Co-funded by the Walloon region

Stockley Park geophysical survey summary

Date: September 19, 2019

SUBJECT:	**…**						
☐	report	☒	information	☐	consideration	☐	decision
To:	…			From:	BGS		

Introduction

The following report describes the results of the geophysical survey carried out at the landfill of Stockley Park on the 11th to the 14th of June 2019. We present here the results and a preliminary interpretation in terms of landfill characterisation. They mainly inform on waste thickness and compositional changes within the watste material. Further, more advanced processing is still required in order to integrate the available ground truth data, and correlate them with the geophysical investigations.

Summary of the study area

The site is located in Stockley Park near Heathrow airport. The site is relatively large (12 ha) and consists of a former sand, gravel and clay quarry, which was utilised as a solid waste landfill from the 1940s. The landfill was progressively filled with domestic and commercial waste, reaching a peak in activity in the late 1960s and 1970s. Since the landfill has ceased to operate, the site is now relatively flat, covered by grass and used for horse grazing.

Two intrusive sampling campaings have been performed on the site a first one composed of 12 boreholes, 20 trial pits and Cone Penetration Tests (CPT) in 2015, and a second one composed of 25 trial pits performed in 2019. They have highlighted inhomogeneity in the waste distribution throughout the site, and are expected to provide extensive information for calibrating and verifying the geophysical survey data.

Geophysical investigations

The geophysical survey covers the central part of the landfill site, as shown in Figure 1. Covering the whole landfill was not feasible in the available time. We therefore limited the survey to the central part which overlaps several boreholes and trial pits, allowing to verify and calibrate the geohysical measurements. From a practival point of view, this area is also pretty clean in terms of vegetation, as compared with the northern part of the landfill. All trial pits and boreholes within this investigation area have shown the presence of a 5 to 12.5 m thick waste layer. Therefore, appart from potential clay stanks and the eastern landfill boundary we wouldn't expect any part of the investigation area to be waste free.

Geophysical methods and coverage

In the following, all applied geophysical methods are listed with their expected main sensitivities on landfills. Different geophysical methods are sensitive to different physical properties and can therefore complement each other. For a more detailed description of each geophysical method, please refer to the following report T1.3.1: Swot analysis of LF characterization methods.

In order to get a full areal coverage the following mapping methods were used:

- **Magnetic field mapping:** to identify zones with high metal content (measuring changes in total magnetic field/gradient)

- **Electromagnetic (EM):** to reveal lateral extent of different waste composition or leachate content at several distinctive depths (mapping changes in electrical conductivity and magnetic susceptibility)

More focused 2D surveys, providing detailed information about changes of physical properties with depth, were done along distinct profiles including the following methods and their sensitivities:

- **Electrical Resistivity Tomography (ERT):** to discriminate different waste types and investigate changes in leachate content (measuring resistivity distribution)
- **Induced Polarization (IP):** to detect metallic scraps or zones of higher organic content (measuring chargeability distribution)
- **Seismic Refraction Tomography (SRT) and Multichannel Analysis of Surface Waves (MASW):** to characterize the geometry of the subsurface layers presenting different compactions (measuring seismic velocities)

The extent of each applied method is shown in Figure 1. The EM and magnetic mapping were performed on a grid, formed of parallel lines (yellow, blue and green dots in Figure 1). The 2D surveys were done along the profile lines indicated in Figure 1.

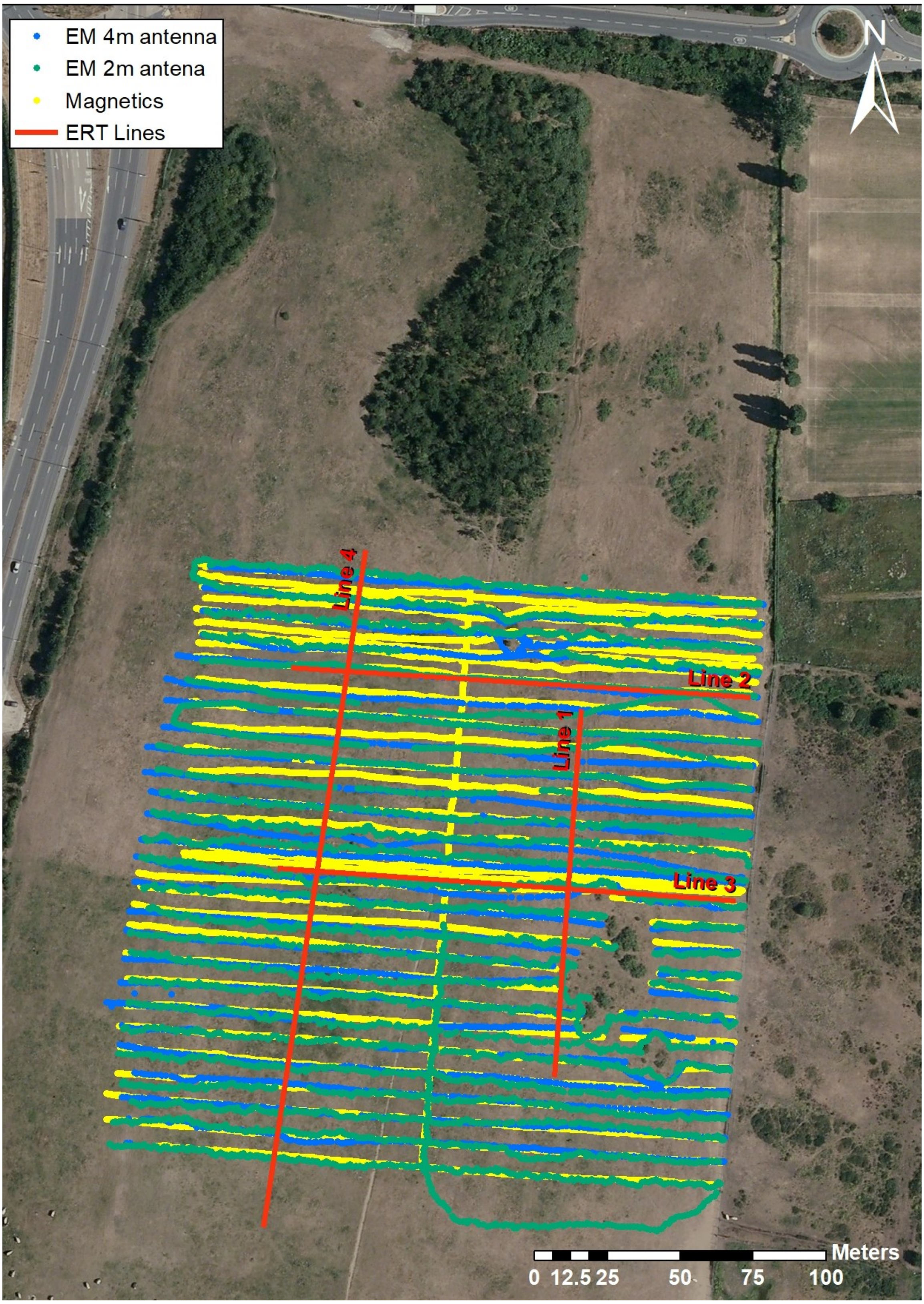

Figure 1: Extent of the performed geophysical measurements

Electromagnetic Mapping

Figure 2 displays the measured electrical conductivity at different depths below the surface. Similarly, Figure 3 displays the measured magnetic susceptibility. The depths are indicative only. Due to the integrative nature of the EM measurements, they effectively refer to depths of maximum sensitivity, which are influenced by the vertical and lateral distribution of conductivity in the vicinity of the sensor.

Changes in electrical conductivity can have several causes including:

- change in **water/leachate content** (higher water content = higher conductivity)
- waste composition variations (higher conductivity is caused e.g. by higher amount of **metallic scrap** and/or higher **clay content**)
- variation in **clay cap thickness** (areas with a thinner clay cap above the waste material are seen as higher conductive areas)

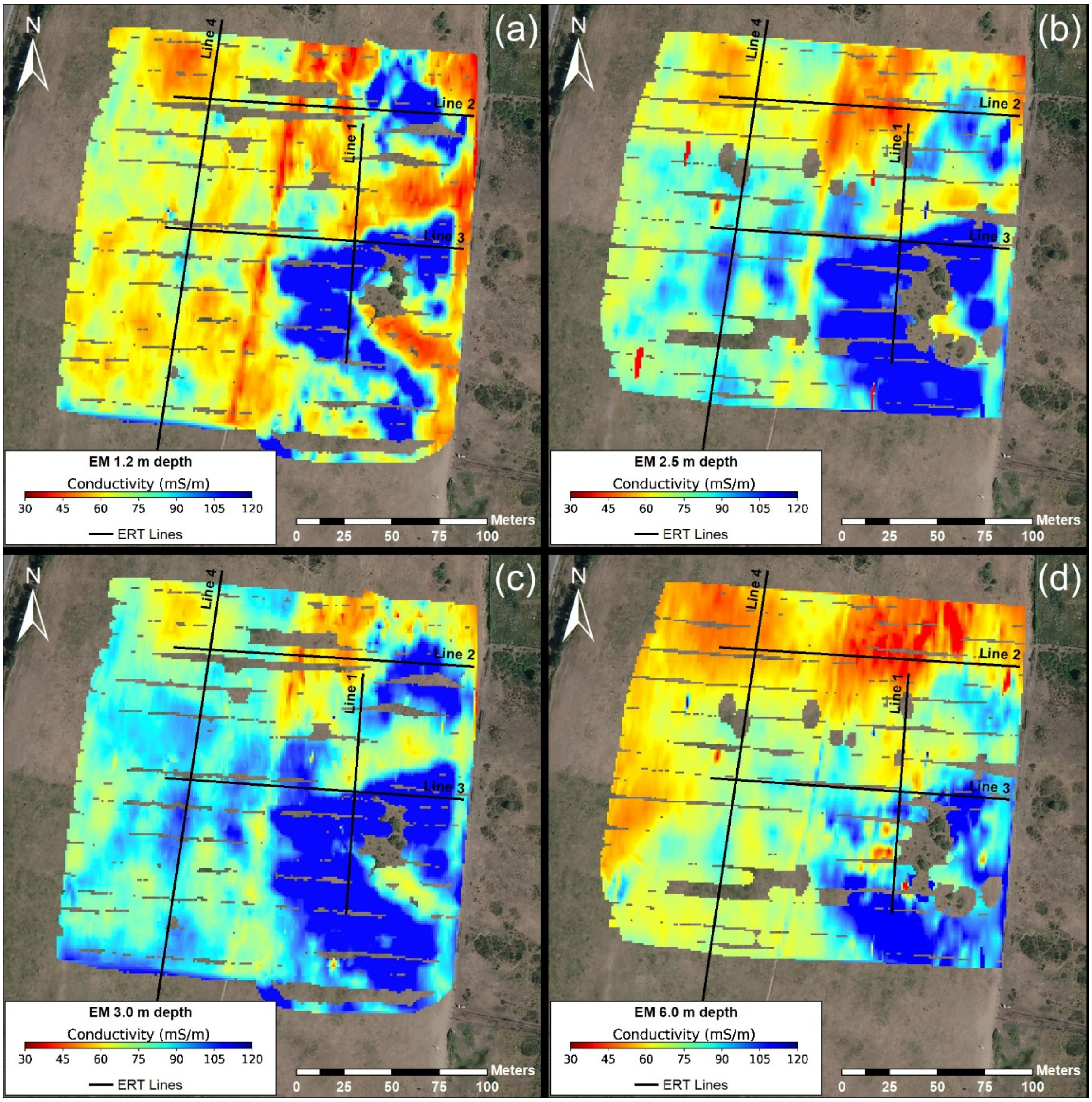

Figure 2: Electrical conductivity map at the following depth: a) 1.2m, b) 2.5m, c) 3m and d) 6m.

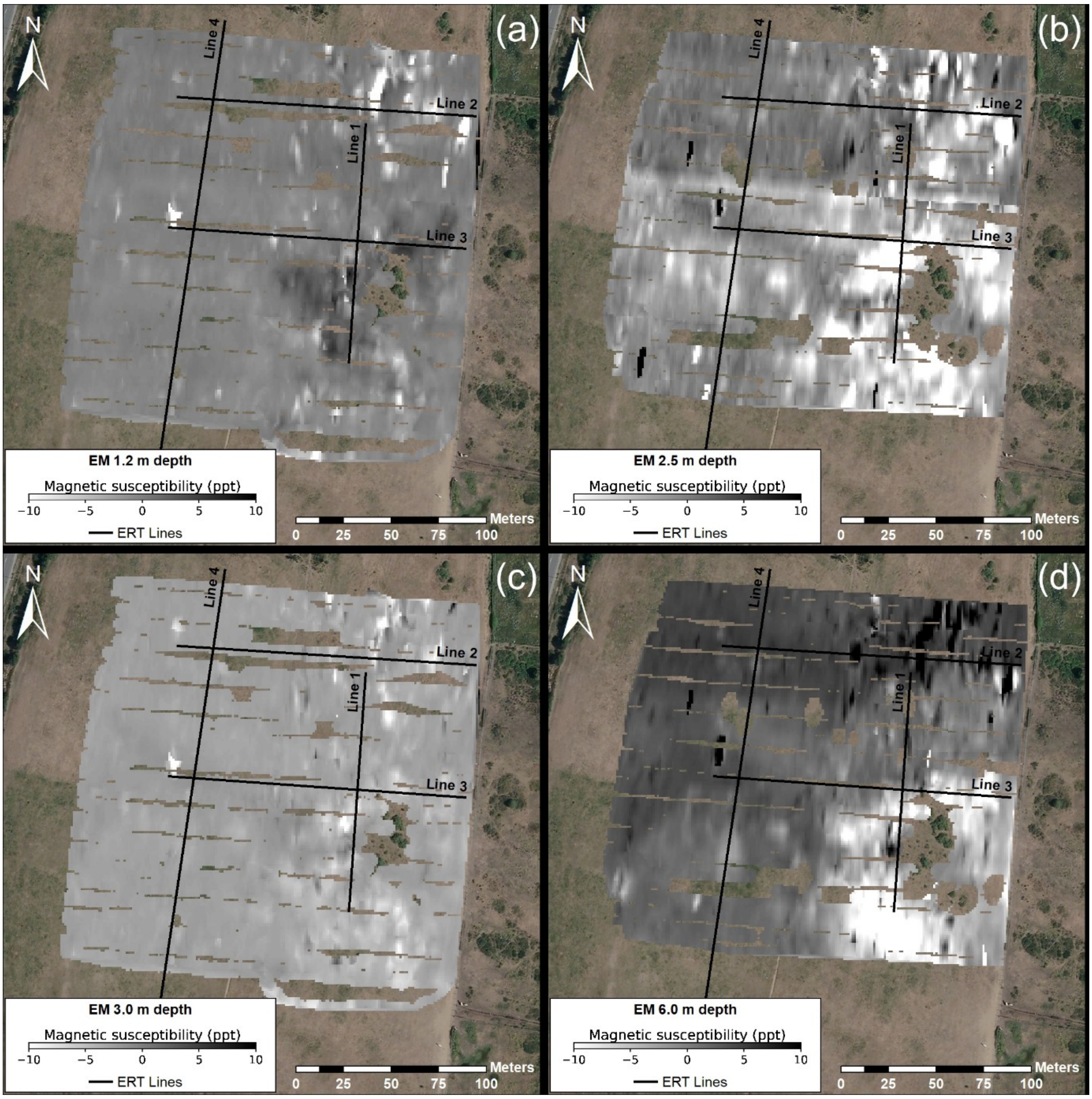

Figure 3: Magnetic susceptibility map at the following depths: a) 1.2m, b) 2.5m, c) 3m and d) 6m.

The sampled conductivity distribution ranges from 30 to 200 mS/m, which is quite low and is likely to highlight:

- At the lower end (around 30 mS/m): dry clayey structures (unsaturated London clay host material or clay cap)
- At the higher end (>120 mS/m): waste material with increased leachate or metal content or at greater depth the saturated clayey host material (saturated London clay)

The maps in Figure 2 show strong contrasts in conductivity, with a clear patch of increased conductivity (blue tones), visible at the 4 sampled depths, in the South-East corner of the surveyed area. A smaller patch with increased conductivity also appears in the North-East corner. However, this anomaly appears significantly less pronounced at 6 m depth. The increased conductivity at these patches could be caused by a higher leachate content, a thinner clay cap or a changed waste composition such as higher amount of metallic scraps material or a higher content of clayey soils. Since both patches are associated with high amplitudes in magnetic susceptibility (Figure 3), an increased metal content or a reduced clay cap thickness are the most likely explanations. The fact that these two patches show up at 1.2 m depth already, reinforces the presence of a relatively thin clay cap. The eastern edge of the EM map is associated with lower conductivity values at intermediate depths (1.2 – 3.0 m). The fact that this feature disappears in the deepest image suggests that it does not correspond to the landfill edge. It can rather be associated with a shallow clay dam or a gravel filled drainage trench. The further extension of the landfill towards east is verified by boreholes BH08 and BH04 (see the "Environmental and geothechnical assessment" report ref. 70011351 by WSP | Parsons Brinckerhoff).

The drain running approximately North-South in the middle of the surveyed area, and discernible in the satellite imagery, also clearly shows up in the EM images as an elongated low conductivity feature.

Overall, the western half of the mapped area is characterised by a more homogeneous conductivity distribution and relatively low amplitudes of the magnetic susceptibility. The absence of high conductivity features at 1.2 m depths suggests a thicker clay cap or a top layer of low conductive inert waste. The comparably low conductivities at intermediate depth together with the low amplitude magnetic susceptibilities could be a follow-up effect of the thicker clay cap but could also indicate a reduced content of metallic scraps material.

A more detailed correlation analysis of the electromagnetic measurments with the ground truth data is required in order to discriminate between different potentail causes of the described features.

Magnetics

Figure 4 displays the results of the total magnetic survey. The magnetic data were acquired with two vertically aligned sensors, whereas both sensors measure the total magnetic field (in nT). The map in Figure 4a displays the data measured with the lower sensor after applying a spatial interpolation with inverse distance weighting (IDW). The normal magnetic field intensity at the landfill site is about 48850 nT (taken from IGRF online tool which takes into account the latitude, longitude and elevation of the site, in greenish tones on the map). Therefore, the blue and red colours on the map in Figure 4a correspond to magnetic anomalies.

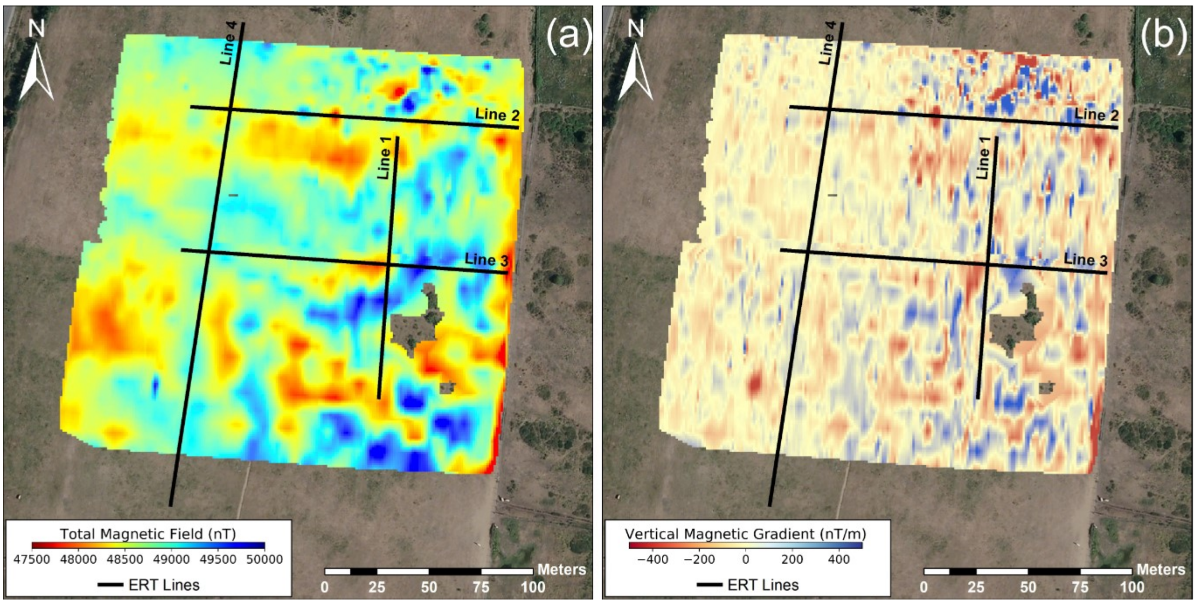

Figure 4: Results of the magnetic survey showing the total magnetic field (a) and the vertical magnetic gradient map (b).

Figure 4a shows several magnetic anomalies to the normal magnetic field intensity, especially in the easter side of the studied area. These broad anomalies are expected to reflect compositional change within the waste, or a change in the geological composition of the underlying material.

The vertical gradient map in Figure 4b is obtained by calculating the difference of the total magnetic field measured at the two sensors and interpolating the data using IDW. Especially for landfill studies, the vertical magnetic field gradient offers several advantages. Firstly, it is more sensitive to near-surface anomalous magnetic sources. Secondly, due to the signal subtraction, unwanted signal perturbation such as the influence of temporal variations of the total magnetic field and the influence of the earth magnetic field inclination, can be reduced (e.g. Roberts et al. 1990a and Roberts et al. 1990a).

In comparison to the total magnetic field measurements, the magnetic gradient data is much more perturbed with values fluctuating from negative to positive (Figure 4b). Such fluctuating values are a typical observation for landfills due to their high concentration of ferromagnetic material and is described for example in Knoedel et al. (2007). This is especially visible for the north-eastern part of the studied area, and more broadly, there is an increase in the amplitude of the gradient in the eastern part compared to the western part. This suggests a higher presence of ferromagnetic material in the eastern part.

Electrical resistivity (ERT) and IP

The ERT and IP results are summarized in Figure 5. As for the EM results, strong contrasts of resistivity and chargeability (IP) are imaged, and suggest rather complex structures both in terms of waste and host materials. The IP data shows a very distinct layer of low chargeability along the top of most profiles which can be interpeted as the clay cap. The absence of this layer in the South-East corner indicates that the clay cap is very thin or missing and could not be resolved. In the ERT data however, the clay cap is less clear and interestingly associated with low resistivities on the western half of the surveyed area (blue colours on the ERT images) and high resistive values on the eastern part (red colours on the ERT images). The high resistivity layer could either be caused by a reduced moisure content/lower porosity or a reduced clay content. The interface between the clay cap and the waste material as interpreted from the IP and the ERT data is indicated by white dotted lines in Figure 6. Below the clay cap, the North-West corner shows several resistive anomalies (green to red colours on the ERT images), which coincide to an area of relaitvely homogeneous and moderate chargeabilities. Thus, the waste body in the North-West might be less saturated (causing higher resistivities) and might contain a higher amount of inert material (medium chargeabilities, low resistivities). Conversely, the South-East corner shows a good match between high chargeability and low resistivity zones, which, as already highlighted in the EM and magnetic susceptibility maps, suggests an increased metal content. This is a stong indication for an increated amount of metallic scraps (low resistivity, high chargeability). Figure 6a highlights the good match between the higher conductivity zones imaged by the ERT and the EM.

A mismatch is observed in the South-West corner between the lower boundary of a high resistivity layer and that of a high chargeability layer. This may suggest a more complex waste distribution, with an unsaturated waste layer with a lower amount of metallic scraps (high resistiviy) but a high content of organic material, wood or plastic layering (high IP) at shallow to intermediate depths, and an unsaturated inorganic waste layer at greater depths (e.g. thick concrete layer or inert material, as observed in borehole BH09). The presence of a non-saturated gravel layer at the bottom of the waste could be an alternative explanation to these higher resistivity values.

Saturated London clay at the bottom of the waste is well imaged as a low resistivity shape at the bottom of the waste. The top of the low resistivty layer might correspond to the water table.

In general, it can be concluded that the high chargeability layer corresponds to municipal waste containing a relatively high amount of organic material or wood and towards East increased amount of metallic scraps. The resistivity in contrast might, in the areas with a reduced amount of metallic content, be more sensitive to changes in leachate/water saturation.

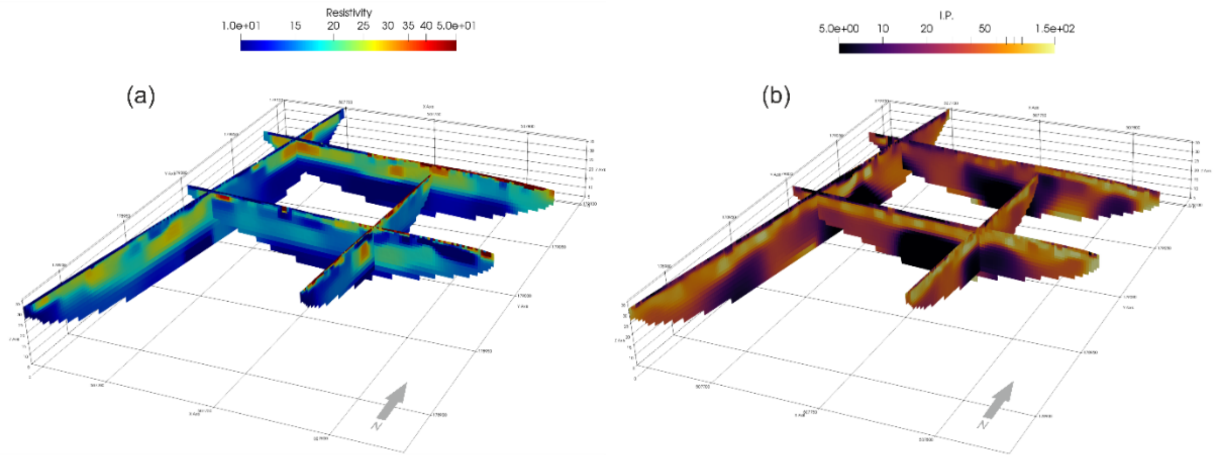

Figure 5: ERT (a) and IP (b) results on the 4 surveyed lines on locations as shown on Figure 1.

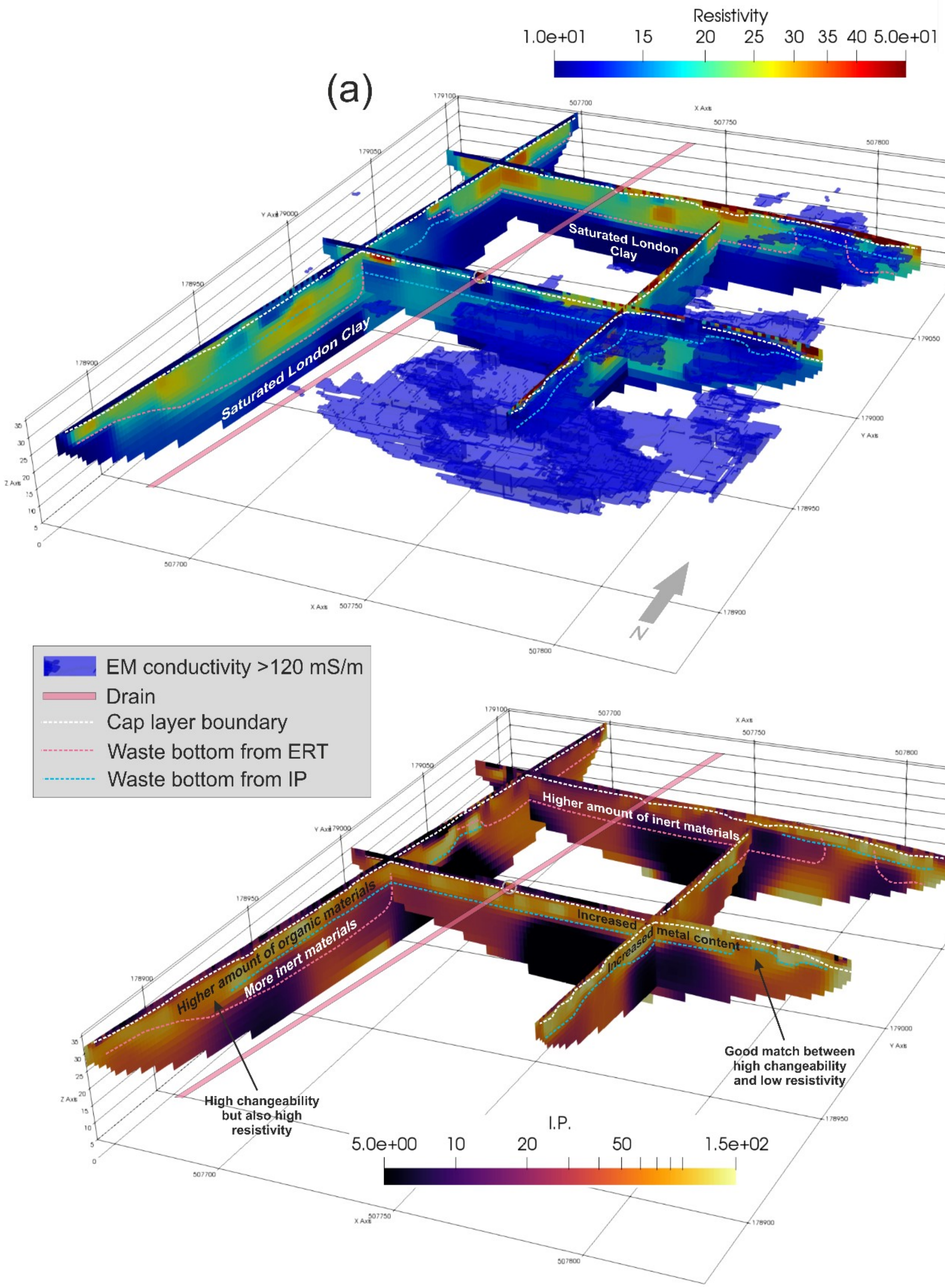

Figure 6: ERT (a) and IP (b) results along the 4 survey lines. Conductivity above 120 mS/m from the EM survey are also displayed as they match properly the conductive features imaged from the ERT profiles on the South-East corner. Boundaries infered from the ERT (blue lines) and from the IP (pink lines) are also featured. The cap layer boundary is also drawn as a white line.

MASW

The multi-channel analysis of surface waves (MASW) allows to derive the shear-wave velocity (Vs) distribution at depth along 2D profiles. Vs mainly informs on the stiffness property of the subsurface materials. MASW measurements were carried out along the ERT lines (see location in Figure 1), and results are yielded on Figure 7. The depths of investigation are shallower than for the ERT measurements (up to ~15 m deep), and as seen from the boreholes, are likely not reaching the bottom of the waste. There is again a strong contrast between the western and the eastern side of the surveyed area. The western side is characterized by a two-layer distribution with a first shallow layer with low Vs (~150 m/s, green colours) and a deeper layer with higher Vs (~500m/s, blue colours), starting roughly at a depth of around 7m. This increased Vs layer could be associated with a concrete slab, and is to be differentiated with the London Clay, which should have slower Vs. The presence of such a concrete layer matches the observation indicated by the intermediate layer of high resistivity and low chargeability on the westernmost ERT profile (Figure 6). The eastern part does not experience such a two-layer distribution, and displays rather slow Vs (Vs (~100 m/s, yellow to green colours), which again suggests a different level of compaction within waste materials, and potentially a compositional change with respect to the western side. A thin banded layer of increased Vs (at about 10 m depth) is visible both in profile Line 2 and 3, and in the South part of Line 1 (compare Figure 1). It could be attributed to a layer of increased stiffness within the waste.

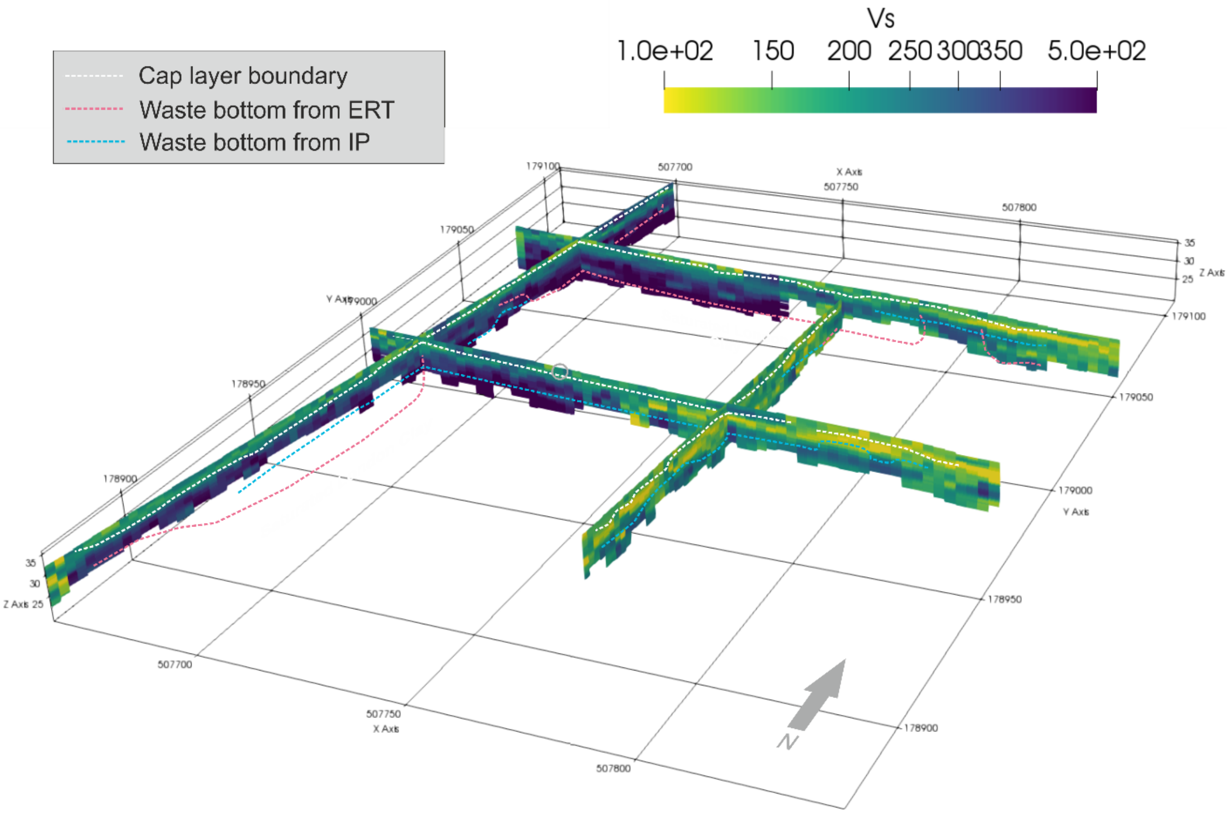

Figure 7: MASW results showing distribution of Vs along the 4 profiles. Limits identified in the ERT and IP results are also displayed.

Conclusion

The geophysical survey in Stockley Park comprised rapid mapping characterisation (EM and Magnetics measurements), as well as measurements along four 2D profiles (ERT, IP and MASW). Broadly speaking, the gathered data from all the geophysical techniques point to a strong contrast between the eastern and the western side of the surveyed area. This has to be explained by a significant change in waste composition:

- A concrete layer at the bottom of the western part of the landfill, covered by a waste layer of lower stiffness and increased amounf of organic material or wood.
- A poorly compacted waste area in the eastern side of the landfill, with large zones of increased metal content.

This above described interpretation is preliminary. A detailed analysis correlating the geophysical measurements with the available groud truth data is planned as the next step. Geophysical signatures can have different causes (e.g. the high conductivity and high amplitudes of magnetic susceptibility seen in the EM results can be caused by a thin clay cap or an increased metal content). Thus, a detailed correlation analysis should help to imporve and verify the interpretation.

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