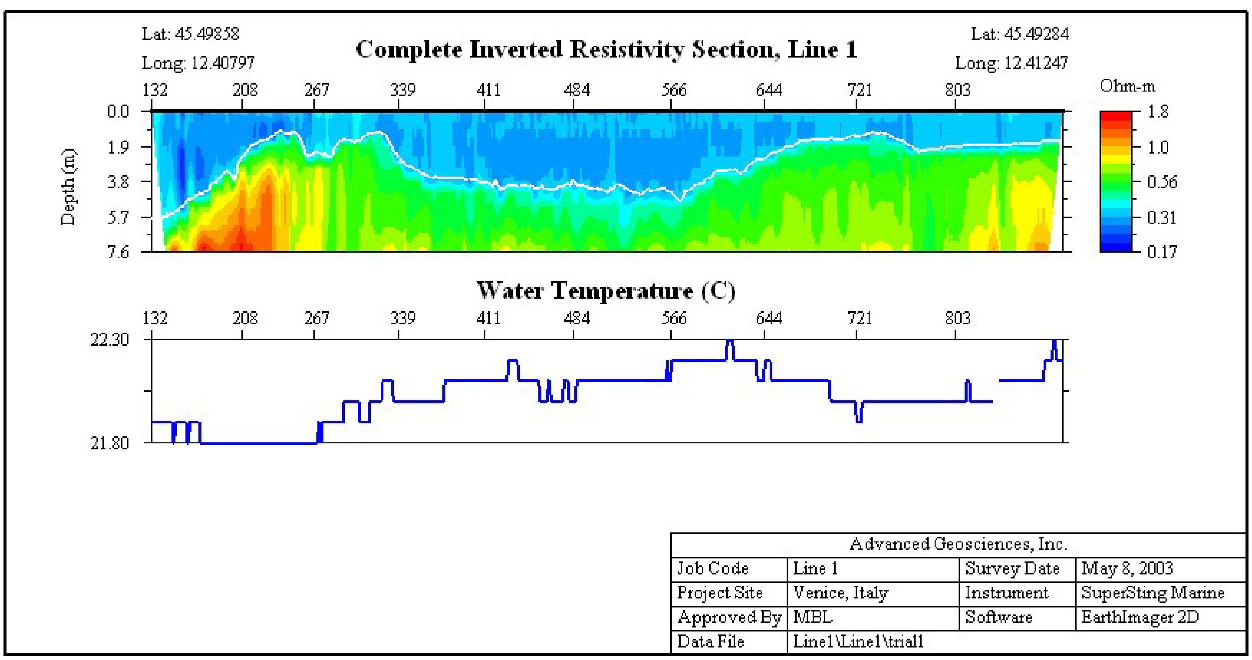

Figure 5 Line 1, resistivity cross section.

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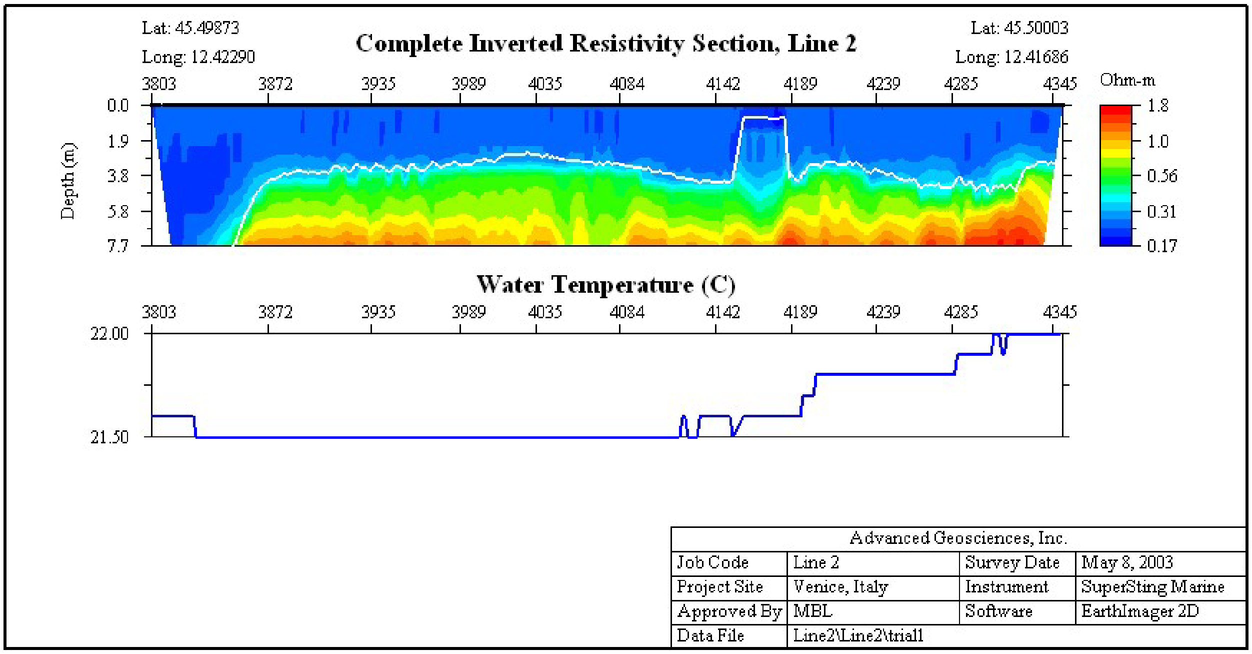

Figure 6 Line 2, resistivity cross section.

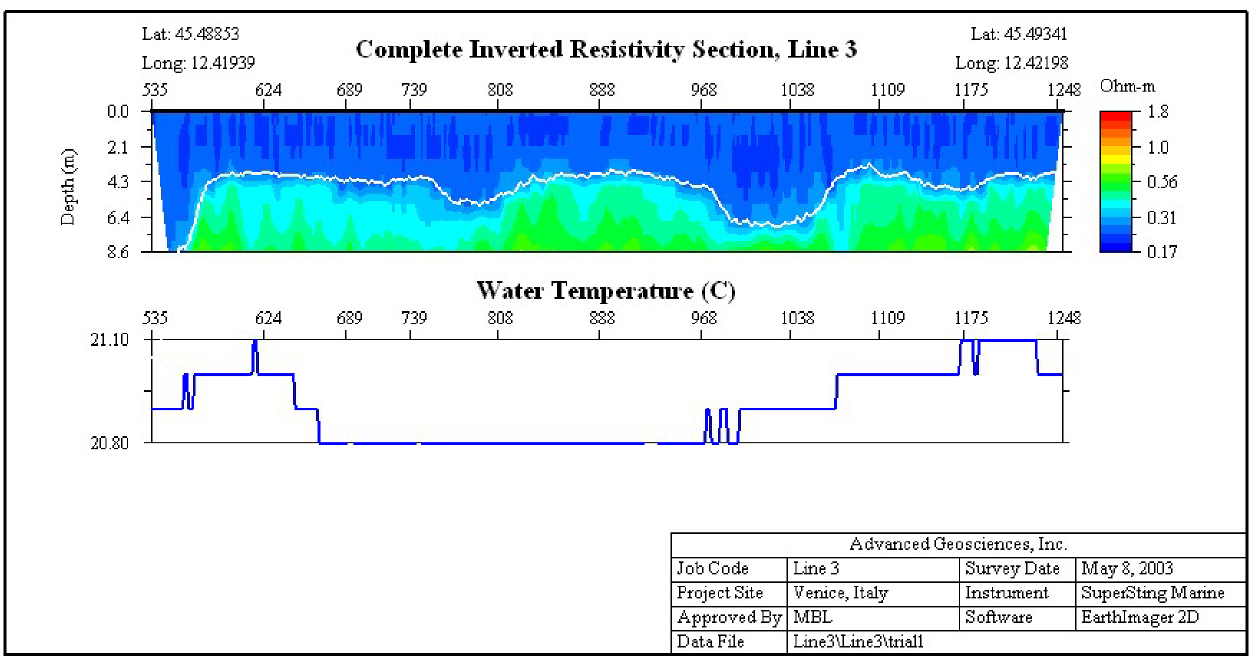

Figure 7 Line 3, resistivity cross section.

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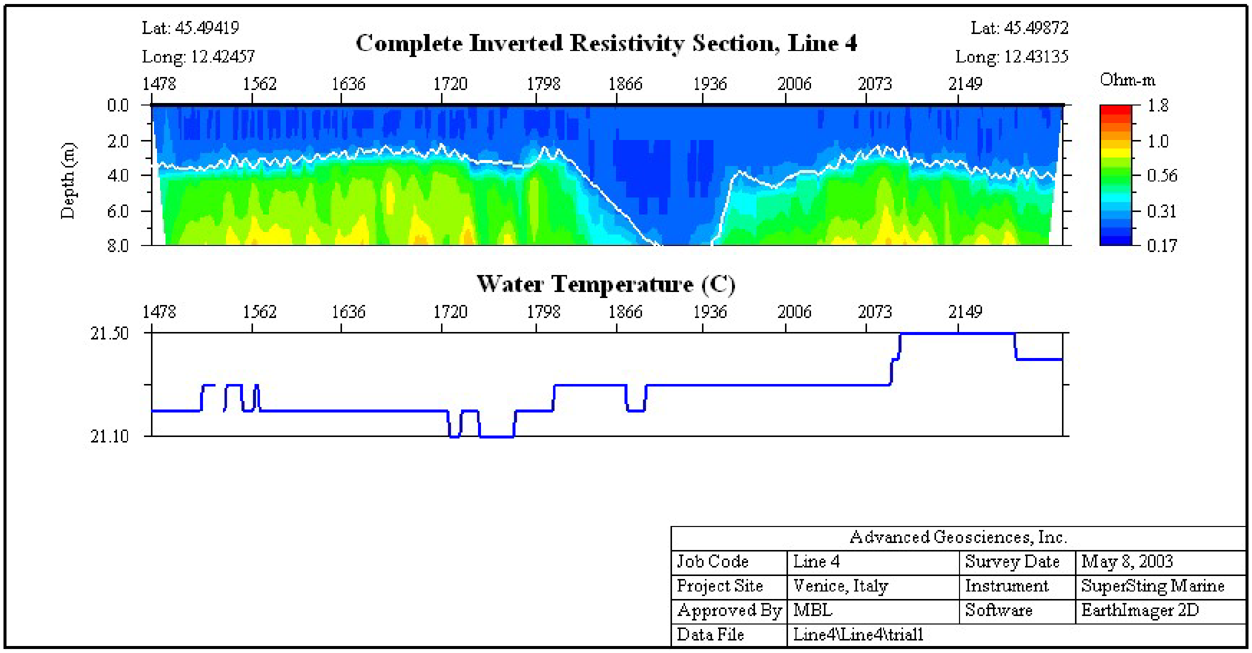

Figure 8 Line 4, resistivity cross section.

Interpretation

Table 2 Resistivity of water and some geological formations.

Materials	Resistivity (ohm-m)
Tap water	20 – 30
Sea water	~ 0.2
Saline water (3%)	0.15
Saline water (20%)	0.05
Surface water (sediments)	1 – 100
Surface water (igneous rocks)	0.1 – 3,000
Clay	5 – 150
Sand (valley)	360 – 1,500
Sand (dunes)	6,200 – 7,700
Gravel	480 – 900
Limestone	350 – 6,000
Sandstone (consolidated)	1,000 – 4,000
Igneous rock	100 – 1,000,000

Resistivity is a material property; different materials, geological and others, have different resistivity. The table to the right shows the resistivity of some common materials found in nature. It is important to remember that the values of the different geological formations represent material in fresh water environment.

The most important factors which affect the resistivity of different geological material are:

- Porosity
- Moisture content
- Dissolved electrolytes
- Temperature (resistivity decreases with increasing temperature)

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- Conductivity of minerals

Since the geological formations vary in porosity, moisture content, and mineral composition even within the same geological formation, the resistivity typically covers a wide range. It is therefore important to know the geology in the area of investigation or have geological information from a borehole in the area when interpreting resistivity data.

Note that distilled water has very high resistivity and gradually becomes more conductive (less resistive) with more dissolved solids. Therefore resistivity is sometimes used as a measure of the quality of ground water.

The relationship between material resistivity, fluid resistivity, and porosity is expressed by an empirical relationship called Archie's Law : $\rho_t = a\rho_w\phi^{-m}$

Where ρ_t is the bulk resistivity
ρ_w is the resistivity of the water contained in the pore structure.
Φ is the porosity expressed as a fraction for unit volume of rock.
m is the cementation factor which varies between 1.3 and 3
a is a proportionality constant varying from 0.6 to 1.5
The a and m are parameters whose values are assigned empirically to make the equation fit a particular group of measurements.

For example, Keller gives a=0.88 and m=1.37 for "weakly cemented detrital rocks, such as sand, sandstone, and some limestones with a porosity range from 25 to 45% usually Tertiary in age" (Keller, G.R.,1987, Rock and Mineral Properties, in Nabighian, M.N. (ed.), Electromagnetic methods in applied geophysics- Theory, Vol. 1: Soc. Expl. Geoph., 13-52.)

According to Archie's law the above mentioned material, fully saturated in fresh water (50 Ohmmeter), would give a bulk resistivity range of 131 – 294 Ohmmeter and in sea water (0.2 Ohmmeter) 0.53 – 1.18 Ohmmeter. Therefore one can expect much lower resistivities in the bottom sediments of the Venice lagoon, than the values given in Table 2 above.

Resistivity varies widely, depending on the interstitial water. This is the reason why the electrical resistivity method is an effective tool for mapping salt water intrusion in coastal areas.

The resistivity values found along lines 1 – 4 vary in the range 0.17 -1.8 Ohmmeter. This indicates that the pore space in the sediments is occupied by salt water.

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Conclusions

This investigation produced inverted resistivity cross sections for the 4 lines of investigation. Several interesting observations can be made:

- The inverted resistivity cross sections show surprisingly good resolution considering the conductive sea water environment.
- Based on Archie's law, the resistivity anomalies encountered in the Venice Lagoon survey roughly reflects the porosity variation (high resistivity = less porosity) in the bottom sediments.
- All sections show that evidence of resistivity gradient agree with the fathometer depth.
- Continuous resistivity profiling have shown effective in rapidly imaging large areas.
- Continuous resistivity profiling has the potential of being an important tool for the study of freshwater/saltwater interaction.
- The SuperSting Marine package is a streamlined system facilitating fast and trouble free marine resistivity imaging surveys.

Acknowledgements

We thank the Renard Centre of Marine Geology at the University of Gent for putting this workshop together and making boats, accommodation and equipment available. Our particular thanks go to Ms. Tine Missiaen who worked hard to pull the workshop together.

List of Deliverables

Attachements to this report:

- Lines 1 – 4 compressed length included as figures and jpg-files.
- Lines 1 – 4 with depth scale approximately the same as the length scale, delivered as jpg-files.
- X, Y, Z ASCII data file for lines 1 – 4.

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