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Geophysical methods applied to characterize landfill covers with geocomposite

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ABSTRACT

We attempt to characterize with geophysical methods the state of landfill covers to detect damages that can induce preferential water pathways and unusual increase of leachate within the waste mass. The geophysical methods used were the Electrical Resistivity Tomography (ERT), cartography with an Automatic Resistivity Profiling (ARP©), and the Self Potential method (SP). We worked on experimental parcels reproducing common defaults on landfill covers (clay material and geocomposite) and on a larger scale on a french landfill cover. The joint use of these methods gives us the opportunity to test their ability to detect defects. Results on the parcels have shown a good detection of the larger cracks (0.10 m) on the compacted clay cover but a less easy detection of defaults on the geocomposite. Results on the landfill have shown conductive zones correlated with important SP variations that could indicate a preferential infiltration zone in the cover.

INTRODUCTION

To minimize infiltration of precipitation and the accumulation of contaminant groundwater within a landfill, impermeable barriers (compacted clay and geocomposite) are covering the overall waste storage. Although ideal barriers are composed of a continuous impermeable clay layer and a geocomposite, real covers are often fractured and eroded due to mechanical, climatic and hydraulic stresses acting on its surface or even be damaged during its laying. These damages can induce an escape of landfill gases and creation of leachate through infiltration of surface water. Geophysical methods would be a good way to detect anomalies due to preferential water pathways and unusual increase of leachate within the waste mass. Currently, these methods are mainly used to trace the migration of leachate inside and away from the landfill (Naudet et al., 2004; Guérin et al., 2004; Suski et al., 2006). As leachate is highly electrically conductive, this is a suitable target for the above-mentioned techniques. Little attention and few published studies have used geophysical methods to evaluate water recharge through the landfill cap (Carpenter et al., 1991; White and Barker, 1997; Revil et al., 2002; Doussan et al., 2002; Guyonnet et al., 2003; Cassiani et al., 2008). Our goal was to test the feasibility of different geoelectrical methods to identify areas of defaults (fractures and thinned areas) on experimental parcels and on a larger scale on french landfill covers. Electrical Resistivity Tomography (ERT), cartography with an Automatic Resistivity Profiling (ARP©) and the Self Potential method (SP) were carried out on these two sites.

METHODS

Geophysical methods

Electrical resistivity methods are active methods based on the measurement of the potential distribution arising when an electric current is transmitted inside the ground via two electrodes. The efficiency of these methods depends mainly on the electrical resistivity contrast induced by the presence of different materials, contrast which can be due to variations in lithology, weathering, increase in water, clay content and presence of a water table. We have used two types of active electrical methods: the Automatic Resistivity Profiling (ARP©) technique developed by GEOCARTA, and the Electrical Resistivity Tomography (ERT).

The ARP technique uses a patented multi-electrode device in which wheel-based electrodes are inserted in the ground and rolled along the surface (Dabas, 2009). An electrical current is injected into the ground using one pair of wheels, and resistance measured on three further pairs of wheels acting as potential dipoles. The system is attached to a quad bike, which facilitates rapid data acquisition. Use of differential GPS navigation within the system enables accurate surveying. Continuous electrical soil mapping is carried out at three different theoretical depths (usually until 2 meters but it depends on the apparatus) below ground surface level. Data is plotted as apparent resistivity maps for each channel.

ERT enables the generation of tomographic images of the subsurface using different multielectrode arrays, such as the dipole–dipole, wenner, gradient and wenner–schlumberger, the choice of which depends on the subsoil, the depth of investigation, the sensitivity to vertical and horizontal changes in the subsurface resistivity, the horizontal data coverage and the signal strength. Features with a different resistivity zone by contrast with surrounding materials may be located and characterised in terms of electrical resistivity, geometry and depth of burial. ERT surveys require the installation of multiple electrodes along transect lines. The current is injected into the ground through a set of electrodes, and the resulting potential differences are measured between another set of electrodes. The mathematical combination between electric currents and voltage measurements provides the apparent resistivity values. Using the RES2DINV software proposed by Loke and Barker (1996), apparent resistivity values are inverted in a model of true resistivity values. The inversion routine is based on the smoothness constrained least squares inversion implemented by using a quasi-Newton optimisation technique. The subsurface is divided into rectangular blocks, the number of which is related to the number of measurement points. Moreover a pseudo-depth as determined by Edwards (1977) is assigned to each of them. Thanks to successive iterations, the optimisation method adjusts the 2D resistivity model trying to reduce the sum of the absolute difference between the calculated and measured apparent resistivity values as one goes along.

We also used the SP method, which is a passive electrical method measuring the natural electrical potential at the ground surface with non-polarisable electrodes. The primary sources of the SP signals are associated with in-body fluids circulation through the electrokinetic coupling, electrochemical coupling like diffusion of ionic species, and oxide-reduction reactions (see Jouniaux et al., 2009 for more details). The secondary sources are due to the electrical resistivity contrasts of the subsurface. The aim of this method is to obtain SP profiles or contour maps that underline anomalous zones which are likely to be connected with underground anomalous electric charge concentrations, sustained by polarisation mechanisms. As concerns the landfill covers, we expect to detect sources mainly due to electrokinetic effect and electrical contrasts in zones where fractures or cracks in the cover facilitate surface water infiltration.

The experimental parcels

An experimental site composed of two parcels reproducing two types of french landfill covers (with and without geocomposite) has been constructed. Several discrete heterogeneities (artificial cracks, depression, tears, overlap failure on geocomposite e.g. Geosynthetic Clay Liner) have been created on different places and depths inside the geocomposite and the clay cover (Figure 1). They are considered to be characteristic of heterogeneities that could occur in practice in landfill covers. Because it was technically not possible to keep cracks filled with air, we filled them with sand that is assumed to have the same hydraulic and electrical behavior. Three layers of 0.40, 0.30 and 0.30 m have been successively compacted before adding 0.15 m of top soil. On parcel 2, a geocomposite (bentomat® AS3700) has been added with 0.30 m drainage layer (gravel) and a geotextile under the top soil (Figure 1). The succession of these layers has been chosen in accordance with usual practices on french landfills.

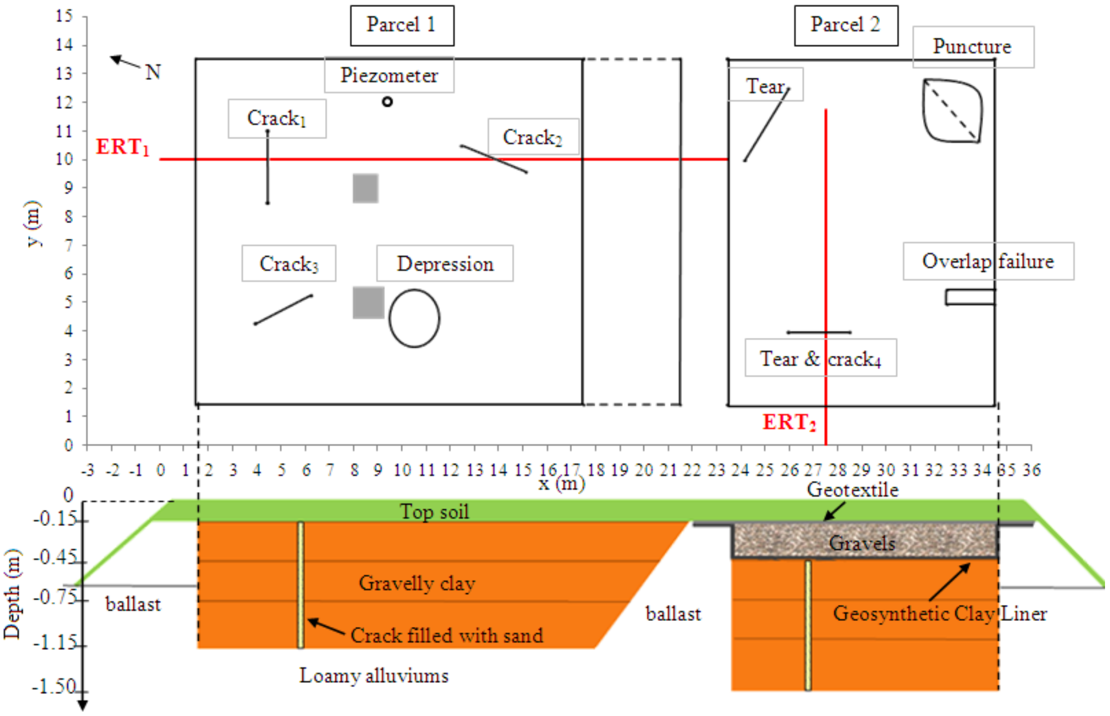

Figure 1. Top view and section of the two experimental parcels. On parcel 1, $Crack_1$ and $Crack_3$ are 0.10 m wide while $Crack_2$ is 0.04 m wide, the depression is 0.20 m deep. On parcel 2, tear is 0.05 m wide, tear and $crack_4$ is crossing all the gravelly clay. Red lines represent the two ERT profiles.

The landfill site

A geophysical survey has been carried out on a french industrial waste landfill. This landfill has been in activity from 1978 to 1988 and covers about 0.0042 km^2. Impermeable barriers cover the overall waste storage in order to prevent vertical entry of water into the waste. They are composed, from top to bottom, of 0.1 m of top soil, 0.5 m of ballast, 0.5 m of compacted clay and a GCL. A vertical cement-bentonite cutoff wall is present all around the landfill to prevent horizontal flow of groundwater through the waste. The production of leachate inside the landfill is considered abnormally high, suggesting surface and/or groundwater infiltration through the cover. ARP and SP measurements were performed in november 2009 to try to characterize the state of the landfill cover and locate possible preferential infiltration zones.

RESULTS

The experimental parcels

Two ERT profiles were carried out in october 2009 with forty-eight electrodes installed every 0.5 m for a dipole-dipole array on parcel 1 and every 0.25 m for a wenner array on parcel 2. ERT_1 intersects perpendicularly a 0.1 m crack and sideways a 0.04 m crack on parcel 1. ERT_2 on parcel 2 is perpendicular to a 0.04 m tear of the GCL which extends in the clay layer along a crack (location on Figure 1).

These ERT profiles obtained after inversion of the field data with the RES2DINV software are presented on Figures 2 b and 3 b.

On parcel 1, the first crack (0.10 m) was correctly and easily detected; the second crack may also be detected by analysing the pseudo-sections. As it can be seen on Figure 2 a, the first crack C_1 is very clearly identified by the two sets of high apparent resistivities. Since the second one C_2 is smaller, the two sets are also outlined but in a weaker way. Furthermore, the contact between the conductive gravelly clay and the loamy alluviums was correctly detected as well as the contact in bevel with the ballast for a thickness greater than 0.25 m e.g. half of the electrodes spacing.

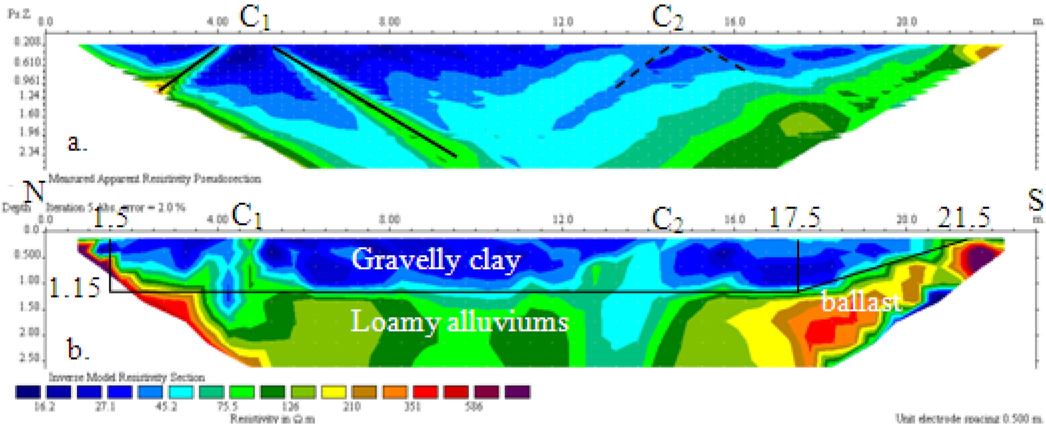

Figure 2. ERT_1 intersects the two cracks C_1 and C_2. a. Measured apparent resistivity pseudosection (dipole-dipole array). b. Inverse model resistivity section (robust inversion).

On parcel 2, the GCL seems to be represented by a very high resistivity value and an overestimated thickness (Figure 3 b). It is not easy to identify the crack but some noticeable features appear: on the one hand we can observe some irregularities in the high resistive set and on the other hand there are two sets with low resistivities on each side at the bottom of the ERT.

To understand these characteristics, we have perfomed a forward modeling (RES2DMOD software) using values of 50 000 ohm.m for the GCL and 1 000 ohm.m for the crack (Figure 3 a). A very interesting result is that even with an overestimated thickness of the GCL (0.125 m instead of 0.006 m) we obtain the same following features: the two sets of low resistivities and a lowering of the GCL resistivities below the cracks.

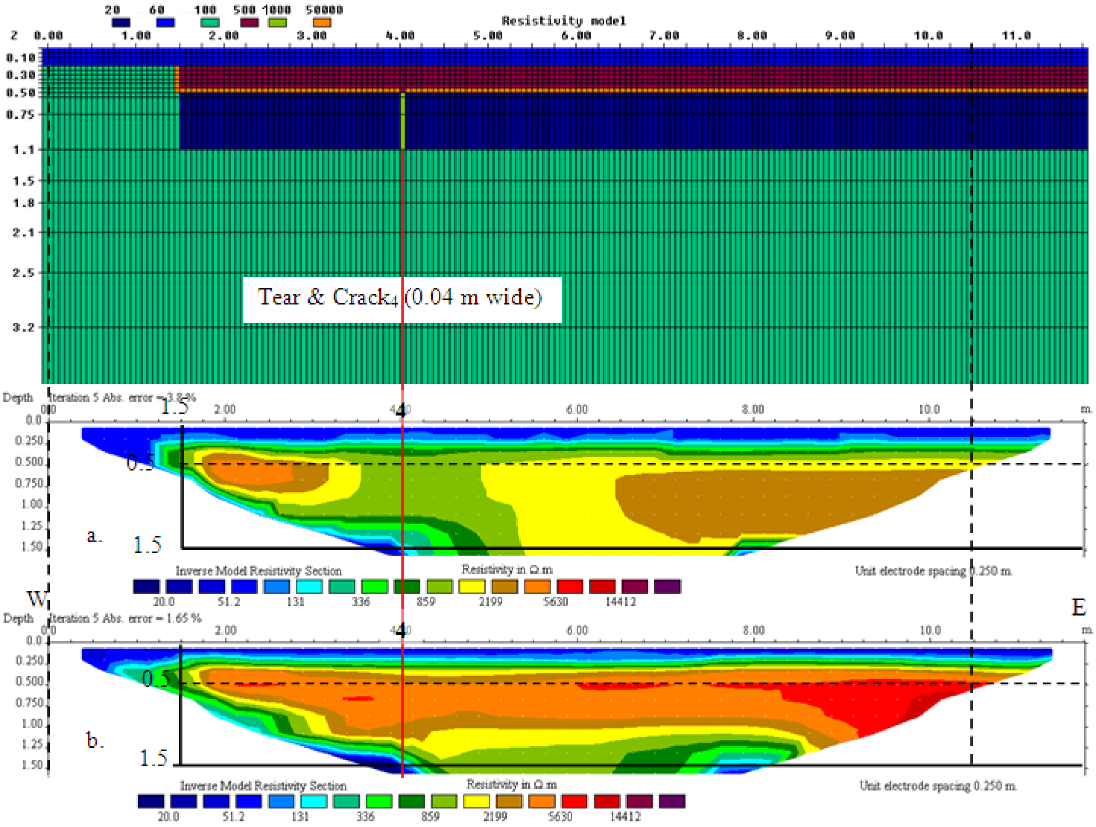

Figure 3. a. Forward modeling of ERT$_2$ intersecting the tear of the GCL and crack of the gravelly clay (5 % noise added, wenner array, robust inversion). b. Inverse modeling of the field data (wenner array, robust inversion). Red line indicates the location of the crack and black lines the limits of the gravelly clay material.

The SP map was obtained in february 2010 with a measurement every 2 meters (Figure 4). Despite the weak amplitude of the signal, few positive SP anomalies appear, particularly close to cracks 1 and 2 on parcel 1 and failures on parcel 2. They could be linked with the electrical contrast between the sand and the gravelly clay. An anomaly with decreasing SP values is located close to the depression and could be the signature of preferential infiltration. Even if the sampling step was 2 meters, all the failures seem to have been detected but not with a good precision.

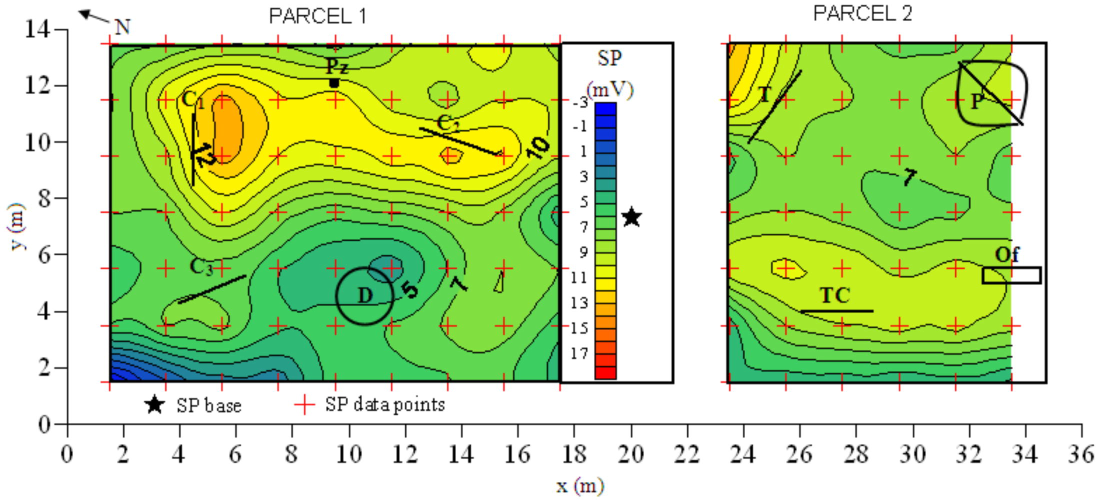

Figure 4. SP map obtained by kriging interpolation (with spherical model fitted to an omnidirectional variogram) of data point every 2 m (red crosses) compared to a fixed base (dark star). Failures have been reported: cracks (C_1, C_2, C_3), piezometer (Pz), depression (D), tear (T), tear and crack (TC), overlap failure (Of), puncture (P).

The ARP map obtained with a 1 meter electrode spacing clearly differentiates the two parcels with conductive values associated with the gravelly clay cover and very resistive values due to the GCL (Figure 5). On parcel 1, the larger crack (C_1) perpendicularly cut seems to be detected (more resistive zone) as well as the decreasing of the resistivity values on the right of the parcel 1 (e.g. the contact in bevel with the ballast). On parcel 2, no anomaly has been detected. As for the ERT, the very resistive property of the GCL seems to prevent the electric current from flowing through it and hides all the failures.

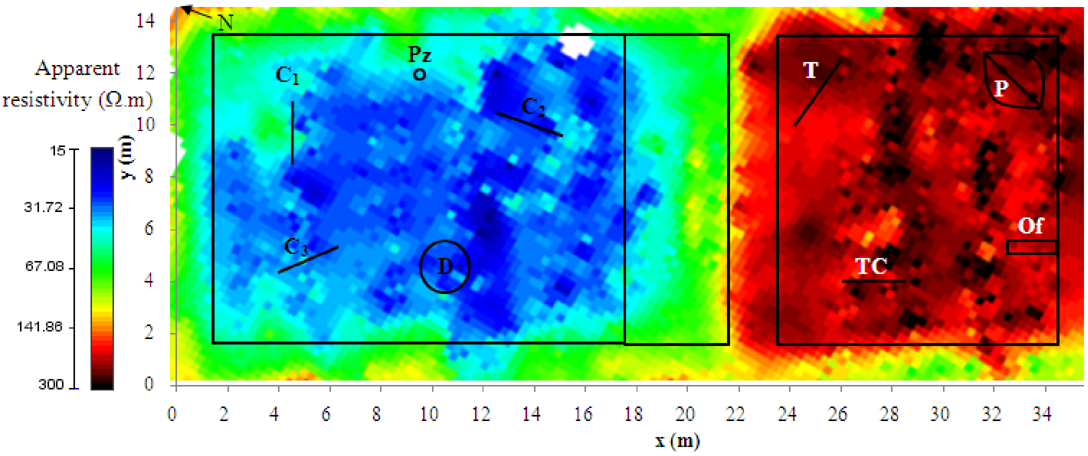

Figure 5. Apparent electrical resistivity map obtained with the ARP technique (with a point every 1 m in y and every 0.25 m in x direction). See Figure 4 for failures identification.

The landfill site

The GCL is supposed to be at around 1.0-1.20 m deep. Therefore, the ARP map obtained with a 1.70 meter electrode spacing (Figure 6) should detect it as a resistive body. Based on these considerations, we will explain the ARP map as follow: resistive zones locate the GCL while conductive zones indicate that the GCL cannot be detected due to a more important thickness of the clay material (see black dotted lines on Figure 6). Conductive zones can also indicate preferential water infiltrations due to failure in the cover.

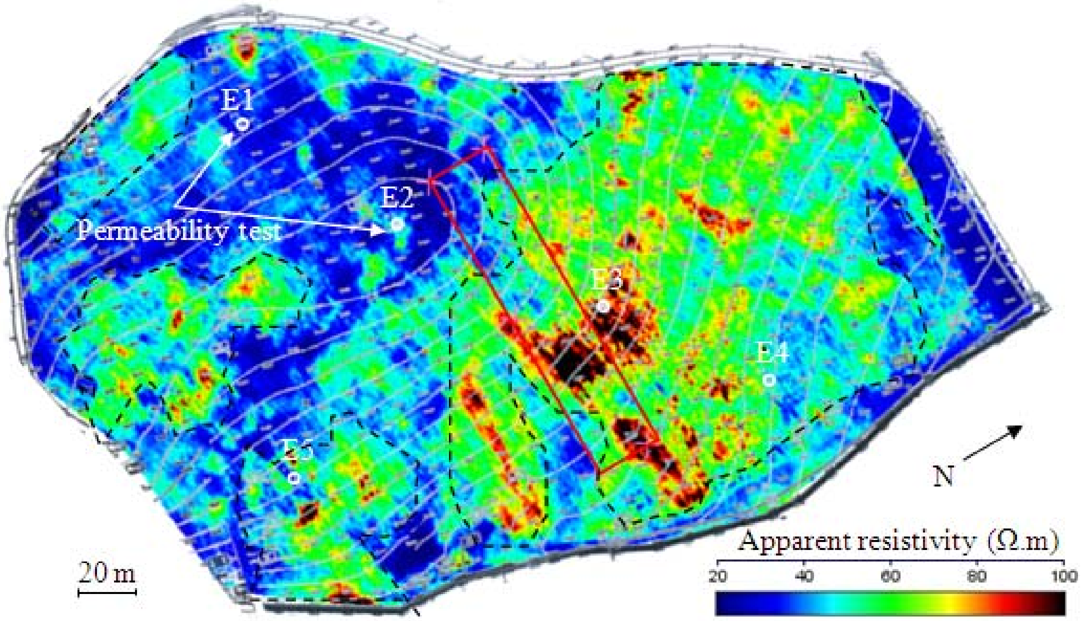

Figure 6. Apparent electrical resistivity map obtained with the ARP technique (with a point every 0.25 m along profiles separated by 1 m). The red rectangle corresponds to the SP prospected zone. E1 to E5 correspond to permeability tests and mechanical surveys made in 2006. Topographic lines have been reported.

The resistive zone in the northern part is located in the sloping part of the landfill and indicates the presence of the GCL, which was found at 1.10 m at the mechanical survey point E3. The conductive south-western part zone, located at the top of the landfill, can be due to a more important thickness of the clay material.

Permeability tests on point E2 revealed higher permeability values of the clay material (≈ 10^{-8} m/s) compared to points E3 and E4 (≈ 2.10^{-9} m/s). By this way, the conductive zones detected with the ARP could be also the signature of preferential water infiltration. But caution must be taken regarding this interpretation because other parameters can play a part in the electrical signature and the investigation depth (e.g. the clay content, thickness of the clay cover). Future analyses on the clay material and ERT profiles will be performed to refine our interpretations. The conductive zone at the north-eastern part of the map can be linked with a surface water accumulation down the waste mass.

An SP map has been obtained on the central part of the landfill where electrical contrasts were important (Figure 7). Results show a high SP signal from -75 mV to +45 mV, with a sharp gradient located in the more electrically conductive zone, where the permeability of the clay material was the lowest (E2). This result could indicate a preferential infiltration of surface water in this zone.

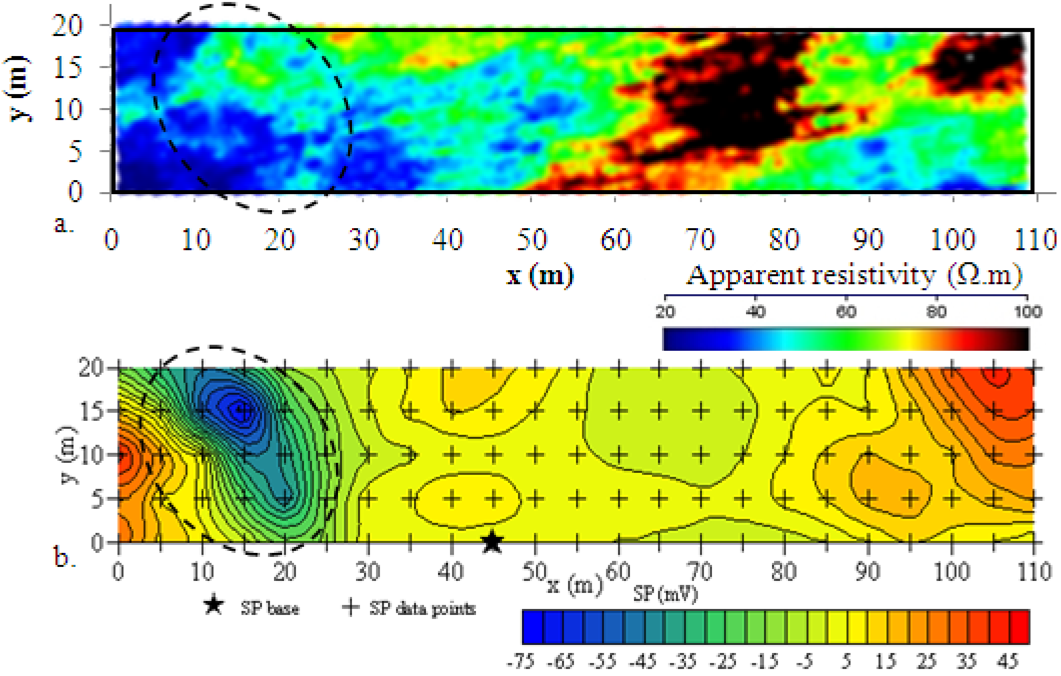

Figure 7. a. Zoom over the ARP zone surveyed with the SP method. b. SP map obtained by kriging interpolation (with spherical model fitted to an omnidirectional variogram) of data point every 5 m (red crosses) compared to a fixed base (dark star).

CONCLUSION

Three geophysical methods, the ERT, the ARP© and the SP, have been applied on experimental parcels and on a french landfill in order to determine their ability to detect defects in the covers (clay material and geocomposite). Knowledge of the defect' location is important because they can induce preferential water pathways and unusual increase of leachate within the waste mass. On experimental parcels, active methods (ERT, ARP) have very different signatures depending on the cover type. Conductive electrical response attests to the presence of gravelly clay whereas resistive electrical response means the presence of the GCL. It is easier to detect defects artificially created in these parcels with the ERT than with the ARP. It can be due to the interpolation method used to create an ARP contour map and also in the geometry of the electrodes. On the contrary of active methods, SP is not affected by the GCL, and with a 2 meter sampling step, SP signal variations appear near defects. We hope that with a smaller sampling step, variations would be more precise close to defects.

On the french landfill, as ARP is sensitive to material change, the different apparent resistivity could result in thickness variations of the clay cover. Moreover, sharp negative SP signals would indicate weakness areas where surface water goes preferentially through the clay cover.

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