A COMBINED GEOPHYSICAL SURVEY FOR HYDROGEOLOGICAL PURPOSES IN NORTH-EASTERN ITALY

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Abstract

An extended geophysical survey using electromagnetic and electrical methods (EM-34, VLF and VES) has been carried in a mountainous area in North-Eastern Italy (Southern Alps). The purpose of the geophysical survey was to provide information on the subsoil for the best location of water wells.
Several profiles were performed using a frequency domain low induction system with 20 m and 40 m separation distance between the two coils in order to obtain information on the electrical resistivity at the target depth (about 30-50 m). The resistivity values were calibrated using the results of some vertical electrical soundings. The electromagnetic survey was completed with VLF profiles along the same profiles of the low induction survey. Attention was focused on the faults, which are the potential groundwater path-ways, to their direction and structural features (infilling, opening, etc.). The geophysical results were calibrated through the drilling of a borehole, which confirmed the reliability of the geological model.

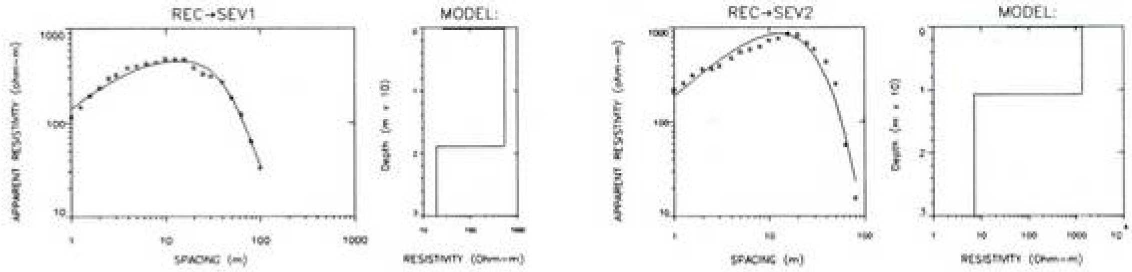
Foreword

The measurement of electrical resistivity of the subsoil has been used for groundwater exploitation for many years (Zohdy et al., 1974), using different configuration of electrodes array. The use of grounded electrodes can cause many problems in difficult terrain due to the physical coupling between the ground and electrodes and due to the necessity of large spacing between the current electrodes in order to obtain the expected survey depth. To overcome these problems, electromagnetic methods offer a valid alternative to conventional resistivity measurements and are sometimes the only tools that can resolve the groundwater problems. Published reports on the use of EM profiling in groundwater exploration cover a wide variety of field applications, dealing with the Slingram methods (Palacky et al., 1985) and low induction methods to study fracture zones in limestones aquifers (Wood and Stewart, 1985). EM or resistivity soundings are usually more effective than profiling to detect and delineate possible water-bearing levels; however, in many mountainous regions, groundwater flows in structures such as fractures zones in weathered crystalline rock. Unless the fractures are very wide, they cannot be detected by sounding techniques; they can instead be delineated using electromagnetic profiling.
An integrated geological and geophysical survey was carried out in a mountainous area in Northern Italy in order to outline the geological and hydrogeological features for a more rational exploitation of the groundwater resources. A previous geological survey had depicted the existence of dolomite and volcanic rocks, strongly jointed with fractures filled with clay and shale materials. An overburden, mainly composed of glacial sediments, was found above the dolomite and volcanic rock. The main geological features were previously outlined by aerial photo interpretation and by a detailed geological survey. In order to confirm the geologic model, a geophysical survey was conducted on two different zones of the area. The main goal of the survey was to validate the geological set up of the area, with reference to the lithological and hydrogeological features. The hydrogeological setting of the area is characterized by a high porosity aquifer within the bedrock with water paths along fractures and karst opening and channels; a shallow aquifer is located inside the overburden and is linked to the first aquifer. The chemical composition of the groundwater can be affected by the water circulating in the overburden and in some gypsum or anhydrite levels (evaporites). Springs used for drinking water supply are located mainly at the contact between the impermeable bedrock and the slope surface.

Data acquisition and elaboration

The survey was conducted in a rough topographic area using vertical electrical soundings (VES), very low frequency (VLF) and low induction electromagnetic profiling. The data acquisition can be summarized as follows: vertical electrical soundings employing the Schlumberger array with a maximun spread of 200 m; low induction profiles using EM-34 (Geonics) equipment in vertical and horizontal loop configurations; VLF profiles using an OMNI Eda receiver. The VLF response was probably affected from variations of the overburden thickness or changes in the near surface material conductivity; the results are not discussed in this paper.

The electrical survey pointed out the existence of an upper resistive layer which represents the detritical overburden and a very conductive bedrock, probably due to the strong degradation effects of the upper part of the volcanic bedrock: the presence of the conductive layer affected the depth of the electrical survey which was unable to obtain information at a depth greater than 20-25 m (see figure 1).



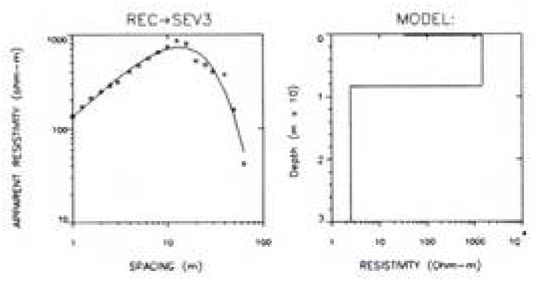
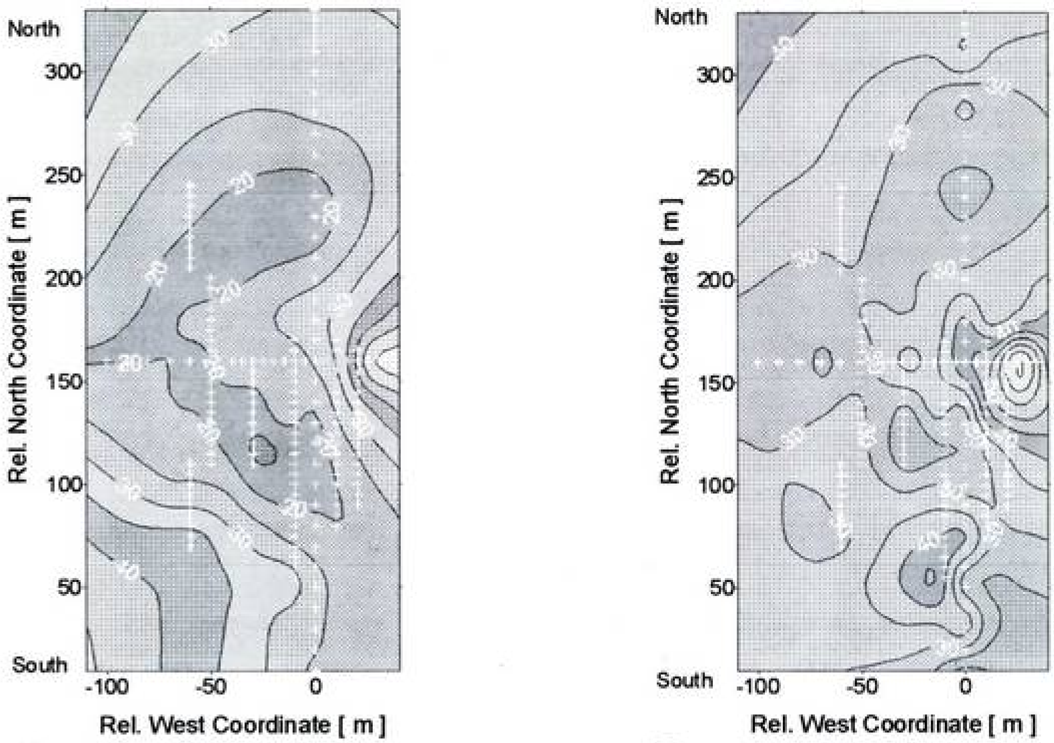


Figure 1: results of three VES; the interpretation pointed out a very conductive layer at the depth of 10-20 meters from the surface (probably the strongly weathered upper part of the bedrock); some lateral effects can affect the reliability of the interpretation model.

The acquisition set up of the electromagnetic *low induction* survey was organized along parallel profiles oriented along the North-South direction, perpendicular to the target strikes of the main faults and perpendicular to the water paths in the subsoil. An East to West profile was acquired using either vertical dipole (VD) and horizontal dipole (HD) modes with two different inter-coil spacings (20 and 40 m); a subsequent quantitative interpretation and a comparison with the results of some vertical electrical soundings was applied to this line.

The data processing involved the mapping of conductivity values with respect to the coordinates of each measurements station; both the VD and HD results of a survey using a 20 m inter-coil spacing are plotted in figure 2. A qualitative analysis of the maps of figure 2 outlines the presence of two areas with maximun conductivity values; these areas could be related to seepage zones. However, it has been shown that EM-34 HD mode is highly sensitive to near surface anomalies which can mask the conductivity response of the deeper levels (see also Goldstein, 1990).



A) B)

Figura 2 : maps of conductivity (mS/m) for the EM-34 survey using a 20 m inter-coil spacing in the vertical dipole mode (A) and horizontal dipole mode (B); the two maximun peaks depicted in figure (B) are well correlated to seepage zones.

A quantitative interpretation of the EM34 data can be obtained according to the formulation of the response of a layered earth proposed by McNeill (1980). The cumulative response (Rv and Rh for the vertical and horizontal dipole modes) gives the relative contribution to the secondary magnetic field or apparent conductivity (σ_a) from all the material below a normalized depth D with respect to the coil spacing. For a two layer earth with conductivity σ_1 and σ_2, the total response is due to the single contributions of each layer:

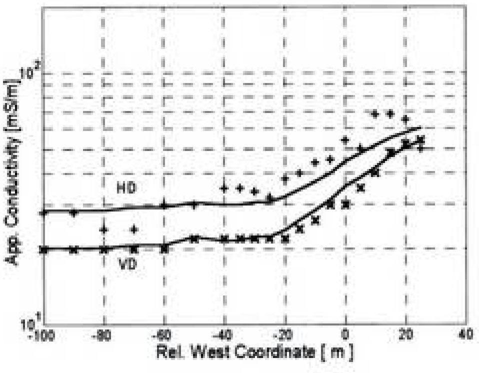
$$\sigma_a = \sigma_1[1 - R(D)] + \sigma_2 \cdot R(D) \qquad [1]$$

where R(D) is the cumulative response normalized with respect to the inter-coil spacing and the true depth of the second layer. It is possible to generalize the previous formula for earth with n layers:

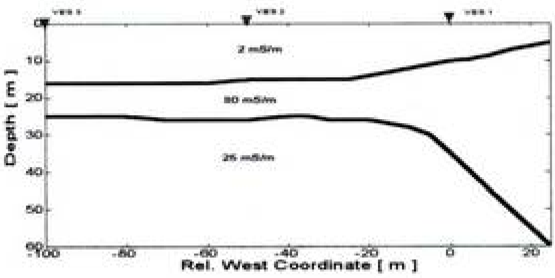
$$\begin{aligned}\sigma_a &= \sigma_1[1 - R(D_1)] + \sigma_2[R(D_1) - R(D_2)] + \ldots\ldots \\ &\ldots\ldots\ldots\ldots + \sigma_{n-1}[R(D_{n-2}) - R(D_{n-1})] + \sigma_n \cdot R(D_{n-1})\end{aligned} \qquad [2]$$

where $R(D_n)$ is the cumulative response for the normalized depth related to the interface of the n-th layer. This approach is much simpler than the inversion method suggested by Esparza and Gómez Trevino (1987) but it is quite effective for studying simple geologic model.

As can be seen in figure 3, the presence of a sub-vertical fault is well depicted in the interpreted section; a borehole confirmed the reliability of the interpretation. However, the model was forced in the East part of the profile due to the abrupt change in the depth of the bottom of the second layer; the discrepancy between the observed and predicted data regarding the HD mode can be due to the poor reliability of the model and the noise which affected the experimental data.



A)



B)

Figure 3: (A) Observed data (points) and predicted values (continuos lines) for the profile in the West-East direction (see maps of figure 2) for the inter-coil spacing of 40 m in the vertical dipole (VD) and horizontal dipole (HD) mode; (B) final model of the true conductivity obtained from matching data at two inter-coil spacing (20-40 m).

Final remarks

An integrated geophysical survey was conducted in a difficult terrain in the Alps with the main goal of obtaining information on the hydrogeological and geological setting of the area. The results of the EM34 mapping seem to reflect the near surface morphological features with a lack of information on the deeper levels; however, a quantitative interpretation of the EM34 profiles, performed using different loop configurations, allow one to achieve a reliable electrical model of the subsoil. The electromagnetic profiling technique, offered a good technical solution also in rough terrain and offered the possibility of delineating sub-vertical anomalies, which can be related to the main faults. The final geological and hydrogeological model was selected by integrating the geophysical survey with a borehole; the results obtained from the borehole were in good agreement with the electrical section. Deeper fractures and geological features, related to the hydrogeological setting, will be further investigated in a new geophysical survey using both TDEM and magnetic methods.

References

Goldstein, N.E., Benson, S.M., Alumbaugh D., 1990, Saline groundwater plume mapping with electromagnetics. Geotechnical and Environmental Geophysics, Vol, II: Environmental and Groundwater, Society of Exploration Geophysicists, Tulsa, OK, 17-26.

Esparza, F.J., Gómez Trevino, E., 1987, Electromagnetic sounding in the resistive limit and the Backus-Gilbert methods for estimating conductivities. Geoexploration, 24, 441-454.

McNeill, J.D., 1980, Electromagnetic terrain conductivity measurements at low induction numbers. Geonics Ltd. Technical Note TN-9.

McNeill, J.D., 1985, EM34-3 measurements at two inter-coil spacing to reduce sensitivity to near surface material. Geonics Ltd. Technical Note TN-6.

Palacky, G.J., Ritsemo, I.L., De Jong, S.J., 1981, Electromagnetic prospecting for ground water in Precambrian terrains in the Republic of Upper Volta. Geophys. Prospecting, 29, 932-955.

Wood, J.H., and Stewart, M.T., 1985, Geophysical and geologic characteristic of fractures zones in the Carbonate Floridian acquifer. Fla Wa. Resources Center, Pub. 88, Univ. Florida, NTIS PB86-156999.

Zodhy, A.A.R., Eaton, G.P., Mabey, D.R., 1974, Application of surface geophyiscs to groundwater investigations: Techniques of Water-resources Investigations of the U.S. Geol. Survey, Book 2, Chapter D1.