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OLD MUNICIPAL AND INDUSTRIAL WASTE LANDFILLS: EXAMPLES OF POSSIBLE APPLICATION OF GEOPHYSICAL SURVEY TECHNIQUES FOR ASSESSMENT PRIOR TO RECLAMATION

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ABSTRACT

Further to the implicit environmental risk, abandoned municipal and industrial waste landfills frequently represent a serious problem, particularly as adequate information relating to their depth and lateral extension is either very limited or completely lacking. Moreover, knowledge of waste consistency, presence and quality of saturating fluids, metals and so on, should not be neglected when designing reclamation procedures. With the purpose of overcoming -at least partially- the abovementioned lack of information, the potential role of geophysical techniques including gravity, electrical and seismic methods, and their convenience of use, is proposed and examples provided. The first example relates to a combined application of gravity and shallow reflection geophysical methods in a mine tailings basin; in this case, the geophysical results obtained allowed the geometry and depth to the bottom of the landfill, the presence of fractures affecting the bottom and the density of disposed materials to be estimated; the second example related to application of seismic refraction tomography by means of which the structure of an old municipal waste landfill was derived; in the third example an old disposal site hosting demolition rubble was explored using the electrical resistivity tomography technique. On the whole, the convenience of applying geophysical exploration techniques for the pre-reclamation assessment of old waste landfills has been demonstrated.

1. INTRODUCTION

In the majority of cases, old waste landfills represent a serious environmental problem, and site reclamation interventions should be carefully designed and estimated prior to realizing the reclamation works. Therefore, an accurate knowledge of the landfills is strictly necessary while, in many cases, the overall information relating to the old landfills is scarce, with even details of their horizontal extent and depth lacking.

Direct investigation methods that provide information on the surface and subsurface extent and composition of wastes include excavating shallow test pits, using direct-push exploration techniques and drilling boreholes. However, drilling into or through the waste and into the underlying soils and/or bedrock should be performed only if necessary, and only if the driller is experienced in the methods used to prevent cross-contamination. Additional health and safety concerns (especially exposure to methane gas) should be addressed in the health and safety plan when borings are located in the waste; it should also be mentioned here that information obtained from direct investigation is punctual and generally expensive. On the contrary, surface geophysical methods (e.g. see Dobrin and Savit 1988; Sharma 1997) are prevalently non-invasive and may play an important role in delineating and characterizing the waste dump (Balia and Littarru, 2010; Cardarelli and Di Filippo, 2004; De Iaco et al., 2000; Johansson et al. 2007).

The following sections will attempt to demonstrate how geophysical techniques can contribute to the pre-reclamation assessment of old landfills; namely, applications of gravity, seismic -both reflection and refraction- and electrical resistivity techniques will be shown.

2. A COMBINED APPLICATION OF GRAVITY MEASUREMENTS WITH SHALLOW REFLECTION SEISMOLOGY

In this case, the gravity and the shallow reflection methods have been used.

As known - and widely illustrated in several textbooks of applied geophysics (e.g. Sharma 1997)- the physical parameter at the base of the gravity method is the density

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of the underground materials. Gravity measurements are normally taken at the surface by means of gravity meters, which measure relative values of the gravity field. Field measurements should be compensated for the effects of the elevation of measuring points, for the latitude and mass distribution in the surroundings, to enable the residual point-to-point differences to be attributed exclusively to underground density variations. Gravity surveys are often carried out along profiles conveniently placed at the surface. Therefore, in the case of waste disposal sites, if the density of wastes differs from the density of the land that hosts the landfill, a gravity anomaly can be measured and processed.

Figure 1 shows the mine tailings basin of San Giorgio situated in the most relevant mining district of Sardinia, Italy where the gravity survey concerned was carried out.

Gravity measurements were made along a line (see Figure 1) at 10 m intervals by means of a Lacoste&Romberg model G gravity meter. The associated anomaly profile (relative gravity after compensation) is shown in Figure 2, clearly depicting a gravity depression correlated to waste thickness and density.

However, full interpretation of the gravity anomaly was a problem featuring two unknown elements, i.e. 1) the depth to the bottom of the basin (or thickness of the waste) and 2) the density of the waste. Since the direct measurement of mean density of the waste was a difficult task, a decision was made to identify the bottom of the basin by means of a shallow reflection seismic survey partially superimposed to the gravity profile. It is perhaps pointless to underline that the physical property underlying seismic methods is the velocity of propagation of the elastic - or seismic- waves. As well known, the seismic reflection method is very likely the best-developed method in applied geophysics, particularly due to its role in geophysical prospecting for oil and gas (Dobrin, 1976; Dobrin and Savit, 1988; Yilmaz, 1987). Since the 1990s, reflection seismology has been progressively adapted for use with shallow and ultrashallow targets (e.g. Balia and Gavaudò, 2003 and references therein). In the present case, the shallow reflection profile was achieved using a 48 channel Abem MK6 seismograph, geophone interval 1 m, single geophones natural frequency 40 Hz undamped, shot interval 1 m, energy source 8 kg sledge-hammer, maximum CMP fold 2400%, recording length 0.250s,

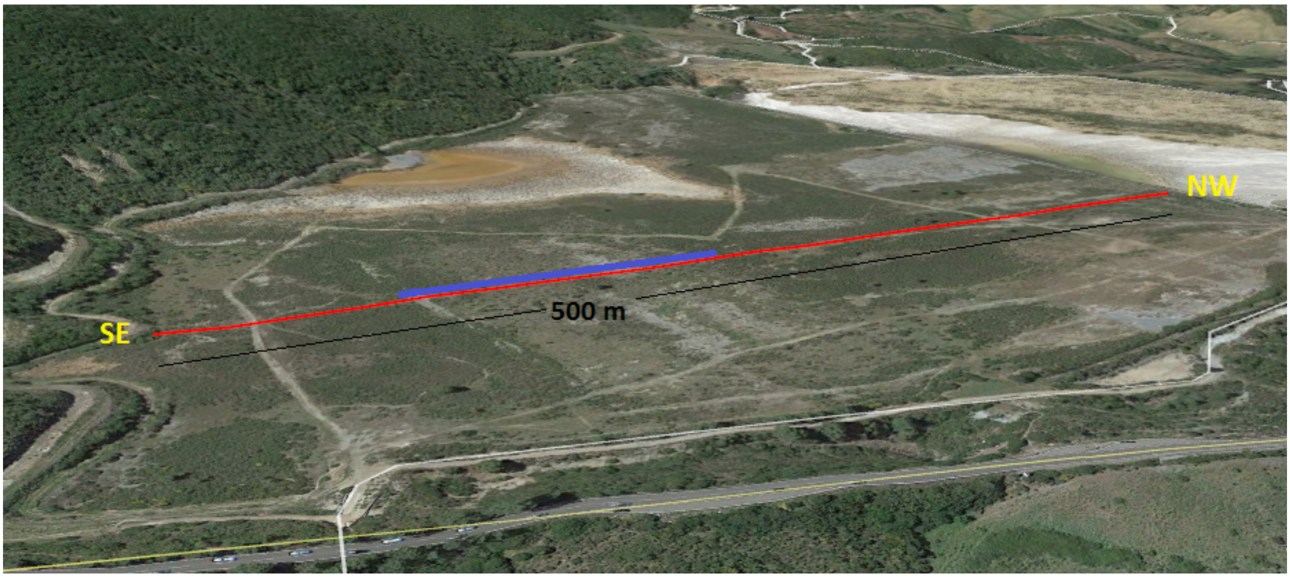

FIGURE 1: The San Giorgio mine tailings basin (southwestern Sardinia – Italy). The red and blue lines indicate, respectively, the position of the gravity and the shallow reflection profiles.

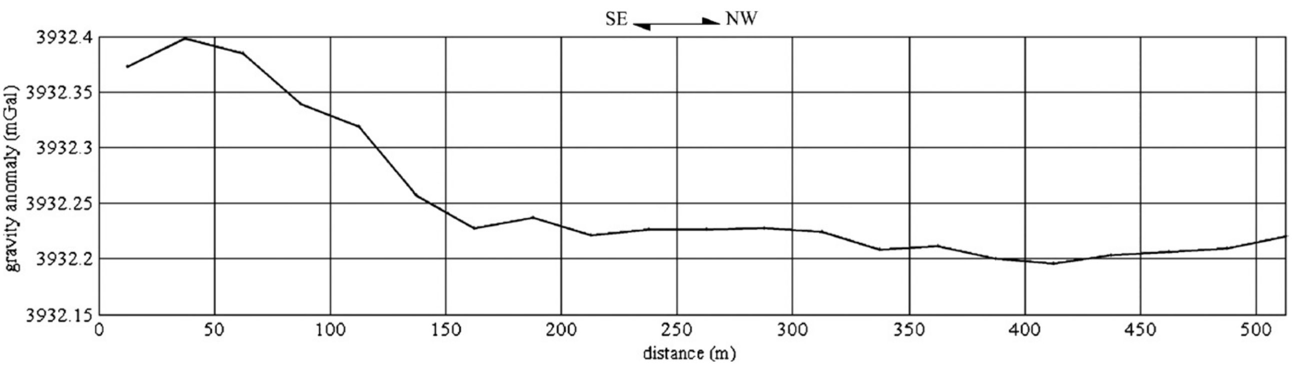

FIGURE 2: Gravity anomaly measured along the profile crossing the mine tailings basin of San Giorgio as shown in Figure 1.

and sampling interval 0.00025 s (Balia and Littarru, 2010). The seismic reflection section time-to-depth converted -also by means of one calibration borehole- is shown in Figure 3: this clearly shows the original ground surface, i.e. the bottom of the tailings basin: this way the only unknown of the problem was represented by the density of waste. In the end, in order to estimate the above said density, the gravity anomaly curve was interpreted using an iterative modeling procedure consisting in the introduction into the calculation software of different values of density to obtain the best match between the calculated and measured anomaly, assuming for the landfill a 2.5D mass distribution model. The result of this operation is shown in Figure 4: the best fit between measured and computed anomaly was obtained with a density of 2140 kg/m^3 for the waste, while the density of the hosting rock, largely known, was 2500 kg/m^3. Subsequently, depth and shape of the bottom, bottom fracturing conditions and waste density were estimated.

In total, the fieldwork carried out involved two days plus five days for data processing and results display. The cost of the entire geophysical work was in the order of costs required for the single calibration hole.

3. AN EXAMPLE OF APPLICATION OF SEISMIC REFRACTION TOMOGRAPHY

Refraction tomography (e.g. Azwin et al. 2013, Osypov 2001 and references therein) is a relatively recent technique that has largely replaced the classical technique of seismic refraction method -based on travel time analysis and interpretation- and the ultrashallow reflection technique (Balia 2013 and references therein). In the seismic tomography technique the acquisition procedure is no different from that used in traditional refraction surveying, although in this case the amount of data is significantly greater and data processing is somewhat different.

The location at which data for this experiment were acquired is shown in Figure 5 as it is today. The landfill was active until the end of the 1970s, when it was simply covered with plant land and covered by a grassy mantle, and was therefore not discernible as a site hosting a large volume of waste. Figure 6 shows the seismic tomography section along the profile in Figure 5. In detail, a Seistronix Abem RAS seismograph and 36 geophones at 2 m interval were used, with 22 on-line shots realized by means of a

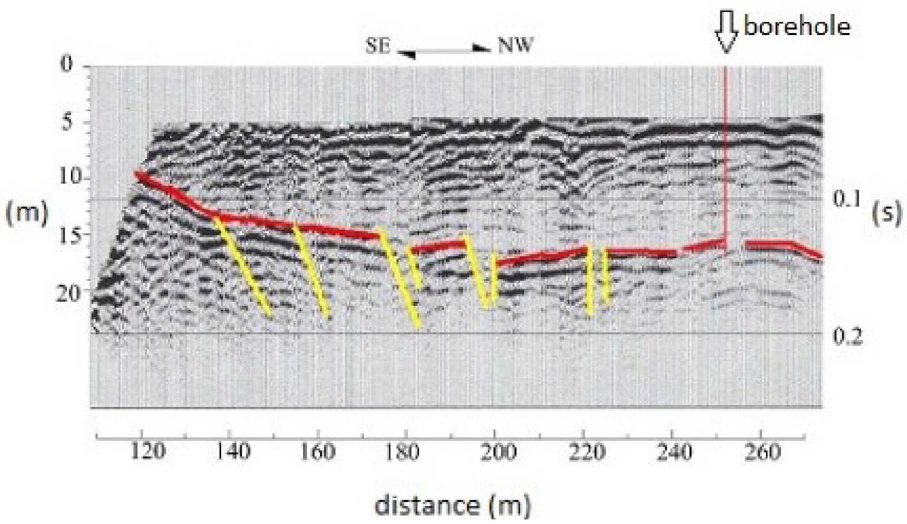

FIGURE 3: Depth-converted seismic section partially superimposed to the gravity profile as shown in Figure 1. The bottom of the basin, as well as several faults affecting the latter, are clearly identifiable.

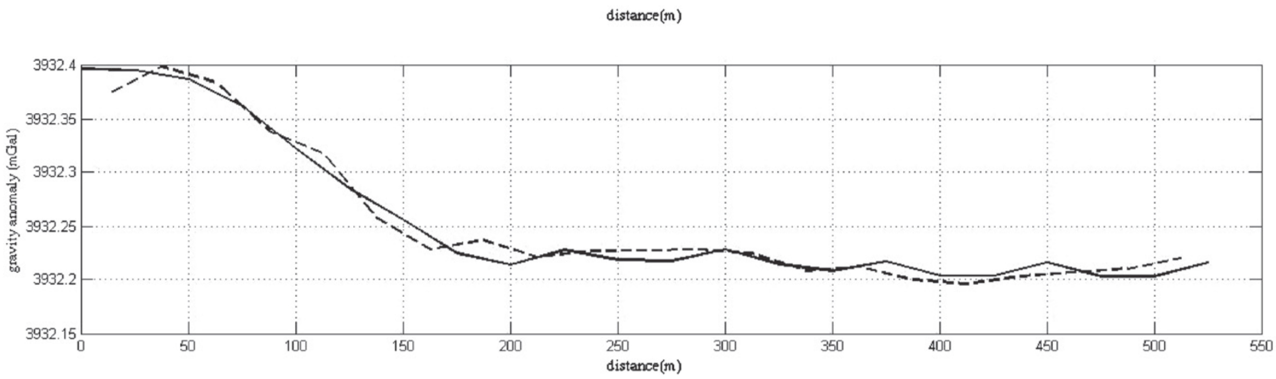

FIGURE 4: Best fit between the measured (solid line) and computed gravity anomaly (dashed line).This result was obtained for a density contrast of - 360 kg/m^3 between the waste and the host rock.

FIGURE 5: The location of the old municipal waste dump (southcentral Sardinia -Italy). The red line indicates the position of the seismic spread for the tomography shown in Figure 6.

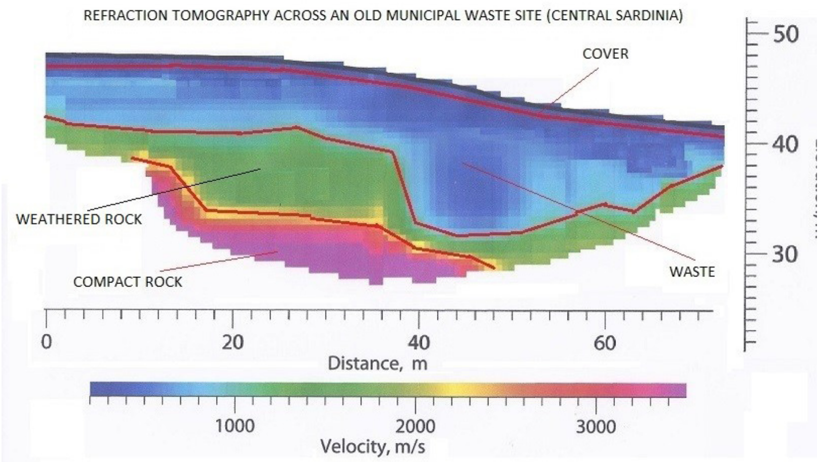

FIGURE 6: Refraction tomography (compressional waves) along a profile crossing the old municipal waste site located as shown in Figure 5.

simple hand-hammer to cover the section with (36 x 22) = 792 seismic rays. As mentioned, the processing software is quite sophisticated: briefly, it uses only the acquired first-arrival times, planimetric coordinates and elevations of both geophones and shots to derive the distribution of seismic wave velocity in the subsoil. In detail, the software (Optim- SeisOptPro V5.0) employs a non-linear optimization technique known as ASA -Adaptive Simulated Annealing (e.g. Ingber 1996).

As shown in Figure 6, the quality of information provided by the tomography is very good: the typical levels of the dump are clearly depicted and, from top to bottom, can be interpreted as follows: 1) ground cover approx. 1 m thick with P-wave velocity of 200-300 m/s; 2) waste body 3-12 m thick with P-wave velocity of 400-800 m/s; 3) upper portion of the bottom made up of weathered Miocene marl with a thickness of 2-6 m and P-wave velocity of 1700-2000 m/s; 4) compact Miocene marl with P-wave velocity of 3000-3500 m/s. Since the Miocene marl is known to be impermeable, it therefore ensues that at least the deep aquifers are protected from pollution. The above interpretation has been validated by means of a shallow excavation on the right end of the tomography. The field-work took place over half a day, plus two days for data processing, thus yielding a highly advantageous cost-benefit ratio for seismic tomography.

4. AN EXAMPLE OF APPLICATION OF ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

As widely known, underground resistivity is a highly relevant property since it depends on base properties and characteristics such as mineralogical composition, porosity, ground water and its salinity and/or contamination, clay content, compaction degree, soil lithology, fracture zones, etc. Electrical resistivity is usually estimated by transmitting into the underground an electrical current using two current electrodes and measuring the electrical potential difference -induced by the above said current- between two other electrodes. Then, based on current intensity and induced potential difference and taking into account the position of the four electrodes, i.e. the geometry of the quadrupole, the underground resistivity can be estimated applying Ohm's law for a half-space (Sharma 1997, Parasnis 1996). A series of different electrode array configurations are available, but all configurations are aimed at gathering data to be used in estimating lateral and vertical variations in ground resistivity values; among these configurations the famous "Schlumberger", "Wenner" and "dipole-dipole" should be cited (e.g. see Parasnis 1996). With regard to electrical resistivity tomography (ERT) data acquisition is normally carried out using the "Wenner" or/and the "dipole-dipole" electrode configuration; the basic differences of ERT compared to traditional procedures (vertical soundings, resistivity profiles, resistivity pseudo-sections) are represented by the larger quantity of acquired data and the data processing method (e.g. Chambers et al. 2006; Sing et al. 2010; Tripp et al. 1984 and references therein).

Figure 7 shows the results obtained from a set of electrical resistivity data referring to a relatively old disposal site hosting demolition rubble, situated in south Sardinia. Data acquisition was carried out at the beginning of spring after a relatively rainy winter, and therefore the subsoil was significantly wet. The cover of the wastes was made of moderately clayey soil, which was not particularly wet due to sun and wind. Data acquisition and processing were performed using the electrical resistivity tomography (ERT) technique, by means of an IRIS Instruments Syscal Pro apparatus. In the ERT technique the acquisition of data involves the provision of a large number of electrodes along the measuring profile, all connected to the measuring apparatus by a multipolar cable. The measuring software automatically selects all possible quadrupole configurations and, for each of these, measures the apparent electrical resistivity of the subsoil. In the case at hand, 126 electrodes at 1 m intervals were arranged and the Wenner configuration was selected.

Once the measurements are completed, the system processes these to provide the true-resistivity section, or ERT tomography. In addition to the measurement of resistivity, the use of modern equipment also facilitates the obtaining of induced polarization (IP) measures (Parasnis 1996) . However, the acquisition and processing times for induced polarization measures may be significantly extended, implying in the majority of cases that resistivity measurements alone are executed, with IP measurements being made only when strictly necessary.

Interpretation of the resistivity tomography is clear: it shows a 1-2 m thick top layer with an electrical resistivity of 20-90 ohm-m covering the waste. The underlying wastes are not homogeneous and their variable resistivity suggests the presence of varying degrees of humidity: in fact very low, medium and relatively high resistivity can be observed.

The lowest resistivity (1-14 ohm-m, blue color) very likely corresponds to waste moistened with water salinized by dissolution of the salts contained in rubble and to the presence of concrete reinforcing iron; medium resistivity (30-80 ohm-m, green color) is associated with moderately wet rubbles; highest resistivity (up to 300 ohm-m and more) may be interpreted as dry rubble, very likely with voids.

This interpretation was supported by the findings of three very shallow excavations carried out in the center and close to both sides of the tomography. Data acquisition and processing required a full day's work, yielding a satisfactory level of information. The tomography does not show the bottom of the dump.

5. CONCLUSIONS

The examples shown in the previous sections do not cover the complete spectrum for the wide potential of geophysical methods in the assessment of old waste disposal sites. However, it has been demonstrated how relevant information for use in the proper planning of reclamation interventions, namely geometry of the dump, physical properties of the waste and hydrogeological and geotechnical conditions of the site, may be obtained by means of appropriate well designed and well executed geophysical surveys.

From a strategic point of view, gravimetric surveys may be conveniently employed, particularly when the external borders of an old landfill need to be identified; seismic techniques yield information on the thickness of the waste body, the degree of compaction of the waste and the conditions of the bottom; electrical techniques provide information on hydrogeological conditions and leachate presence and distribution. Moreover, it should not be overlooked that the cost/benefit ratio of geophysical techniques is considerably advantageous compared to that of direct survey techniques, the use of which following a previous geophysical study, may be conveniently optimized.

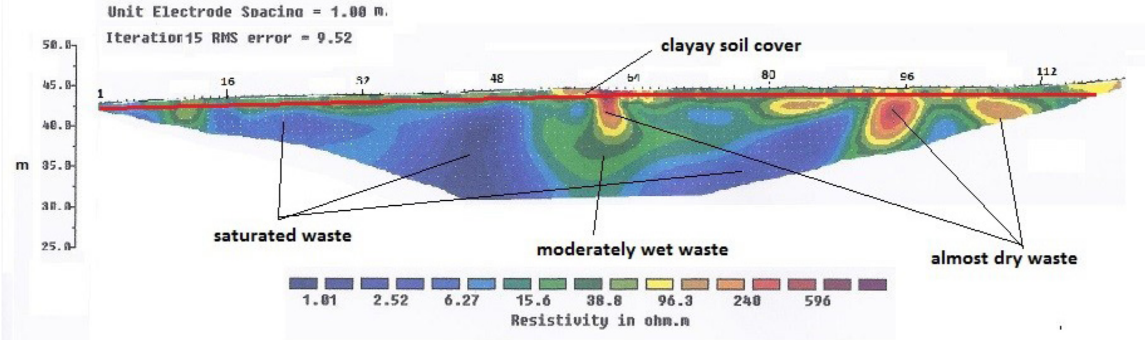

FIGURE 7: Electrical resistivity tomography on an old disposal site hosting demolition rubble in southern Sardinia - Italy.

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