Geophysical Exploration of Buried Glass Hotspots

Report on Electrical Resistivity Tomography (ERT) Survey at Bergdala and Strömbergshyttan Glass Dumps

Patent pending by Ragn-Sells Group on the use application of ERT technology on glass-dump hot-spots

Performed witin the TUFFO project:
"Verifiering och införande av ny metod för återvinning av blyglas från glasdeponier"
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Ragn-Sells has co-developed the approach presented in this report and has a pending patent on the scanning approach for glass dump hot-spot scanning. For more information on the approach please contact Tommy Ohlsson or Graham Aid. Firstname.Lastname@ragnsells.com

1. Introduction

This report presents results of geophysical investigations carried out around old glass waste dumps at Bergdalahyttan and Strömbergshyttan in Lessebo Municipality, Kronoberg County from 1st to 5th July 2020. Bergdala glass factory and the waste dump are located at the properties *Hovmantorps-Hästebäck 1:38* and *Hovmantorps-Hästebäck 1:41*, respectively. The factory has been in operation since 1889 and over the years produced crystal and household glass. Strömbergshyttan, on the other hand, is located at the properties *Linneskruv 1:56* and *1:63*. The factory was in operation from 1876 to 1979 and produced crystal and soda glass (Länsstyrelssen, 2018). The two glass waste dumps are known for arsenic (As) and lead (Pb) contamination. The aim of the investigation, therefore, was to identify regions of buried glass hotspots at the dumps to facilitate site remediation and acquisition of enhanced glass quality for use in metal extraction processes.

2. Survey Methodology

The investigations were achieved using Electrical Resistivity Tomography (ERT), a 2D resistivity survey method that maps buried waste materials based on their electrical properties. The survey procedure was adopted from Mutafela et al. (2020). An ABEM Terrameter LS2 was used for the measurements, supplemented with an Electrode Selector ES10-64C in order to measure with separated electrode cable spreads for current transmission and potential measurements. This measurement procedure can improve the data quality substantially in areas with highly resistive material at the surface, which is commonly encountered for glass dumps. Multiple gradient array was used throughout with an electrode spacing of 1 m in order to achieve good resolution. However, the number and length of ERT lines were site-specific. The boundary of each site, as well as every electrode on each line, was positioned using Real-Time Service (RTS) corrected Global Navigation Satellite System (GNSS). Induced polarisation (IP) data was acquired simultaneously with the ERT data for all lines, and although the data quality generally looks good, it would require more thorough processing and data quality assurance than the ERT data, which was not within the scope of this study.

The resistivity obtained in the field by the Terrameter was apparent resistivity. To obtain an estimate of the true or most likely distribution of subsurface resistivity in the dumps, the field data was analysed through the process of inversion using the software RES2DINV (Mutafela et al., 2020). After inversion, identification of glass hotspot locations was based on values of resistivity known for glass waste and obtained from similar studies around glass waste dumps.

2.1. Bergdala

Bergdala glass dump is located in the backyard of Bergdalahyttan, enclosed in a wire fence as shown in Fig. 1a and 1b respectively. Six ERT lines were surveyed, three running from north to south (A, B, C) towards the glass factory, and the other three running from east to west (D, E, F) as shown in Fig. 1c, Fig. 1d and Fig. 2. Given the rapid change in altitude at the site, however, there was need to have a longer line descending beyond the dump boundary to acquire backround data around and beyond the dump. Therefore, line E was made longer than lines D and F.

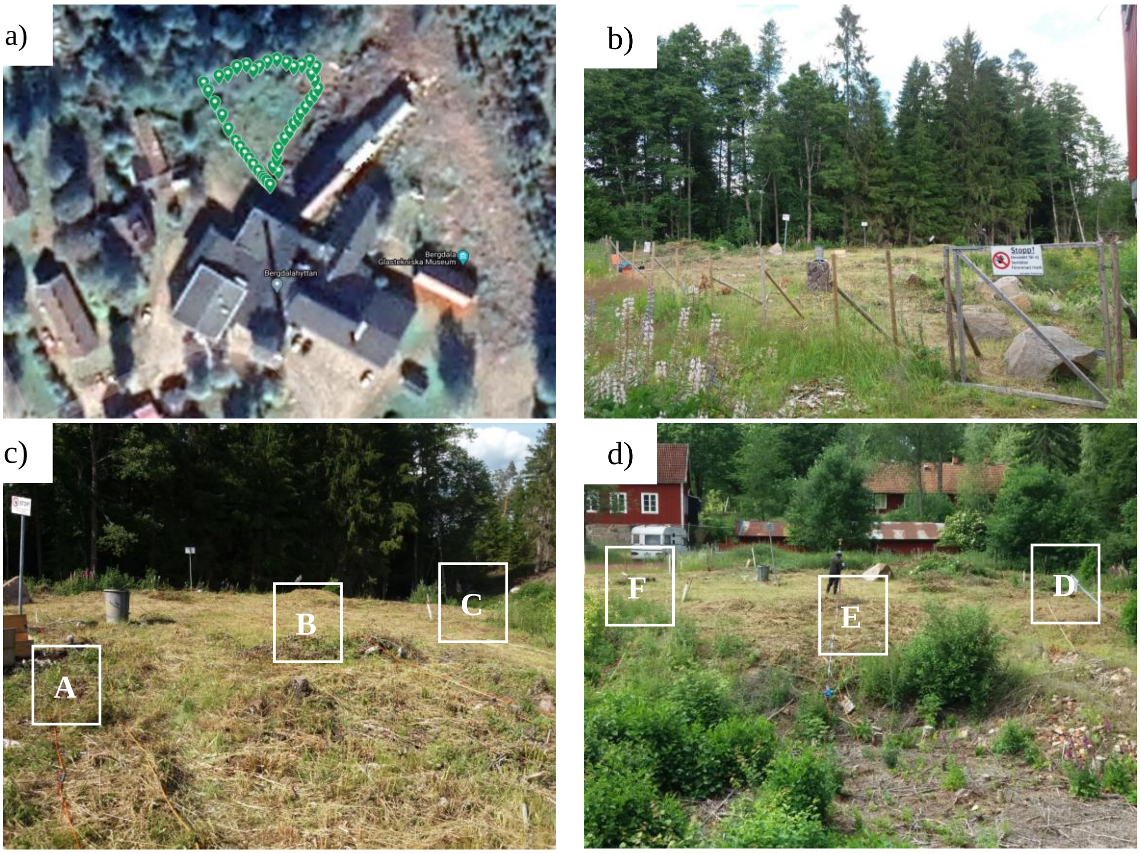

Figure 1. Bergdala glass dump (a) aerial view with GNSS points of the dump boundary as defined by the fence (Map data ©2020 Google); (b) investigated dump area inside fence; (c) layout of ERT survey lines A-C; (d) layout of ERT survey lines D-F.

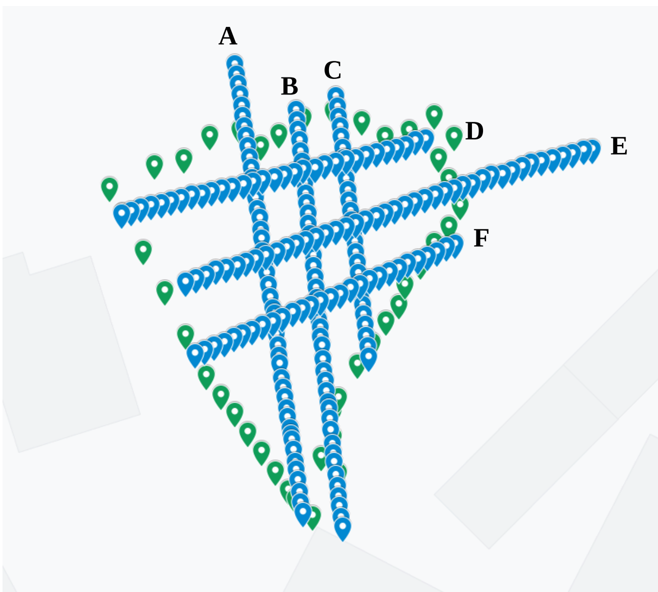

Figure 2. Layout of lines at Bergdala. Lines A (44 m), B (40 m) and C (25 m) oriented north to south; lines D (30 m), E (41 m) and F (27 m) oriented east to west (Map data ©2020 Google).

2.2. Strömbergshyttan

Strömbergshyttan is located some meters away from the glass factory. During the survey, the site was divided into two distinct areas as shown in Fig. 3a. The bigger area was covered by trees (Fig. 3b) that were later cut down, whereas the smaller one was relatively clearer without much tree cover (Fig. 3c). The division was based on the client's interest to know the potential for presence of glass waste around the tree-covered area. Five ERT lines were surveyed at this site, three running from east to west (A-C), and the other two running from south to north (D and E) as shown in Fig. 3d.

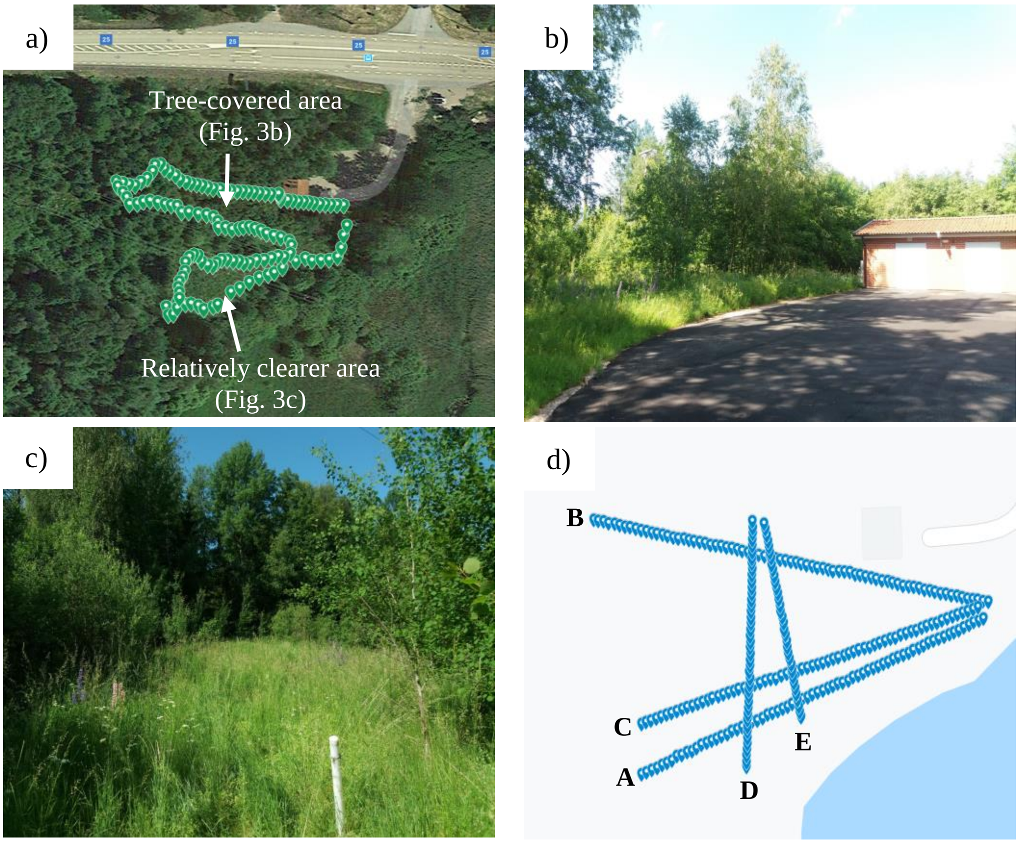

Figure 3. Strömbergshyttan (a) GNSS points of dump boundary; (b) area with tree cover; (c) more clearer area; (d) layout of lines. Lines A (68 m), B (74 m) and C (65 m) oriented west to east; lines D (41 m) and E (36 m) oriented south to north (Map data ©2020 Google).

3. ERT Results

Results of the ERT surveys at both sites are presented as resistivity profiles and as site maps overlaid with interpretations of expected regions of glass hotspots. The resistivity scale on each profile ranges from 20 to 20,000 Ωm, and the colour progression from dark blue to dark red corresponds to resistivity transition from low to high resistivity (Mutafela et al., 2020).

3.1. Bergdala

The resistivity profiles obtained at Bergdala are shown in Fig. 4 and Fig. 5 for lines A to C and D to F, respectively. Generally, there was quite high contrast in resistivity due to tree stumps and bedrock features that were in close proximity to the waste and the dump surface. For instance, in Fig. 4a (line A) a tree stump at 28 m (shown in Fig. 6b) generated artefact-related resistivity, whereas the interval 31 – 42 m was believed to be dominated by rocks. This interpretation is based on similar features in Fig. 4b (line B) around the interval 29 – 36 m, where big rocks were observed on the dump surface (Fig. 6a and 6b).

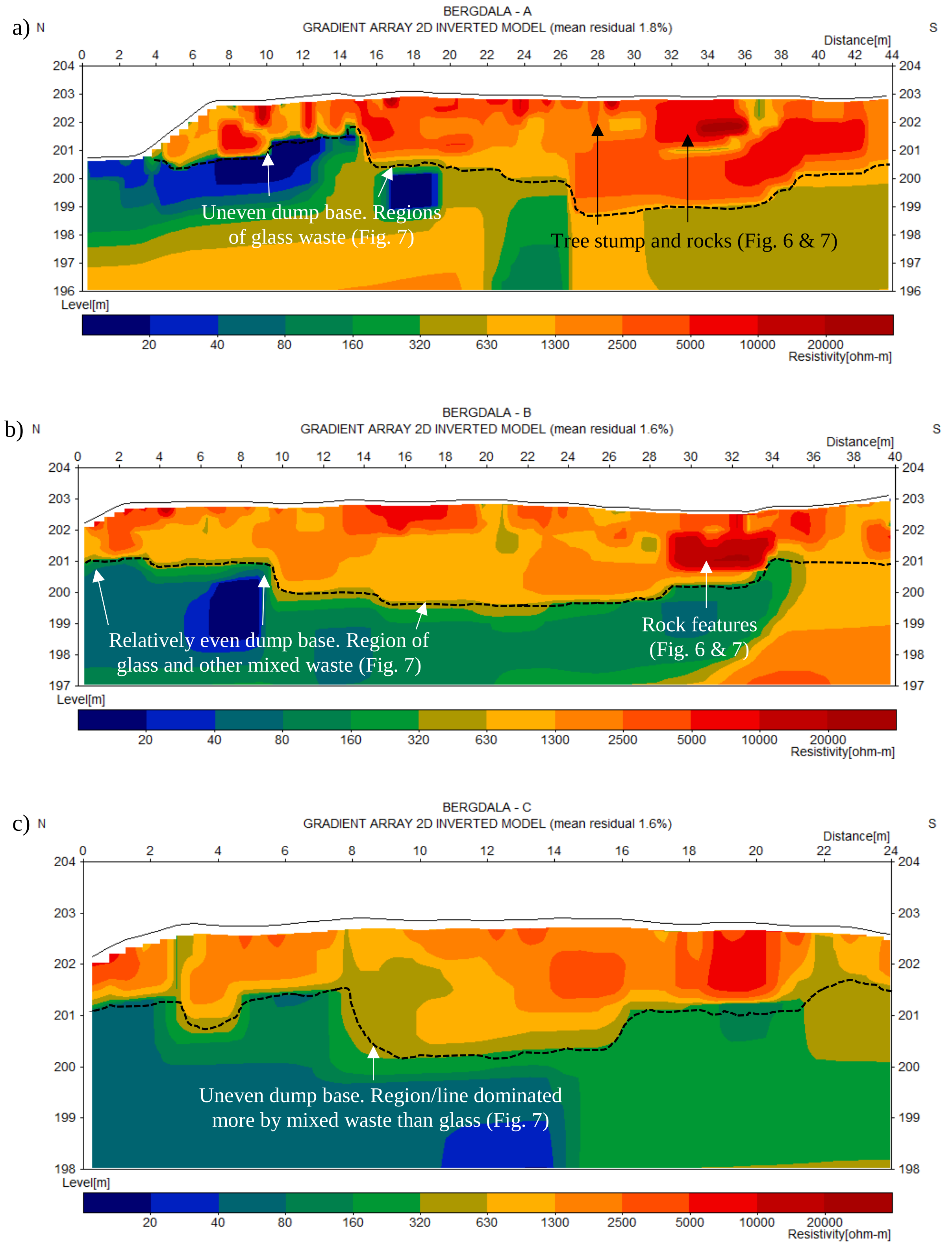

Figure 4. ERT profiles (north to south) at Bergdala (a) line A; (b) line B; (c) line C.

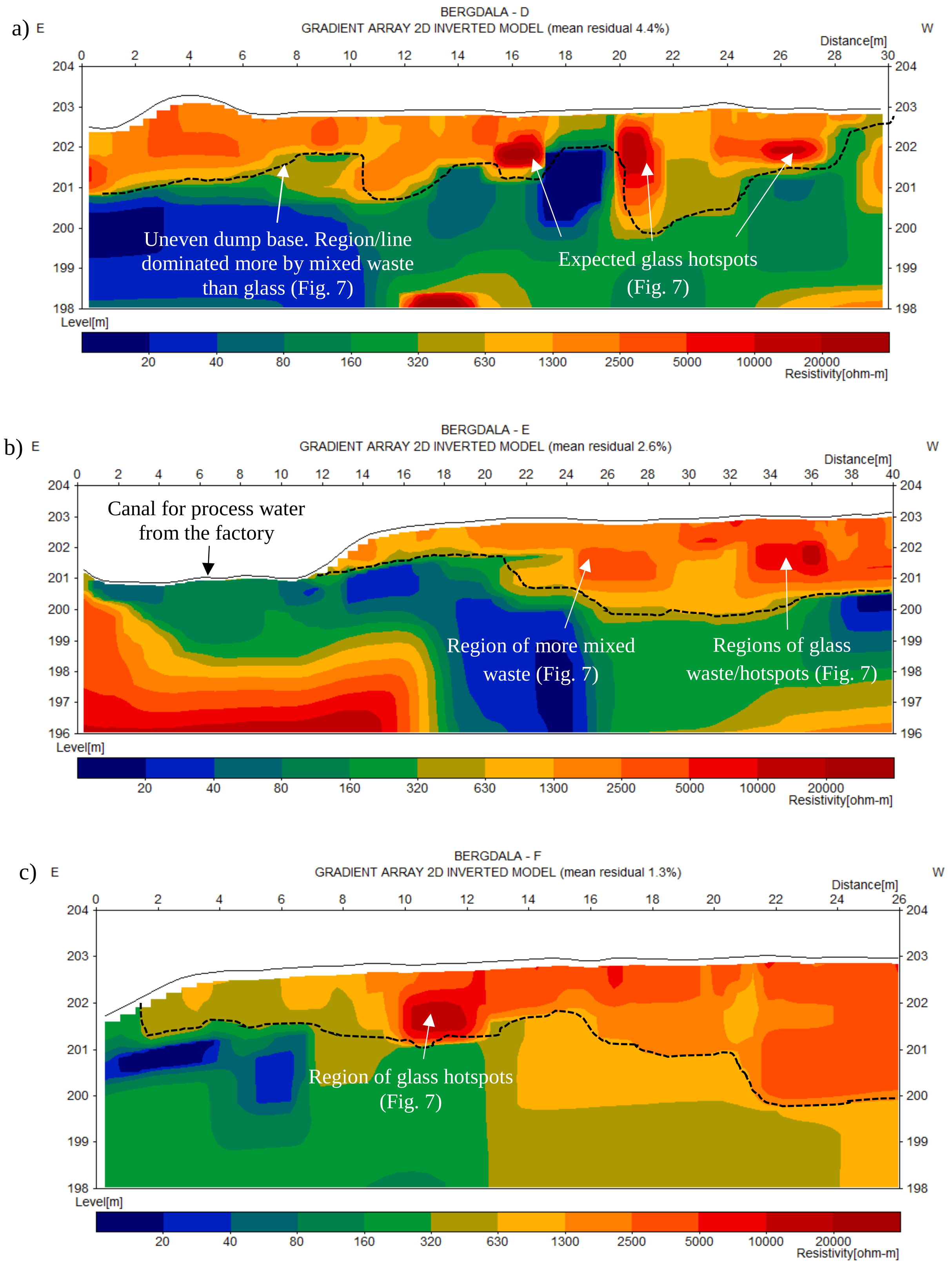

Figure 5. ERT profiles (east to west) at Bergdala (a) line D; (b) line E; (c) line F.

Zones that stand out with low resistivity, for example in the interval 0 – 15 m on line A, may indicate concentrations of material with mobile ions. This could be either due to the original material deposited there or due to leaching and accumulation processes. In the latter case, it might coincide with zones of ion precipitation, which could also be investigated by analysing the IP data that was acquired together with the ERT data. In general, the data quality obtained at the site was good as indicated by the low mean residuals for the inversion models which are mostly in the range 1 – 2 %, and a bit higher for a couple of the lines.

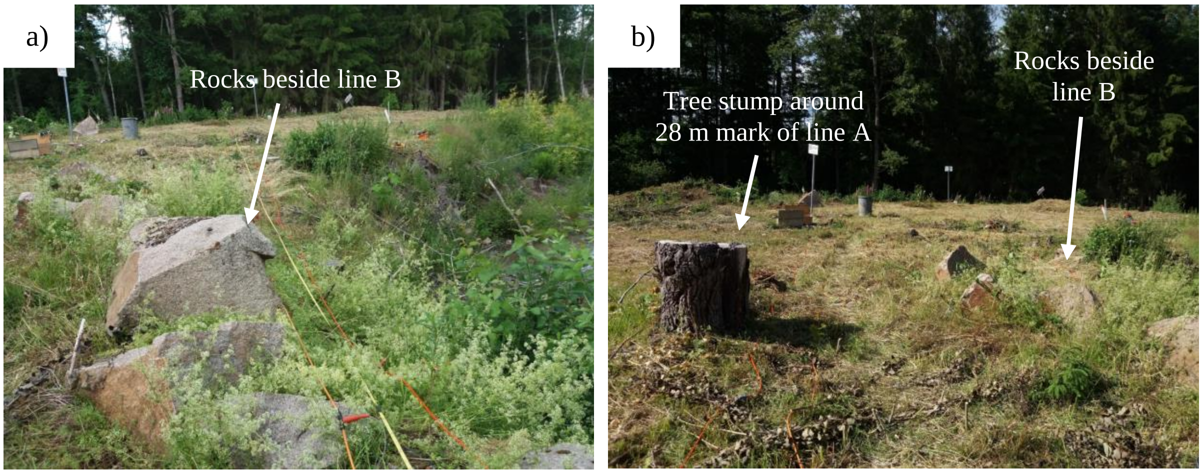

Figure 6. Features contributing to resistivity contrasts in ERT profiles; (a) big rocks besides line B, and (b) tree stump and more rocks along lines A and B, respectively.

Based on resistivity profiles in Fig. 4 and Fig. 5, the results were incorporated in Google Maps to depict locations of different features as shown in Fig. 7. Regions of glass hotspots and rock features are coloured red, based on their resistivity. In most instances, however, the resistivity transition (2500 – 15,000 Ωm) indicated the potential for more mixed waste at the site i.e. regions coloured orange. Generally, the locations of interest on the lines are expected as follows (detailed description in appended GNSS location and kml files, for easy understanding):

- Line A: Glass at 8 – 26 m, but also rocks or other geological features at 31 – 42 m.
- Line B: Glass at 0 – 5 m and 13 – 19 m, rocks or other geological features at 29 – 36 m.
- Line C: Glass at 0 – 3 m and 18 – 22 m.
- Line D: Glass at 9 – 10 m, 15 – 17 m, 20 – 22 m and 24 – 27 m.
- Line E: Glass at 29 – 36 m.
- Line F: Glass at 9 – 19 m and 23 – 25 m.

A region expected to contain glass hotspots at the site was identified based on the above-stated classifications, and was shaded as shown in Fig. 7. However, the shading was an estimate based totally on the spread of red pointers on the lines in the Figure.

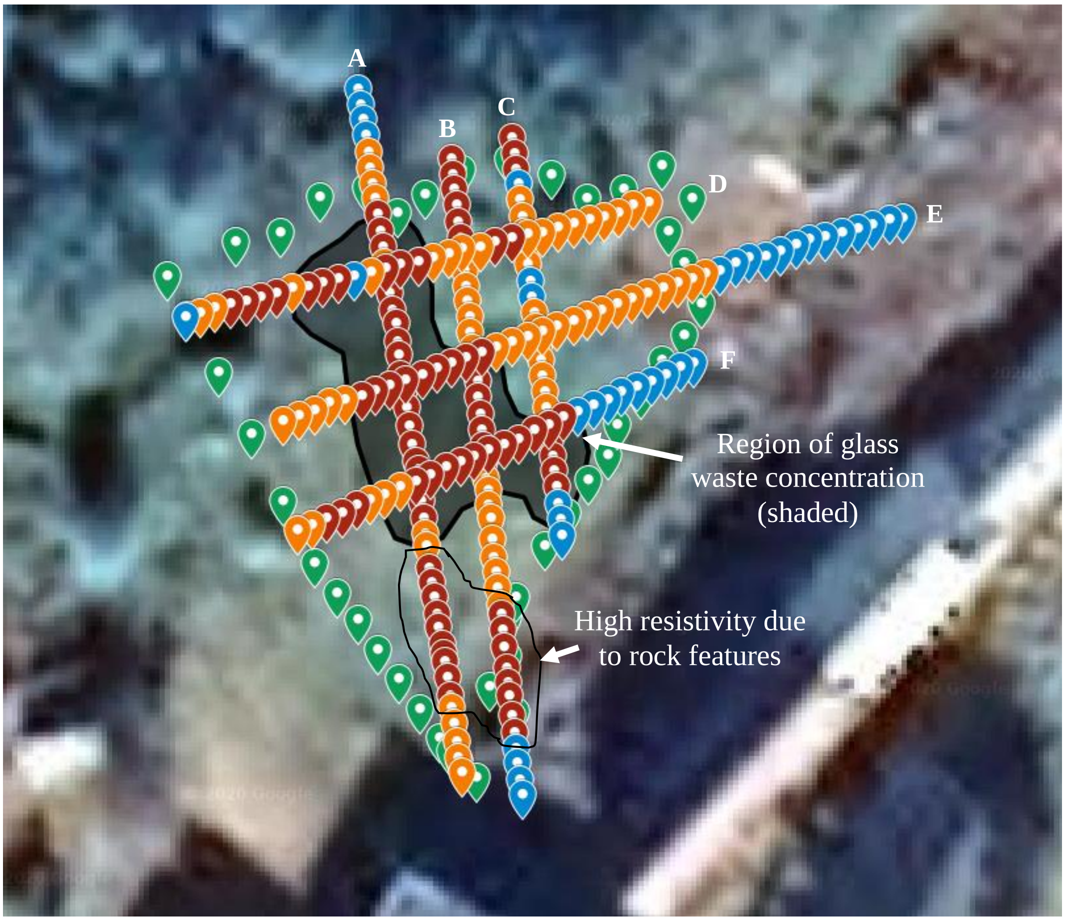

Figure 7. ERT lines at Bergdala with GNSS positions of all electrodes on each line, coloured based on ERT profiles in Figures 4 and 5. Depiction of pointer colours: green for dump boundary; blue for 'non-glass' materials; orange for mixed waste; red for glass hotspots and/or rocks (unless stated, all red dots depict glass hotspots). The shaded part depicts the region expected to contain more glass waste (Map data ©2020 Google). Details in appended *kml* files.

3.2. Strömbergshyttan

The resistivity profiles obtained at Strömbergshyttan are shown in Fig. 8 and Fig. 9 for lines A to C and D to E, respectively. At this site, contrast in resistivity was not as high, and the bedrock features were not as close as at Bergdala. In all ERT profiles, the interpreted dump base (extent of highly resistive waste) was quite easily distinguishable from other features, having a maximum depth of 4 m. In addition, the mean residuals or error margins were relatively lower at Strömbergshyttan (0.7-2.6% in Fig. 8 and Fig. 9) than at Bergdala (1.6-4.4% in Fig. 4 and 5). Many regions of high resistivity were registered within the waste zones of each profile in Fig. 8. These regions in Fig. 8a and 8c were interpreted as predominantly glass hotspots. The regions in Fig. 8b, however, could not be interpreted as such with certainty. Instead, the high resistivity regions were attributed to roots of tree stumps (since the region had tree-cover initially) that potentially influenced the resistivity distribution. This can be seen from photos of the region shown in Fig. 10.

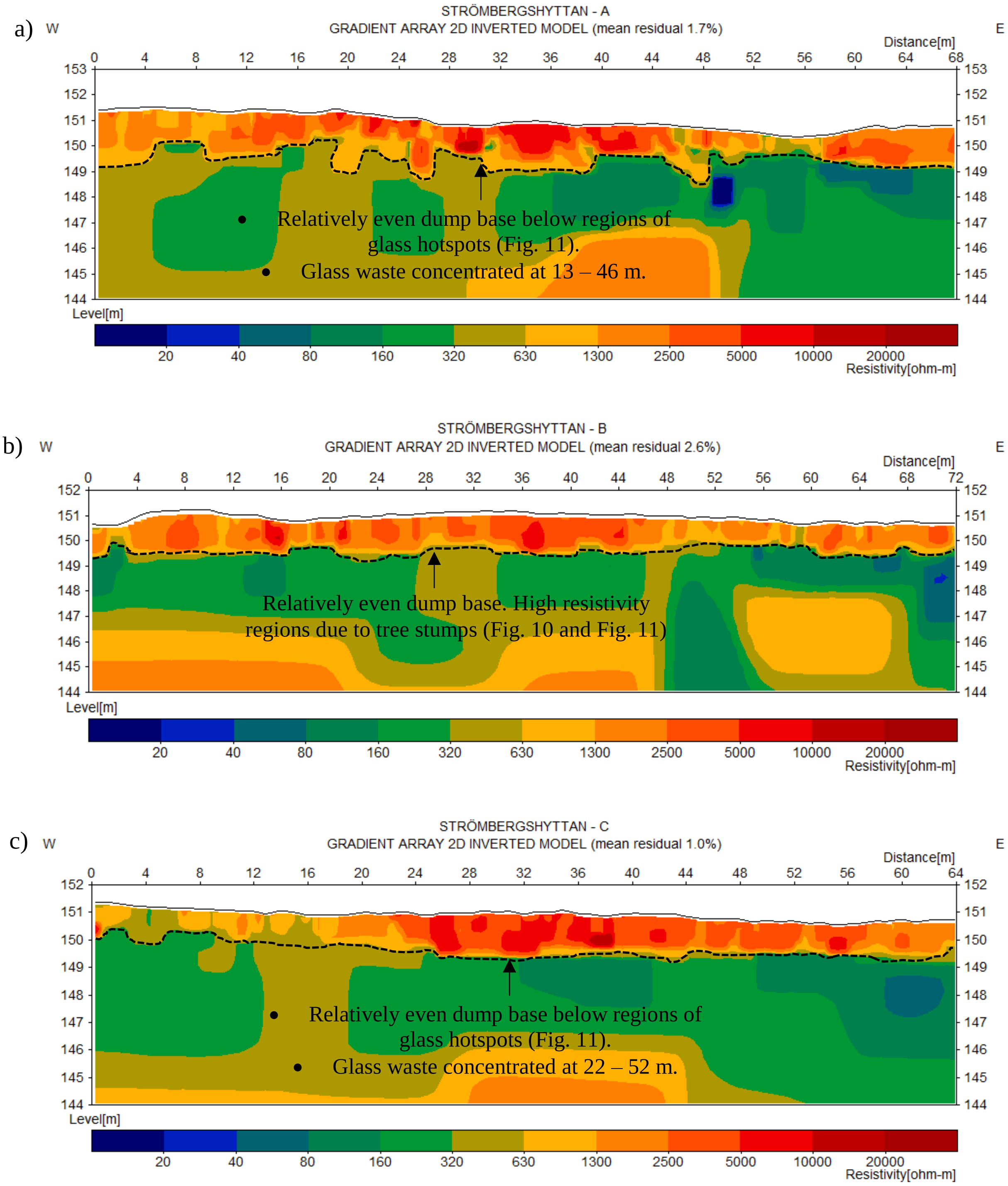

Figure 8. ERT profiles (west to east) at Strömbergshyttan (a) line A; (b) line B; (c) line C.

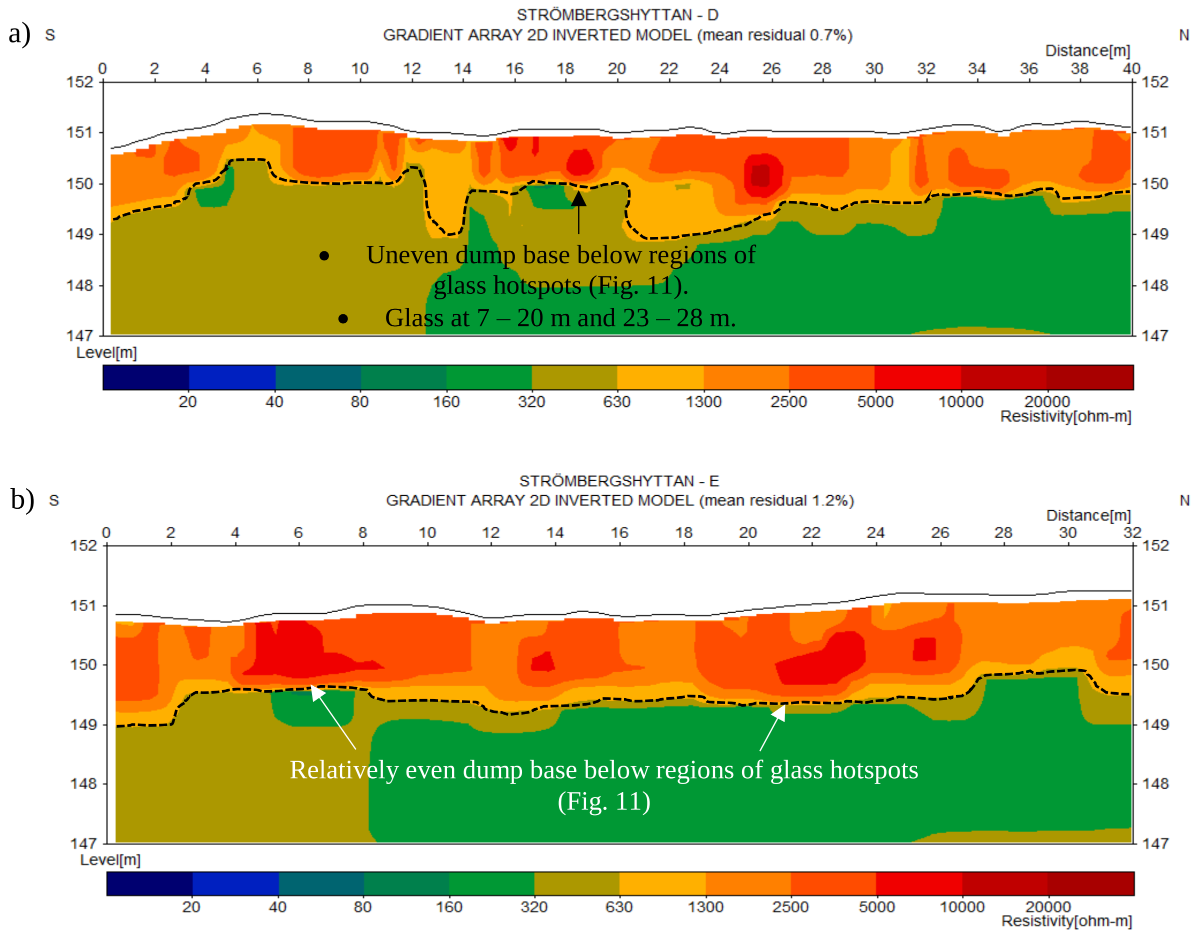

Figure 9. ERT profiles (south to north) at Strömbergshyttan (a) line D; (b) line E.

Figure 10. Cleared area with tree stumps along the survey line. (a) Beginning of the line, near the stream on the western part, and (b) around the middle of the line, eastward.

For Strömbergshyttan also, the results were incorporated in Google Maps to depict locations of different features as shown in Fig. 11, based on the resistivity profiles in Fig. 8 and Fig. 9. Similarly, regions interpreted as glass hotspots are coloured red based on their resistivity. Regions of mixed waste or other materials, on the other hand, are coloured orange. The following were the locations of interest at this site (detailed description in appended GNSS location and kml files):

- Line A: Waste in general concentrated between 10 – 46 m, of which glass hotspots are expected at 13 – 46 m and 57 – 64 m.
- Line C: Waste generally concentrated between along the entire line, of which glass hotspots are expected at 22 – 52 m.
- Line B: High resistivity believed to be due to tree stumps. However, verification excavations are recommended to ascertain the features at 14 – 16 m and 35 – 44 m.
- Line D: Glass at 7 – 20 m and 23 – 28 m.
- Line E: Glass at 2 – 15 m.

Similarly, a region expected to contain glass hotspots at Strömbergshyttan was identified shaded as shown in Fig. 11, estimated based on the spread of red pointers on the lines.

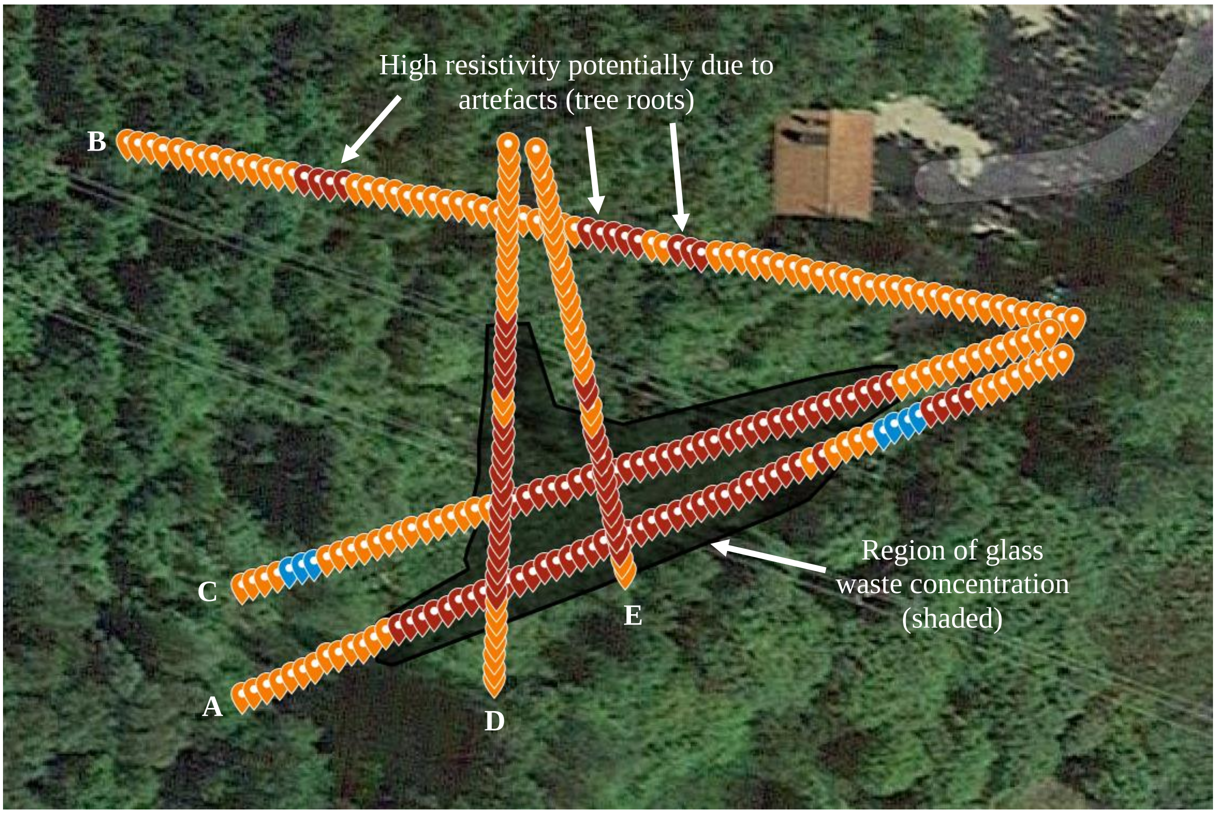

Figure 11. ERT lines at Strömbergshyttan with GNSS positions of all electrodes on each line, coloured based on ERT profiles in Figures 8 and 9. Depiction of colours for location icons: green for dump boundary; blue for 'non-glass' materials; orange for mixed waste; red for glass hotspots and/or rocks (unless stated, all red dots depict glass hotspots). The shaded part depicts the region expected to contain more glass waste (Map data ©2020 Google). Details in appended *kml* files.

4. Remarks

The survey indicated that the glass waste appears more distinctly separated at Strömbergshyttan than Bergdala, suggesting a clearer boundary between the glass waste deposits and geological material. At Bergdala, more mixed waste is expected than at Strömbergshyttan. Alternatively, the character of the glass waste may vary, where the zones with not so high resistivity may be indicative of inclusions of material from incomplete processing in the glass manufacturing.

Furthermore, zones that stand out with low resistivity may indicate concentrations of material with mobile ions, either due to the original material deposited there or due to leaching and accumulation processes. In the latter case, it might coincide with zones of ion precipitation, which could be further investigated by analysing the induced polarisation (IP) data also that was acquired together with the ERT data.

Detailed descriptions of each ERT profile can be obtained from the GNSS location and kml files, which have been designed to make excavations interactive.

5. References

Länsstyrelsen i Kronobergs Län, 2018. Förorenade områden – Prioriterade områden i Kronobergs län (Bergdala och Strömbergshyttan). (In Swedish).

Mutafela, R. N., Lopez, E. G., Dahlin, T., Kaczala, F., Marques, M., Jani, Y., & Hogland, W. (2020). Geophysical investigation of glass 'hotspots' in glass dumps as potential secondary raw material sources. *Waste Management*, *106*, 213-225. doi:https://doi.org/10.1016/j.wasman.2020.03.027

Appendices

The following appendices have been submitted with the report:

1. Raw data files (as obtained in the field, based on apparent resistivity).
2. Inversion files (resistivity profiles after the data inversion process).
3. Fence diagram files (3D resistivity profiles from a combination of line cross-sections).
4. Xpt maps with kml (Keyhole Markup Language) files of all GNSS points taken from the sites.
5. Google Maps integrating GNSS locations (based on kml files) with expected glass hotspots highlighted.
6. Photos from the field surveys.

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