PHYSICAL AND STRUCTURAL CHARACTERISATION OF AN OLD LANDFILL SITE BY A MULTIMETHODOLOGICAL GEOPHYSICAL APPROACH

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SUMMARY: In the frame of an environmental reorganisation plan of an old landfill site (northern Sardinia, Italy), an integrated geophysical survey was carried out to delineate the landfill boundaries, to determine the nature and physical characteristics of the waste materials with special emphasis on outlining the distribution of the leachate and biogas, and to define the pattern of the encasing rocks.

1. INTRODUCTION

Landfills are amenable to geophysical investigations because they usually contain waste materials characterised by high electrical conductivities, high magnetic susceptibility and low seismic velocities. Moreover, the relatively high resistivity values of the bedrock as well as its high seismic velocity allow to delineate the landfill boundaries. Due to the complexity of the phenomena linked to waste disposals, a multi-methodological geophysical approach proved to be the best procedure and probably the only one capable of giving a highly meaningful answer to the general characterisation of a waste body (Cossu et al., 1997, 2001; Green et al., 1999; De Iaco et al., 2000). It is worth stressing that when a multidisciplinary strategy is used, the ambiguities inherent in each method are greatly reduced. In particular, in the investigated area a very detailed exploration was carried out by several geophysical techniques: frequency and time domain electromagnetism, very low frequency electromagnetic, geoelectrical and induced polarisation tomography, seismic refraction and tomography.

The study landfill is built on Miocene litotypes that mainly consist of limestones and marly limestones. These rocks are characterised by permeability that varies from maximum values where the limestones are interested by karstic phenomena, to minimum values where the fractures are cemented by clay materials.

2. GEOPHYSICAL PROSPECTION

2.1 Methods

The main task of the geophysical investigations was the accurate physical and structural characterisation of the waste body and the encasing rocks. Therefore considering the aim of the prospecting and the geological context of the investigated area, the geophysical methods chosen were electric (IRIS RS-2 SYSCAL), electromagnetic (GEONICS EM16, EM34, EM47) and seismic ( ).

In general, in the prospecting, the waste body stands out very clearly as a conductive zone. This is due to the low resistivity of the waste materials, lower than the resistivity of the encasing rocks. Seismic prospecting was well suited to define the thickness and the elastic characteristics of the waste body, to investigate the depth and quality of the encasing rocks and the possible presence of structural discontinuities that can guide leachates and gas migration.

2.1.1 Electromagnetic exploration

The Very Low Frequency (VLF) Electromagnetic (EM) method (Paterson and Ronka, 1971; Phillips and Richards, 1975) was applied using a GEONICS EM-16 VLF receiver. GQD broadcast (19.6 kHz – Anthorn, Cumbria UK) was chosen as transmitter providing maximum sensitivity, because its azimuth coincides with the strike direction of the most important geological structures of the investigated area. The VLF-EM survey was performed over the entire landfill on nine electromagnetic profiles spaced 50 m apart, respectively six profiles (VLF1-VLF6) with E-W direction and three profiles (VLF7-VLF9) oriented N-S. Readings were taken with a station spacing of 5 m, chosen on the basis of the objectives of the investigation and the required detail for the characterization of the waste materials. Measurement of real (in-phase) and imaginary (quadrature) components of the vertical magnetic field were performed.

The Frequency Domain Electromagnetic (FDEM) investigation (McNeill, 1990) was carried out along eleven profiles with the GEONICS EM-34 system. Nine profiles coinciding with the VLF profiles and the remaining two (FDEM10-FDEM11), N-S oriented, located in the central portion of the investigated area. On the basis of the maximum exploration depth and of the detail required for the landfill characterisation plan, 3 measurement sets were carried out along each profile using, respectively, a distance between the transmitting and receiving coil of 10, 20 and 40 m in the horizontal RH mode (with horizontal coil axes). These spacing have permitted to reach, respectively, penetration depths of 7.5, 15 e 30 m. Measurements of the imaginary (quadrature) component of the vertical magnetic field were performed.

The Time Domain Electromagnetic (TDEM) method (Fitterman and Stewart, 1986) was chosen to explore the northern and western landfill borders, not suitable for electrical prospecting due to the presence of anthropic obstacles (i.e. roads), with the main objective to outline eventual leachate escapes. Thirty TDEM soundings were performed using a GEONICS EM-47 transmitter and a Protem receiver. For each sounding, 3 data sets were collected corresponding, respectively, to Ultra-High (236,5 Hz), Very-High (62,5 Hz) and High (25 Hz) acquisition frequencies. The selected frequency bands allow us to explore a depth interval from 40 to 100 m below ground level.

2.1.2 Electric exploration

The electrical prospecting (ERT), consisted in geoelectrical and induced polarisation (IP) 2D tomographies, was carried out using the IRIS SYSCAL RS-2 multiectrode system designed for high resolution resistivity and chargeability measurements. The ERT survey was performed along nine profiles of which seven coincident with the VLF profiles and the other two with the FDEM10 and FDEM11 profiles. Measurements were carried out using a 48 electrodes switching configuration with an electrodic spacing of 5 and 10 m. Therefore, the length of the profiles is varied from a minimum of 235 m to a maximum of 470 m that allow us to reach exploration depths from about 40 m to 80 m below surface.

2.1.3 Seismic exploration

The seismic data were collected in different sectors of the landfill site using a 24-channel high resolution engineering seismograph, and the energy source was both mechanical and conventional by small explosive charges. Different shotpoint and geophone layouts were used depending on the exploration depth and the operative conditions.

3. RESULTS AND DISCUSSION

To assist the interpretation of the VLF-EM data, the in-phase values were processed using proper filtering techniques (Fraser, 1969; Karous and Hjelt, 1983; Ogilvy and Lee, 1991), particularly by the application of the Karous-Hjelt technique the maps of the spatial distribution of the current density in depth (pseudosections) were obtained. These maps represent 2D sections of the landfill body which provide useful information on the depth development of the conductive and resistive zones within the waste disposal.

By the analysis of the E-W trending pseudosections (VLF1-VLF6) it can be deduced that the highest variation in the conductivity is localized in the northern and in the southern sectors of the study area. They also exhibit an extended sub-vertical resistive zone localized in the central-western sector of the waste body, that develops from north to south. Also the N-S trending EM-VLF pseudosections (Figure 1), corroborate the condition of the diffuse conductivity in the landfill mainly in correspondence with the section (VLF 8) in which the waste body has its maximum thickness. In fact, the low constipation of the shallow waste materials (low seismic velocities) favourites the leachate circulation.

Suitable analysis and processing of the FDEM, TDEM and ERT data has provided, as for the VLF data, the resistivity distribution in the vertical sections across the selected profiles supplying a very detailed electrical characterisation of the waste materials and the neighbouring areas. Indeed, the ERT data interpretation has supplied also 2D sections of the chargeability distribution along the vertical plane crossing the nine measurement profiles. It is worth to outline that the chargeability parameter is strictly linked to the diffuse presence and relative abundance of highly conductive particles in the rock matrix. Therefore, the knowledge of the spatial distribution of the chargeability in depth can provide useful information on the presence of contaminated zones (extremely conductive).

In brief, the analysis of all electric and electromagnetic data reveals that the materials, by which are made up the landfill body, are generally conductive and characterized by high variability in the conductivity with respect to the encasing rocks as can be observed in Figure 2, where the results of the EM16 and EM34 along the profile P2 are reported as an example, and in Figure 3 that shows a 3D representation coming from an integrated analysis of the nine 2D resistivity tomographies obtained with the ERT prospecting.

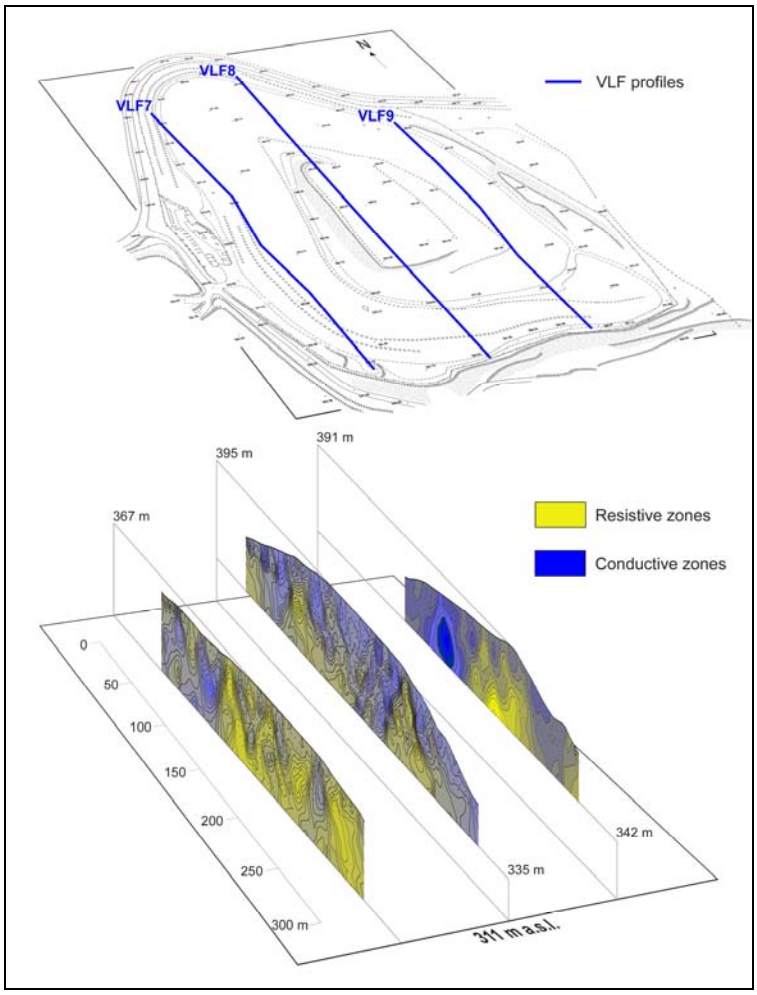

Figure 1. N-S trending EM-VLF pseudosections.

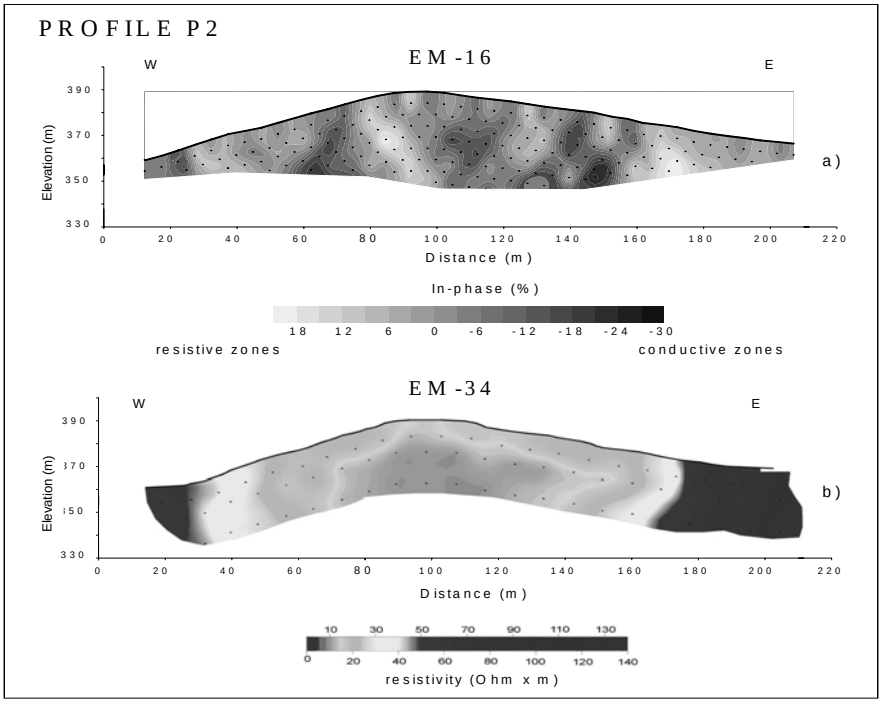

Figure 2. Comparison of EM 16 (a) and EM 34 (b) electromagnetic data along the profile P2.

The wide presence of conductive zones is probably related to leachate pockets and/or materials imbued with pollutant fluid. The high heterogeneity in this physical parameter can be a consequence of the disorderly discharge of the waste materials that for this reason are scarcely constipated. The scarce constipation generates and enhances the leachate and the accumulation of biogas (resistive zones), particularly in the superficial layers of the waste disposal, as the low values of the seismic velocity (ranging from 350 to 900 m/s) corroborate.

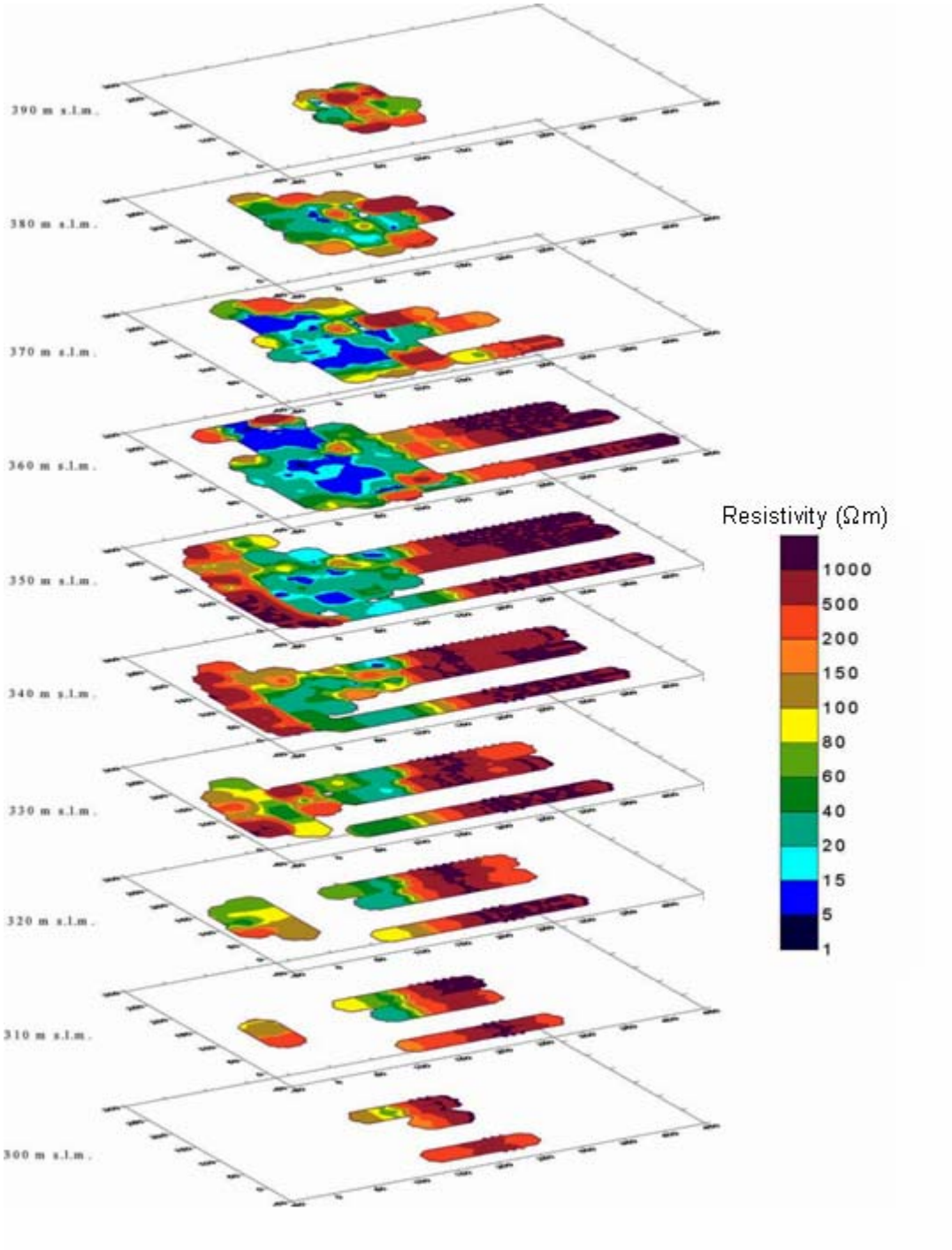

Figure 3. Resistivity maps sequence (horizontal slides) obtained by the interpolation of the 2D models relative to the ERT profiles. On the left the slides elevation is indicated.

The seismic data substantially confirmed the results of the electro-magnetic exploration, and provided more detailed information on the extension, thickness and depth distribution of the waste materials, and on the morphology of the bedrock at the bottom of the waste deposit. Figure 4 depicts a typical section.

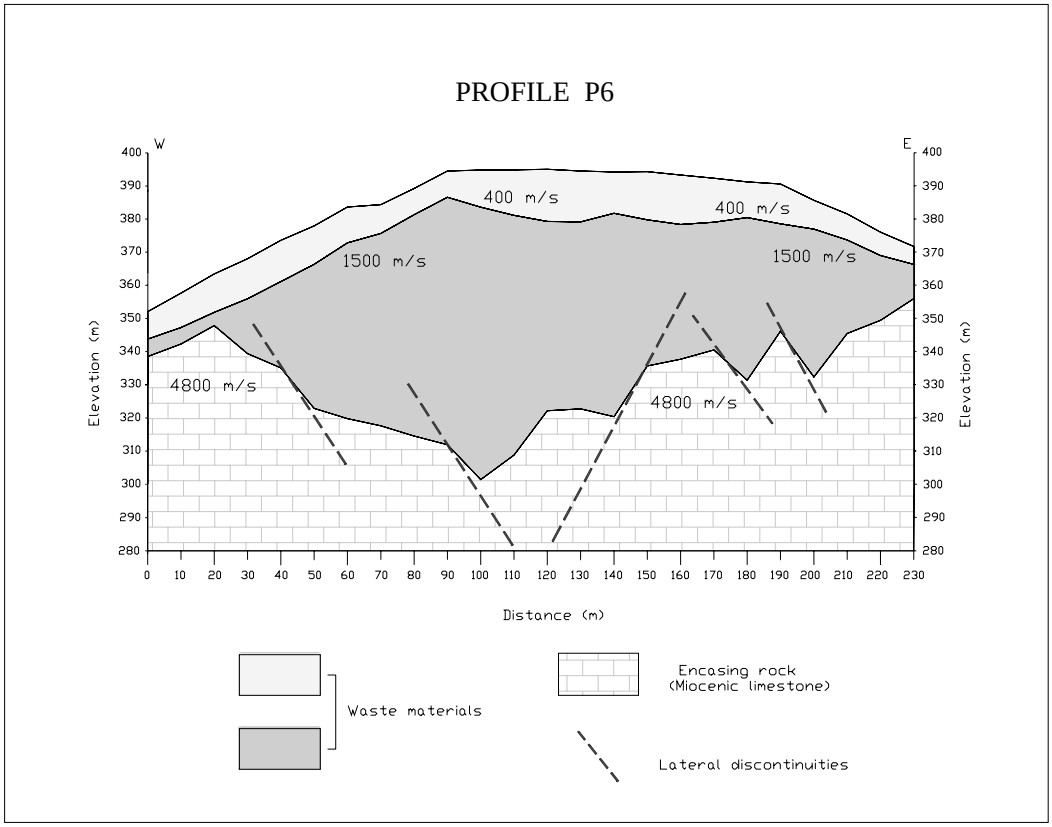

Figure 4. Depth section of seismic refraction profile P6.

On the whole five seismic units were identified. Two of these, which had a compressional (P) wave velocity ranging from 350 m/s to 1500 m/s, were related to the different degree of constipation of the waste materials. In particular, the velocity values lower than 1500 m/s can be attributed to unconsolidated and weathered materials that have high secondary porosity. The other three seismic units are related to the encasing rocks (mainly Miocenic limestones) from fractured and altered (2100 m/s) to compact and unaltered (4800-5500 m/s). The large variation in thickness of all seismic units causes lateral discontinuities that can favour the migration of gas and the circulation of leachates.

4. CONCLUSION

An integrated analysis of the data from the entire geophysical exploration plan provided a very accurate physical and structural characterisation of the waste body and the encasing rocks.

In particular, all the electric and electromagnetic data allowed to delineate the resistive and conductive trends of the waste disposal. This information is very important because the high resistivity values generally observed in the deeper part of the investigated area well describe the

geological nature of the bedrock and its physical status, which is generally rather compact. Local resistivity minima are to be attributed to the presence of fracture systems very likely affected by pollutant fluid infiltrations, as suggested by the high chargeability values observed in the same sectors. As a matter of fact on considering their magnitude and geometry, the many conductivity contrasts detected within the waste body can be ascribed not only to the different composition of the materials, but also to the presence of accumulations of leachate.

The seismic data interpretation corroborated the results of the electro-magnetic investigations and allowed to map in detail both the morphology of the bedrock surface and the boundaries between waste materials at different degree of constipation. The structural discontinuities that can be the outlets of the contaminated seepages were also detected.

On the base of the integrated geophysical survey, a map of the drilling sites where to perform traditional physical, chemical, and biological investigations was proposed.

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