Multi-electrode resistivity imaging for environmental and mining applications

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Summary

For a few years, the evolution of electronic components and of computer processing have permitted to develop field resistivity equipment (SYSCAL Switch and SYSCAL Pro Switch units) which includes a large number of electrodes located along a line at the same time, and which carries out an automatic switching of these electrodes for acquiring profiling data.

The apparent resistivity pseudo sections measured with such a technique are processed by an inversion software which gives interpreted resistivity and depth values for the anomalies detected along the profile.

The multi-electrode resistivity technique consists in using a multi-core cable with as many conductors (24, 48, 72, 96, …) as electrodes plugged into the ground at a fixed spacing, every 5m for instance. In the resistivitymeter itself are located the relays which ensure the switching of those electrodes according to a sequence of readings predefined and stored in the internal memory of the equipment. The various combinations of transmitting (A,B) and receiving (M,N) pairs of electrodes construct the mixed sounding / profiling section, with a maximum investigation depth which mainly depends on the total length of the cable.

The 2D resistivity images obtained with such a multi-electrode technique are used for studying the shallow stuctures of the underground located a few tens of metres down to about one hundred metres depth; these images supply an information which complements the one obtained with the more traditionnal Vertical Electrical Sounding (VES) technique, which mainly aims at determining the depths of horizontal 1D structures from the surface down to several hundreds metres depths.

Several examples are presented for various types of applications: groundwater (intrusion of salt water in fresh water), geotechnics (detection of a fault in a granitic area), environment (delineation of a waste disposal area) , archaeology (discovery of an ancient tomb) and mineral exploration (detection of a metallic orebody).

Principle of multi-electrode resistivity imaging

For a few years, the evolution of electronic components and of computer processing have permitted to develop field resistivity equipment (SYSCAL Switch and SYSCAL Pro Switch units) which includes a large number of electrodes located along a line at the same time, and which carries out an automatic switching of these electrodes for acquiring profiling data.

This technique, called Resistivity Imaging or Electrical Resistivity Tomography (ERT), finds applications in the environment, groundwater, civil engineering and archaeology fields. The images which are obtained (apparent resistivity pseudo sections) are processed by an inversion software which gives interpreted resistivity and depth values for the anomalies detected along the profile.

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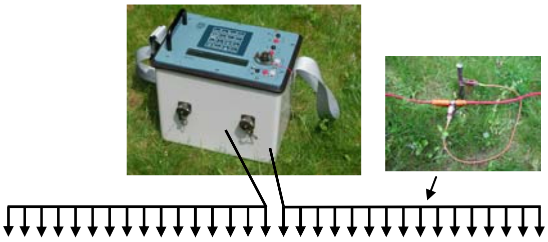

Figure 1 : SYSCAL Switch multi-electrode equipement

Various types of electrode combinations can be used, such as Dipole-Dipole, Wenner-Schlumberger, Pole-Pole arrays. Each type of combination has advantages and limitations in terms of lateral resolution and vertical penetration for instance, as summarized in Figure 2.

Arrays		**DIPOLE - DIPOLE**	**WENNER - SCHLUMB**	**POLE - POLE**
Main criteria	Resolution Depth Field set-up	best weak regular	regular regular regular	weak best weak
Other criteria	Amplitude Natural noise Coupling noise	weak regular best	regular regular regular	best weak weak
CONFIGURATION ESTIMATED INVESTIGATION DEPTH		A B M N a na a L **about 0.2** x **L**	A M N B na a na L **about 0.2** x **L**	B A M N a L **about 0.9** x **L**

Figure 2: Properties of electrode arrays

Depth of penetration in electrical imaging profiles

In electrical methods, the depth of penetration is linked to the distance between electrodes. For a set of 48 electrodes spaced at 5m, two segments with 24 electrodes each are usually used, the resistivitymeter being placed between both segments; the total length of the cables is 240m. In a first approximation, for Dipole Dipole, Schlumberger and Wenner arrays, the maximum depth of penetration is of the order of 20% of the total length of the cable, or 50m in the present case. This depth is reached for the combination of the two extreme left and the two extreme right electrodes of the profile, and the measuring report plotting point corresponds to the bottom angle of the triangle of the pseudo section. For a Pole Pole array, where one current and one potential electrodes are placed at infinity, this depth reaches 90% of the total length, or 220m in the present case (Loke, 2000).

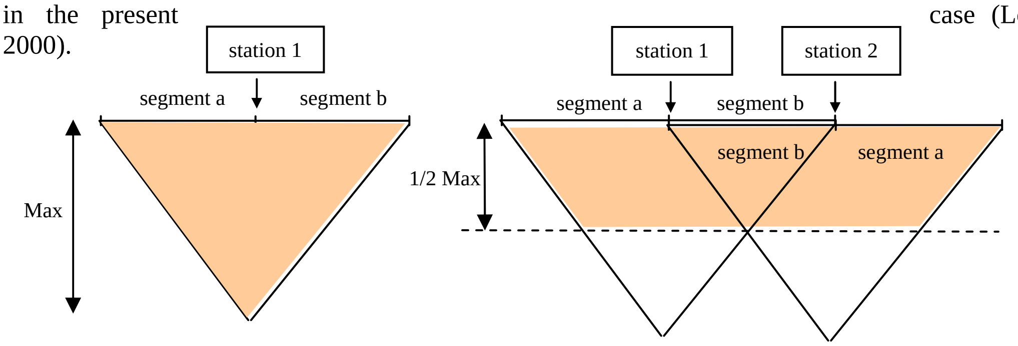

Figure 3: Depth of penetration in multi-electrode resistivity measurements: simple configuration (on left); roll along configuration (on right)

When the length of the profile to explore is greater than the length of the cable, after a first set of readings taken at station 1 with the segments a and b, the operator has to move the first segment a after the end of the second segment b and take a second set of readings at station 2 using segments b and a (see Figure 3), and so on, according to so called "roll along" sequences, until the end of the profile to investigate. It is obvious from figure 3 that if the maximum depth reached for one single layout is "Max" at the extremity of the triangle, it will be "Max/2" for two successive layouts (with roll along) for a flat bottom part of the apparent resistivity image.

Acquisition time in multi-electrode imaging profiling

In such resistivity imaging techniques, the number of readings to take easily reaches several hundreds, and the output power and output voltage of the equipment become important factors to limit the number of stackings (repeated readings) necessary to reach a given quality of the measurements (which can be represented by the standard deviation) and thus to minimize the acquisition time in the field.

In the past three years, multi-channel units have been developed to measure simultaneously several readings (up to ten with the SYSCAL Pro Switch resistivitymeter), so as to drastically reduce the total acquisition time in such techniques. For instance, for a 48 electrode 5m spacing Pole Dipole array, a required quality of 1% in a standard noise, a 100 ohm.m average resistivity and a 2.5 kohm ground resistance, the duration of acquisition of 500 readings is 25 minutes with a 600V output voltage one channel unit (SYSCAL R1Plus Switch 48), while it decreases down to only 2minutes with a 800V output voltage ten channel unit (SYSCAL Pro Switch 48). Such new design of equipment makes nowadays more realistic the acquisition of surface or borehole 3D data, for a more precise description of the bodies responsible for resistivity anomalies in environmental applications.

Figure 4 : SYSCAL Pro Switch, ten simultaneous channel multi-electrode resistivity system, with 250W , 800V and 2.5A outputs

The operating procedure in resistivity imaging techniques

The procedure for getting resistivity imaging includes the following four successive steps :

Creating the sequence of measurements with a PC software ; the sequence depends on the number of electrodes, their spacing, the type of array (Schlumberger-Wenner, Dipole-Dipole, Pole Dipole, Pole Pole…), the investigation depth to reach; loading of this sequence into the memory of the resistivitymeter.

Taking the readings in the field, after the electrode resistance checking, and the introduction of the stack number which depends on the signal to noise ratio. During the measurements, the output voltage of the equipment is automatically adjusted to the level of the signal measured.

Transferring the data from the memory of the equipment to a PC, filtering of noisy data in relation with their standard deviation or on the level of the signal, introduction of the topography (electrode elevation), visualization of the results by level of investigation depth.

Inverting the data with a PC 2D software, which, after a certain number of iterations, gives the values of the interpreted resistivities (through a colour scale), and depths.

Examples of application of resistivity imaging for environmental studies

The multi-electrode resistivity imaging technique can be used in many applied geophysics domains such as Hydrogeology, Geotechnics, Archaeology, Environment, Mining exploration

Hydrogeology: intrusion of salt water within sediments

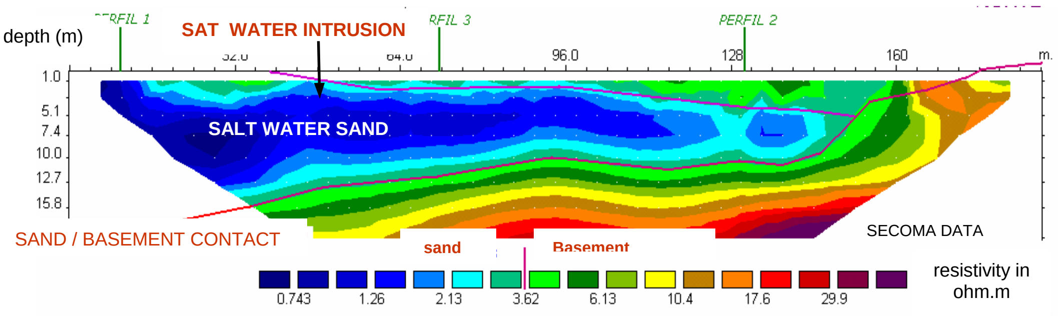

Figure 5: Salt water resistivity imaging (Spain)

In the management of the coastal aquifers, the intrusion of salt water coming from the see represents one of the major issues for the long term evolution of the fresh water resources. Through the important contrast of resistivity between salt water and fresh water, resistivity imaging permits to follow the limit between both types of waters at places where no drillhole is available. In the example of Figure 5 obtained in Spain (Wenner-Schlumberger array), salt water sands feature less than 1 ohm.m of interpreted resistivity, while the non invaded zone gives more than 20 ohm.m.

Geotechnics: localization of a fault in a granitic area

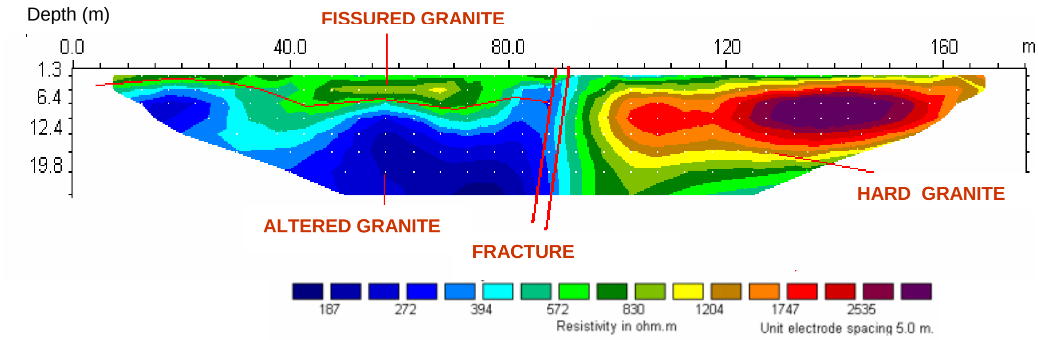

Figure 6: Fault resistivity imaging (Spain)

In linear civil engineering works (roads, railways, …), the detection of geological structures gives an important piece of information before control drillholes. In the example presented in Figure 6, a hard granit area is characterized by a value of interpreted resistivity greater than 2000 ohm.m, while alteration is under 200 ohm.m. A fault, clearly seen on the image separates both types of structures.

Environment: study of a waste disposal area

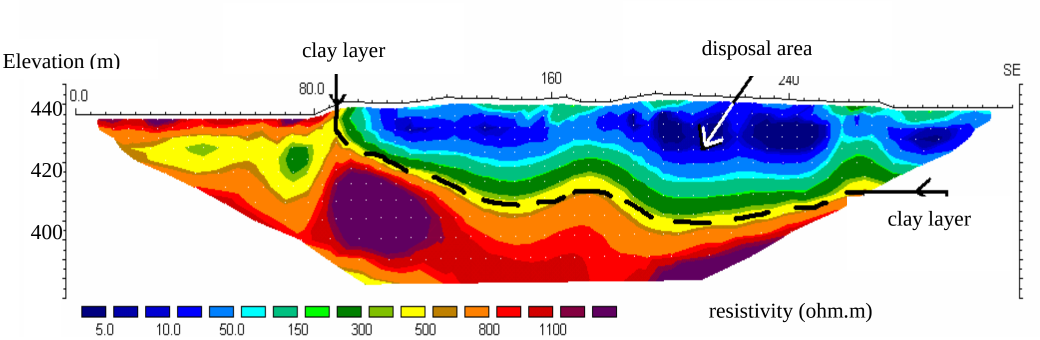

Figure 7: Waste disposal area resistivity imaging (France)

A new subject recently introduced in environmental projects is the control of waste disposal areas with geophysical methods (Guerin et al., 2004). Resistivity methods offer a good opportunity for such monitoring studies, as the resistivity contrast between the inside part of the disposals and the surrounding geological formations is generally high due to the high conductivity of the organic materials (lixiviates): in the example shown in Figure 7, these resistivities are respectively 10 ohm.m and 1000 ohm.m. Measurements carried out on the surface of the area and repeated at time intervals of months will give an idea of the evolution of the physico-chemical processes occurring in the wastes themselves.

Archaeology: detection of cavities close to the surface

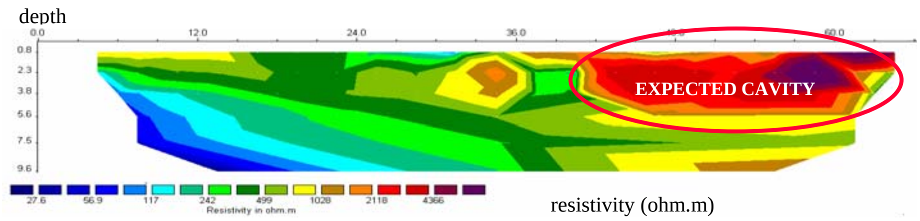

Figure 8: Cavity resistivity imaging (Middle East)

In civil engineering as well as in archaeology, the detection of cavities represents an important activity. A cavity filled with air located above the water level appears as a resistive object with respect to the surrounding formations. In the example of Figure 8, a set of 24 electrodes spaced at 3m has been used to detect an ancient tomb located within the first four metres depth: its interpreted resistivity is greater than 2000 ohm.m, while the sand and gravel layers remain lower than 500 ohm.m.

Mining exploration: delineation of a metallic orebody

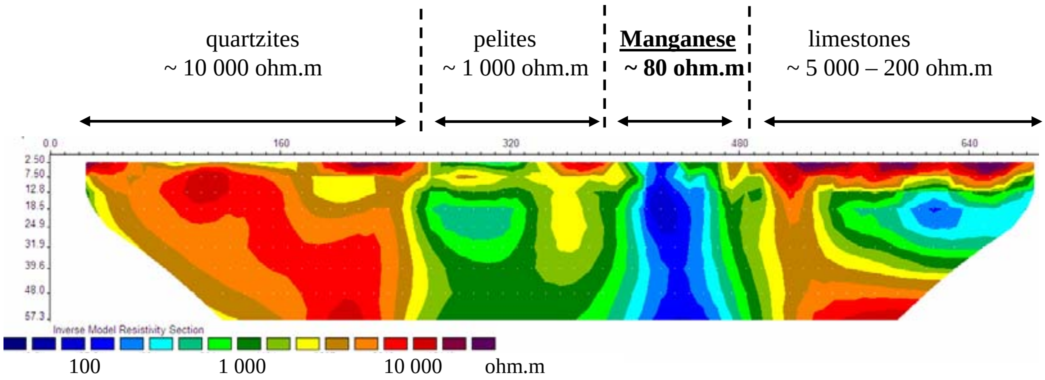

Figure 9: Cavity resistivity imaging (South America)

In mining exploration, most of the orebodies appeared as conductive bodies and can be detected in their more resistive background: in Figure 9, a Manganese orebody gives a conductive image of less than 100 ohm.m among quartzites, pelitic and limestones rocks of more than 1000 ohm.m. The 720m long profile has been measured with a SYSCAL Pro Switch equipment with 72 electrodes spaced at 10m, in a Schlumberger-Wenner configuration, with a measuring time of half an hour for the 2000 readings of the image.

Conclusions

The 2D resistivity images obtained with such multi-electrode techniques are used for studying the shallow stuctures of the underground located a few tens metres down to about one hundred metres depth; these images supply an information which complements the one obtained with the more traditionnal Vertical Electrical Sounding (VES) technique, which mainly aims at determining the depths of horizontal 1D structures from the surface down to several hundreds metres depths.

The newly developed multi-channel multi-electrode equipment will increase even more the field efficiency for both 2D and 3D studies. The automatic processes in the acquisition and the inversion of the data which simplify the work of the operators, but do not replace them for controling the quality of the measurements and for managing the equivalence properties during the interpretation phase.

References

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Loke, M. H., Electrical imaging surveys for environmental and engineering studies, a practical guide to 2D and 3D surveys, 2000, geoelectrical.com