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# Assessment of magnetic data for landfill characterization by means of a probabilistic approach


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# Summary


We investigated a landfill located in a -formerly exploited- limestone quarry using electrical resistivity tomography(ERT), induced polarization (IP), electromagnetic induction (EMI), H/V and magnetometry. In this contribution we focus in one 2D profile where all the previous data was collected.

The main features of the site were imaged with:

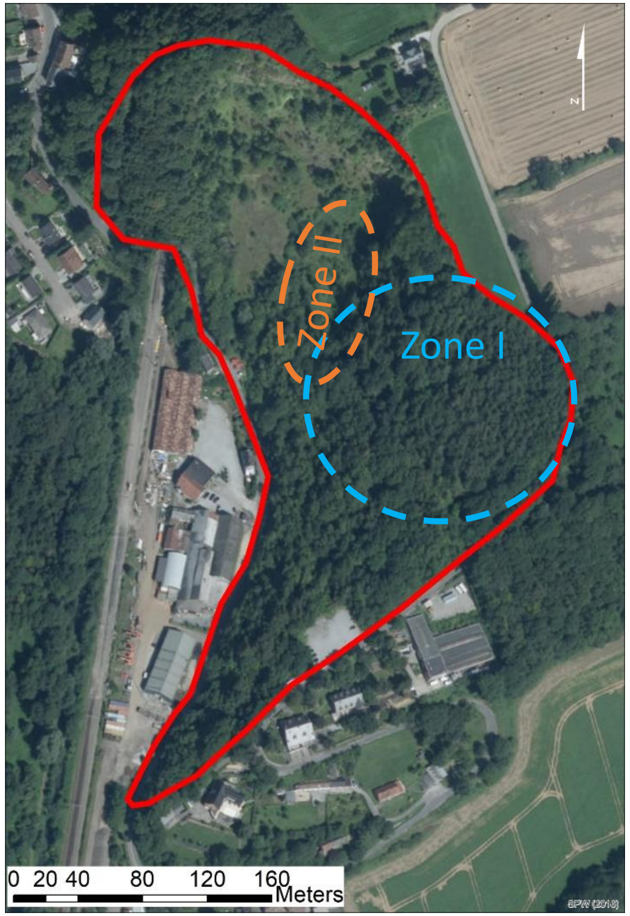
1. ERT → delineate the top of the bedrock (possible leakage) & lime deposits on the top
2. IP → Large chargeability values might be due to the presence of metallic scraps, IW and CDW.

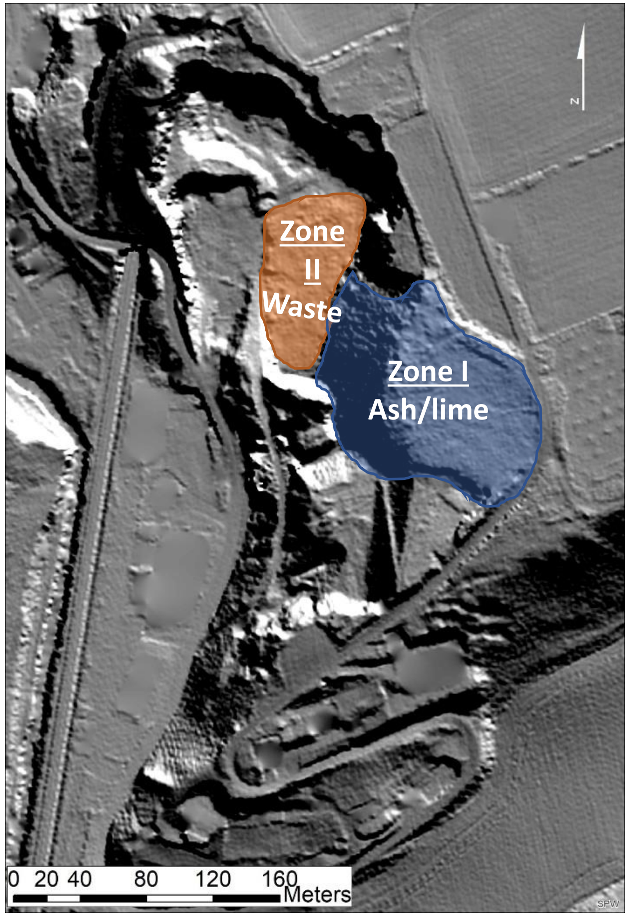
*We assessed these methods by means of a probabilistic approach according to co-located ground truth data

Based on the previous features and a qualitative interpretation of EMI and H/V data we derived a magnetic model using the observed total-field magnetic anomaly (reduced to the pole).

According to the magnetic modeling, some long wavelength anomalies might be associated with infiltrations or leakages (dyke-like structures) into the bedrock. Nevertheless, some magnetic susceptibility values for these possible leakages -probably composed of hydrocarbons- might be overestimated and still need to be verified.

# History




## Onoz landfill

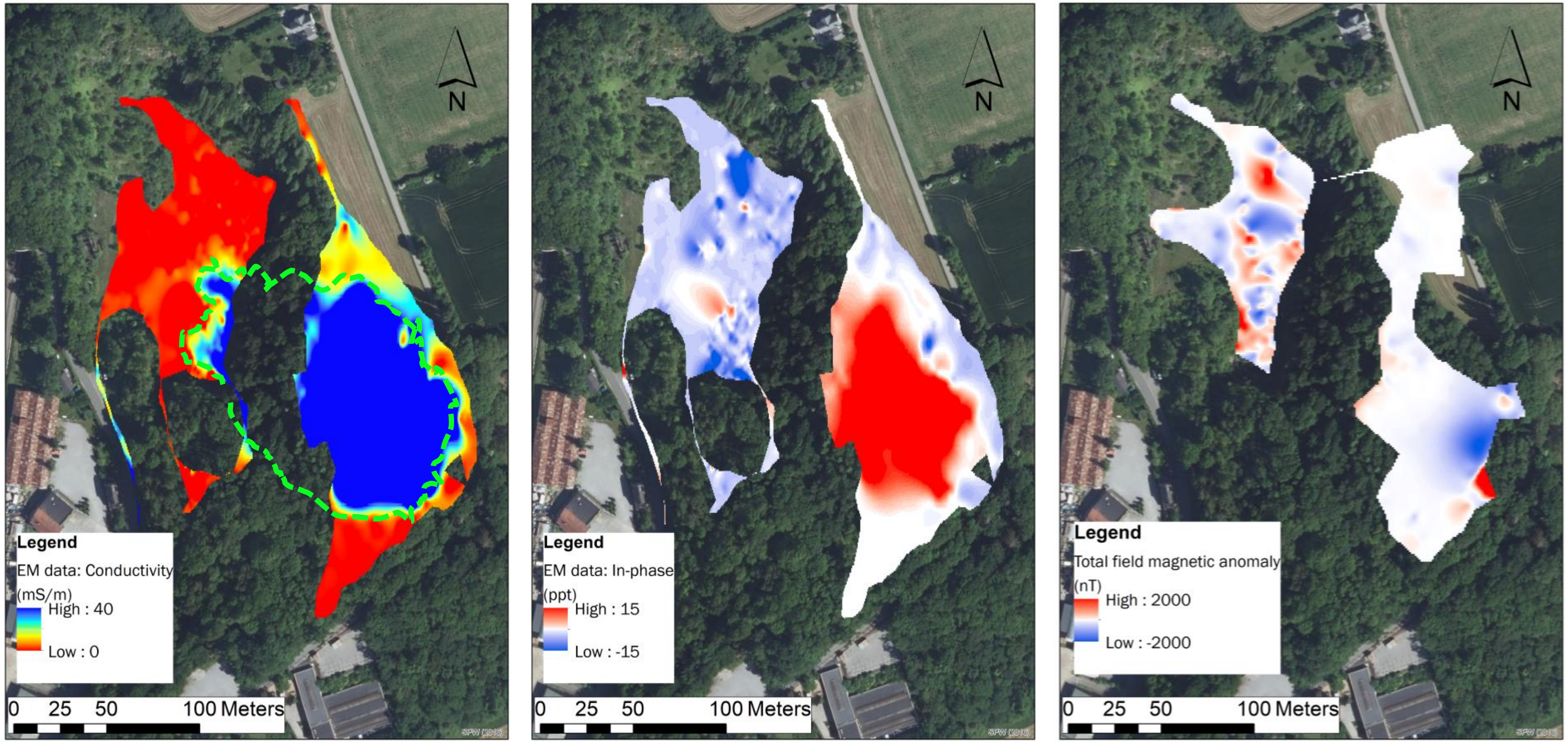
- (1902-1966) Limestone quarry & slacked lime production in situ
- (1967) "Schlamm" deposits in Zone I: Ca(Oh)2 (slaked lime), H2O, calcium sulfate
- (1968) Concrete block factory
- (1975-1987) Deposits of schlamm, acetylene, ashes (probably from a power plant), industrial waste (IW) mostly in Zone I. Rubble, construction & demolition waste (CDW), municipal solid waste (MSW) deposited in Zone II.

# Previous results after 2D mapping

**A)** EMI: quadrature component

**B)** EMI: in-phase component

**C)** Total field magnetic anomaly



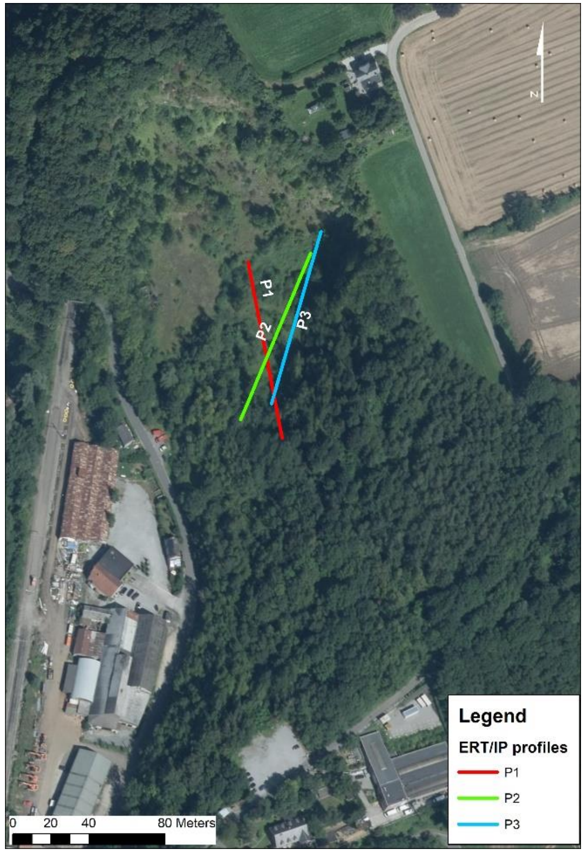

## Preliminary observations

A. Large conductivity values delineated the lateral extension of ashes/lime.

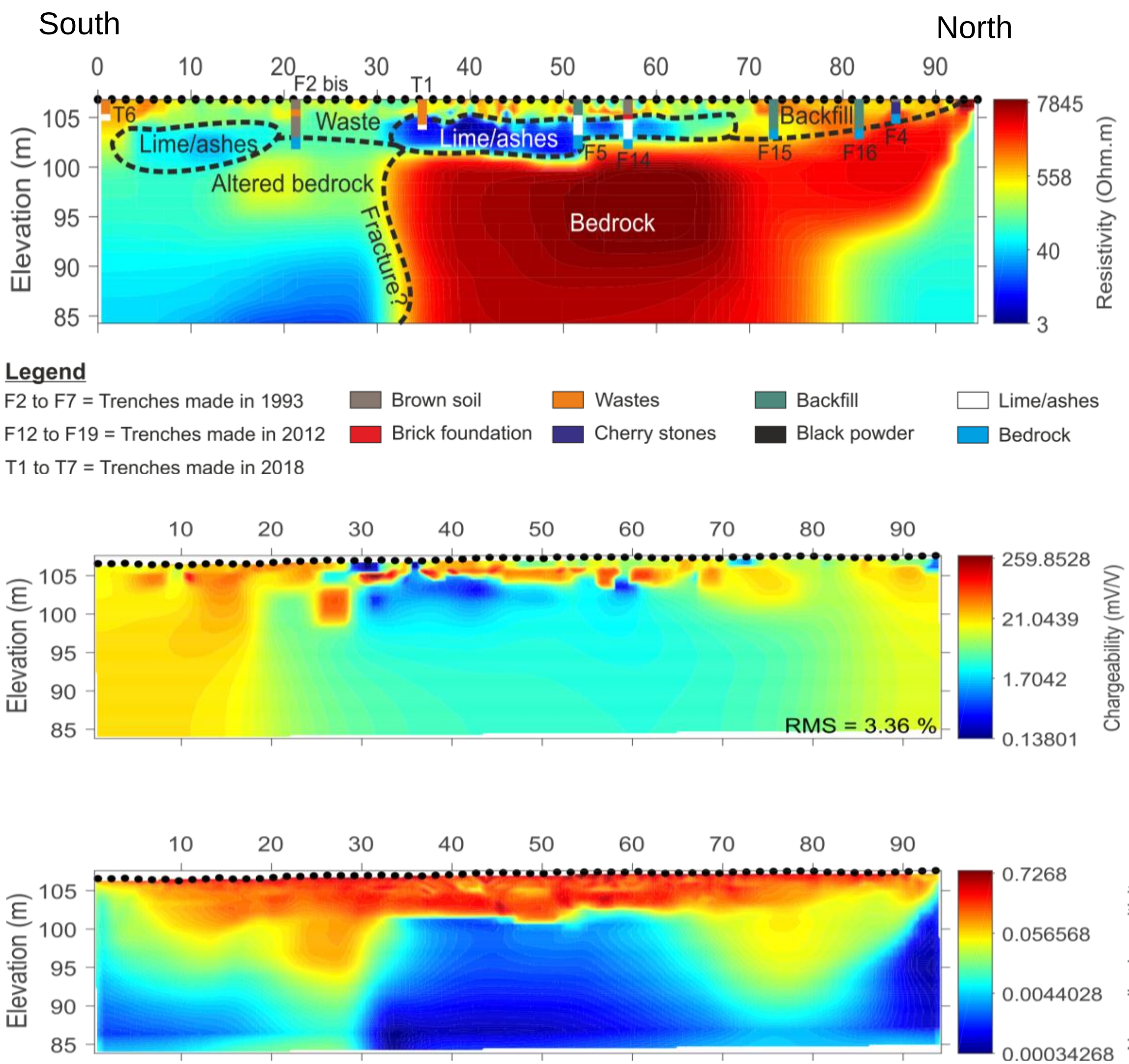
B. Values of magnetic susceptibility are larger in the ashes/lime deposits.

C. Strong magnetic anomalies are present in Zone II but not in the upper part of the site where mostly ashes/lime are located.

# Profiling methods: ERT/IP data in Zone I




Profile 2 – P2



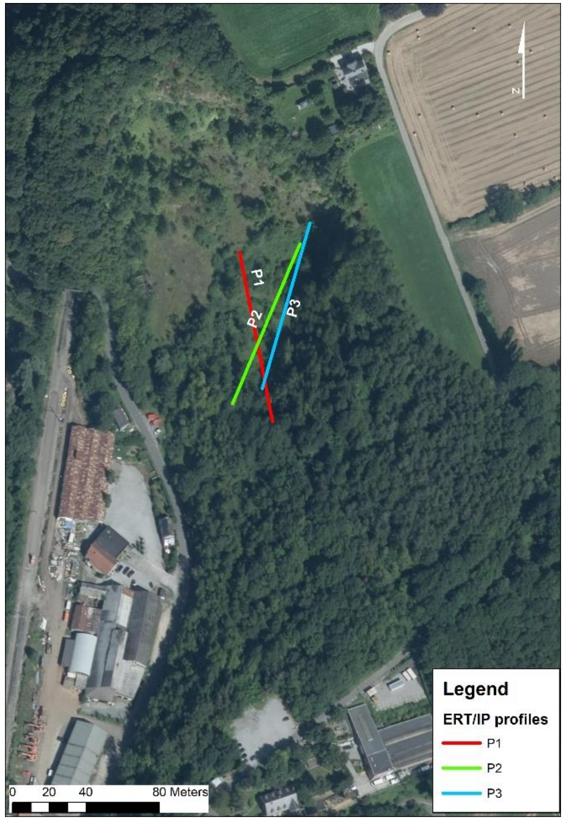

*Set-up: ABEM Terrameter LS, dipole-dipole array, 64 electrodes (1.5 m spacing), 2s current injection,2 s meas. V decay
*inversion RES2DINV (Loke, 1998)

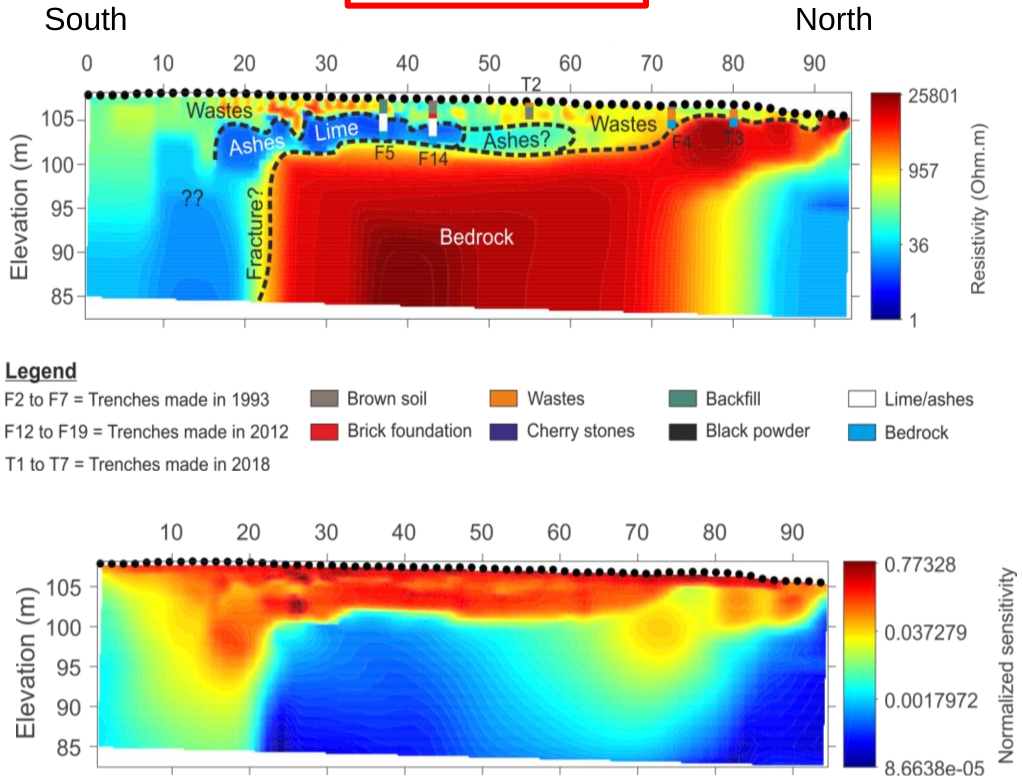
## Preliminary observations

- In general, the largest resistivities might correspond to the limestone and very low resistivities to lime deposits.
- Large chargeability values at the surface might be due to the presence of metallic scraps, IW and CDW.
- Disturbances of the bedrock towards the south. Infiltration, leakage, fracture?

*In the oldest trial pits it was reported a combination between lime and ashes but in recent excavations only ***lime*** was reported in P2

## Profile 3 – P3



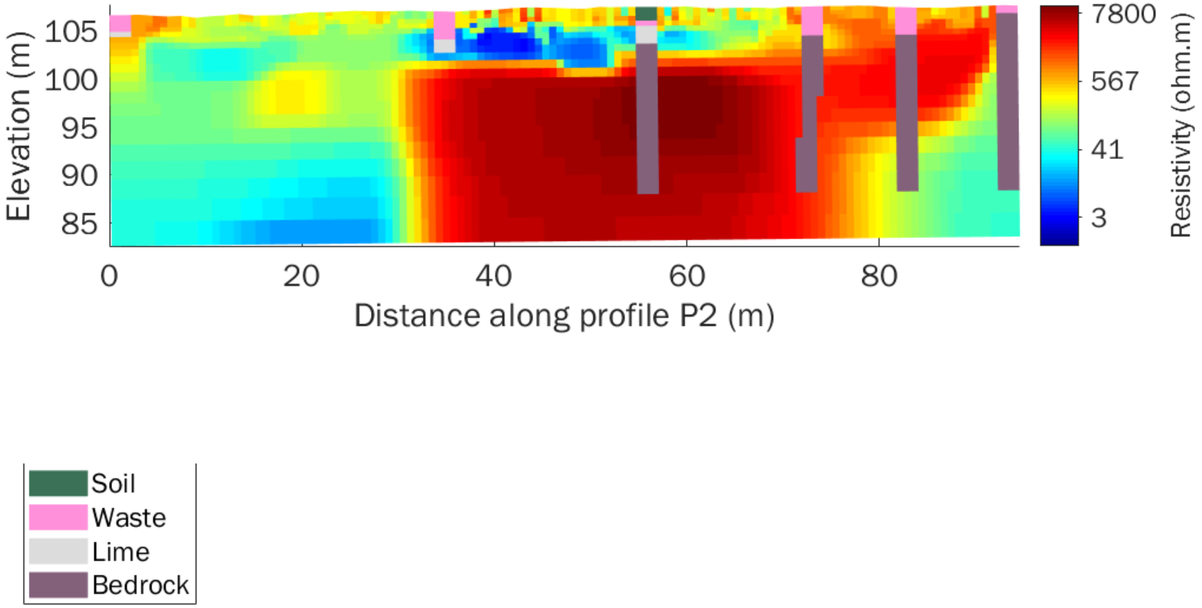




### Preliminary observations

- In general, the largest resistivities might correspond to the limestone and very low resistivities to lime deposits.
- Disturbances of the bedrock towards the south and probably towards the north in a deeper zone. Infiltration, leakage, fracture?

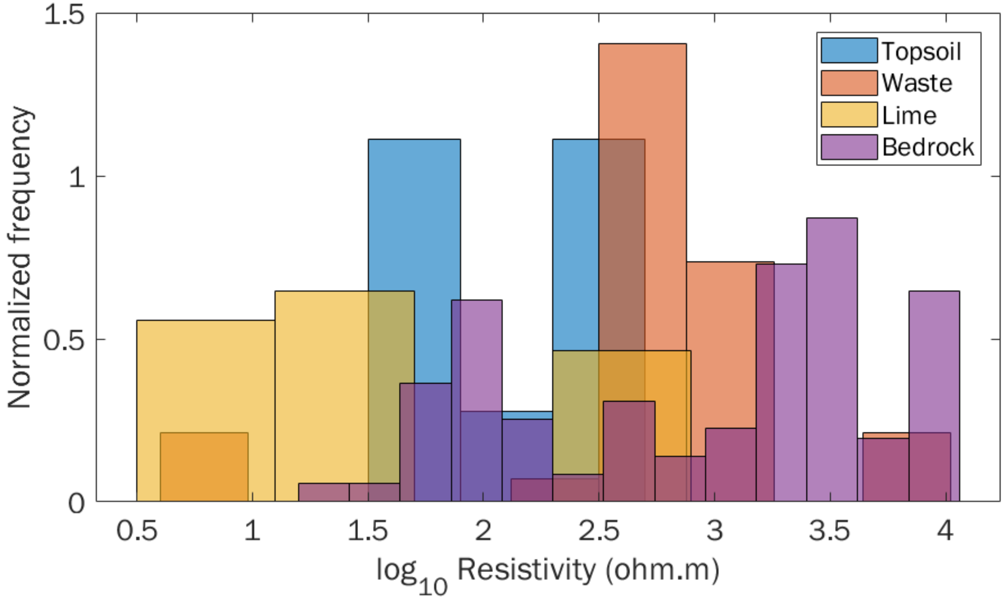
In this contribution we will focus in the resistivity model of **P2** (P1 & P3 have the same tendency)

# Assessment of ERT to resolve layering observed in trial pits

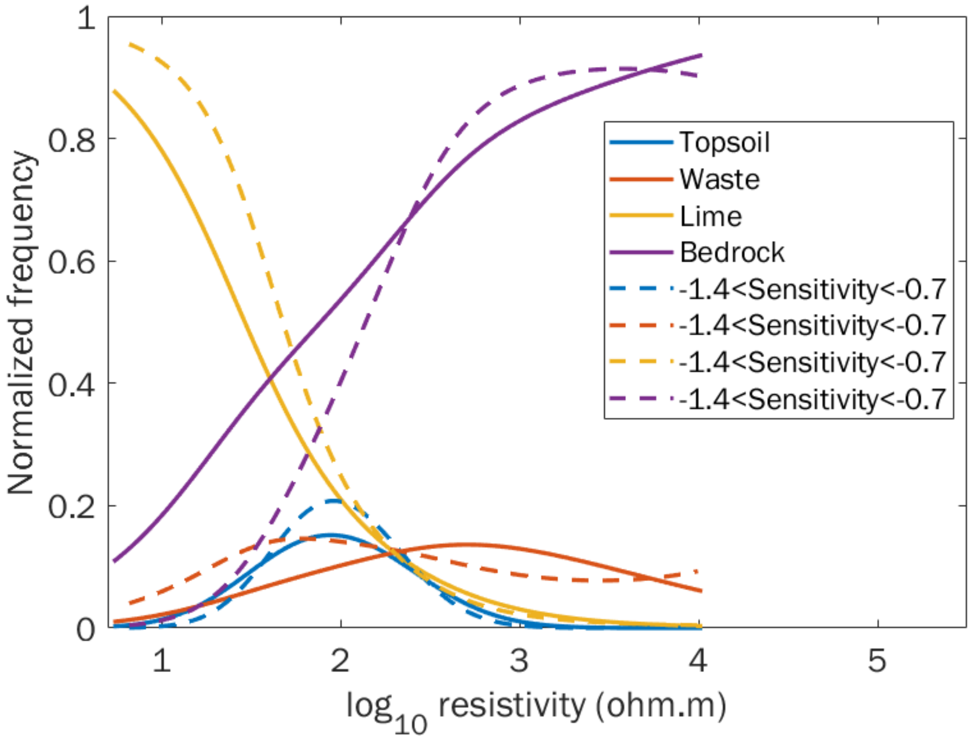



To evaluate the ability of ERT to identify the structure of the landfill, we followed a probabilistic approach proposed by Hermans and Irving (2017).

1. First, we computed the histogram comparing the ERT model with the co-located data from the trial pits:



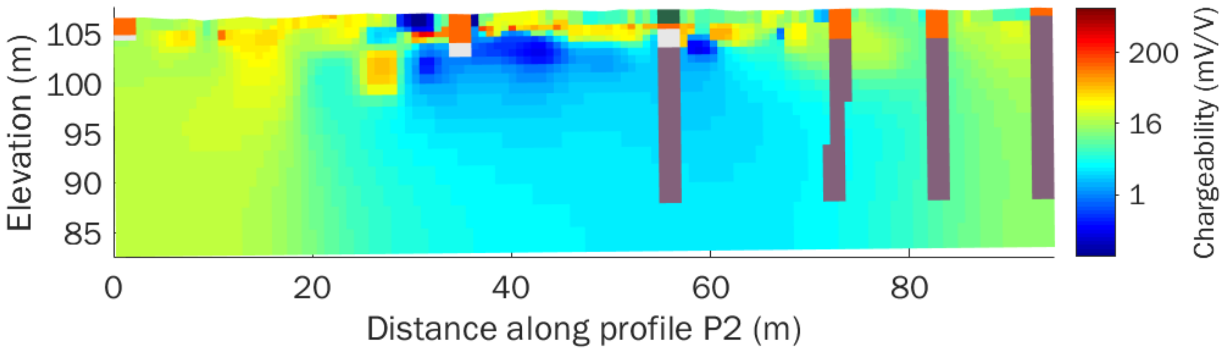
2. Then, we computed the conditional probability of each layer: topsoil, all waste types, lime and bedrock given the resistivity (solid lines). In addition, we considered a sensitivity correction and derived sensitivity-dependent distributions using Bayes' rule (see Hermans and Irving, 2017). The last distributions are displayed in dashed lines.

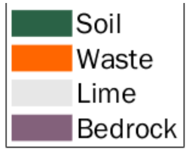



## Preliminary observations

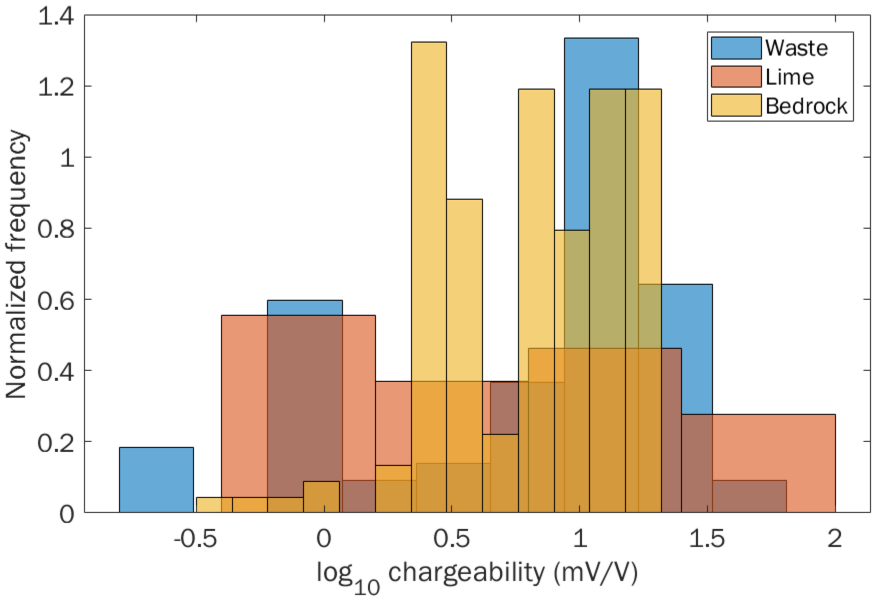
- The bedrock covers a broad range of resistivities. At least 2 maximums are present in the histogram displayed before. Thus the bedrock presents at least 2 states: weathered bedrock? Infiltrations?
- ERT proved to be useful to resolve the layer of lime (smallest resistivities).
- The heterogeneous waste includes CDW, IW and MSW. Resistivity values are also distributed on a broad range. Low resistivities might be related to more metallic content.
- Waste and soil cannot easily be differentiated with ERT.

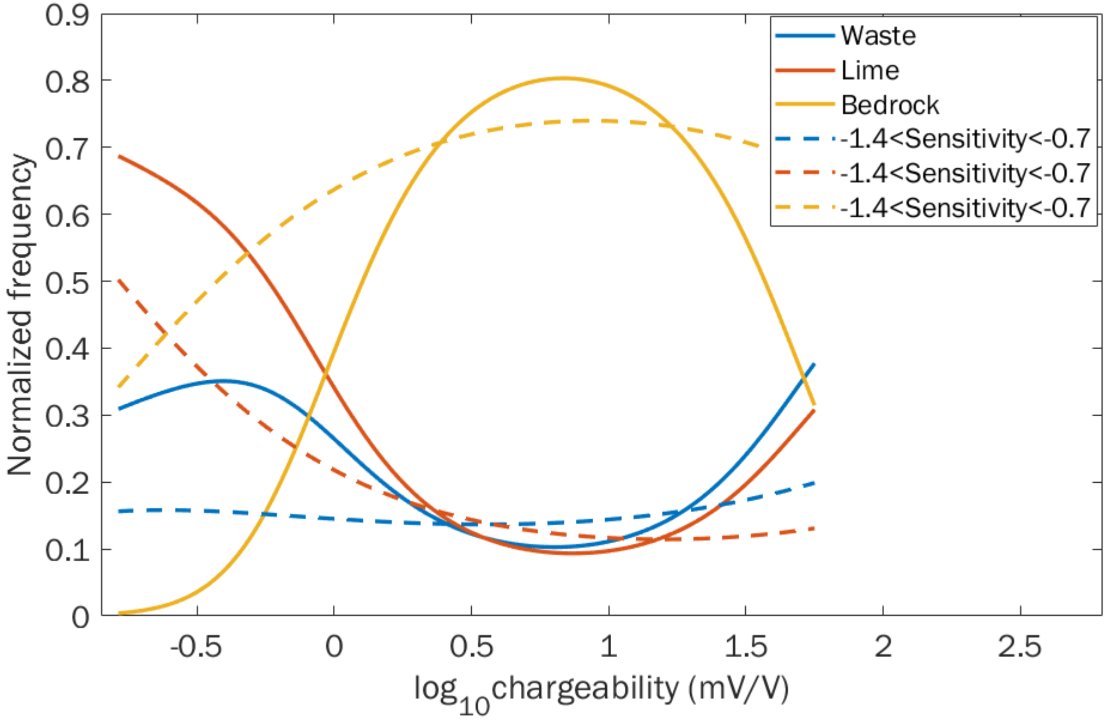
# Assessment of IP to resolve layering observed in trial pits




We followed the same probabilistic approach to evaluate the ability of IP to identify the structure of the landfill. In this model, the layer soil was not distinguishable from the other layers. Thus, we only considered a layer of waste in general, lime and bedrock






## Preliminary observations

- In general, the histograms of each layer are largely overlapped. Thus with the chargeability model we can not clearly visualize structural elements of the landfill as compared to the ERT model.
- According to the conditional probabilities, the lime signature might presented the lowest chargeability in the model.
- The soil and waste in general have the same range of chargeability values and could not be differentiated

# How to improve the landfill characterization?

➢ How can we better delineate the bedrock?

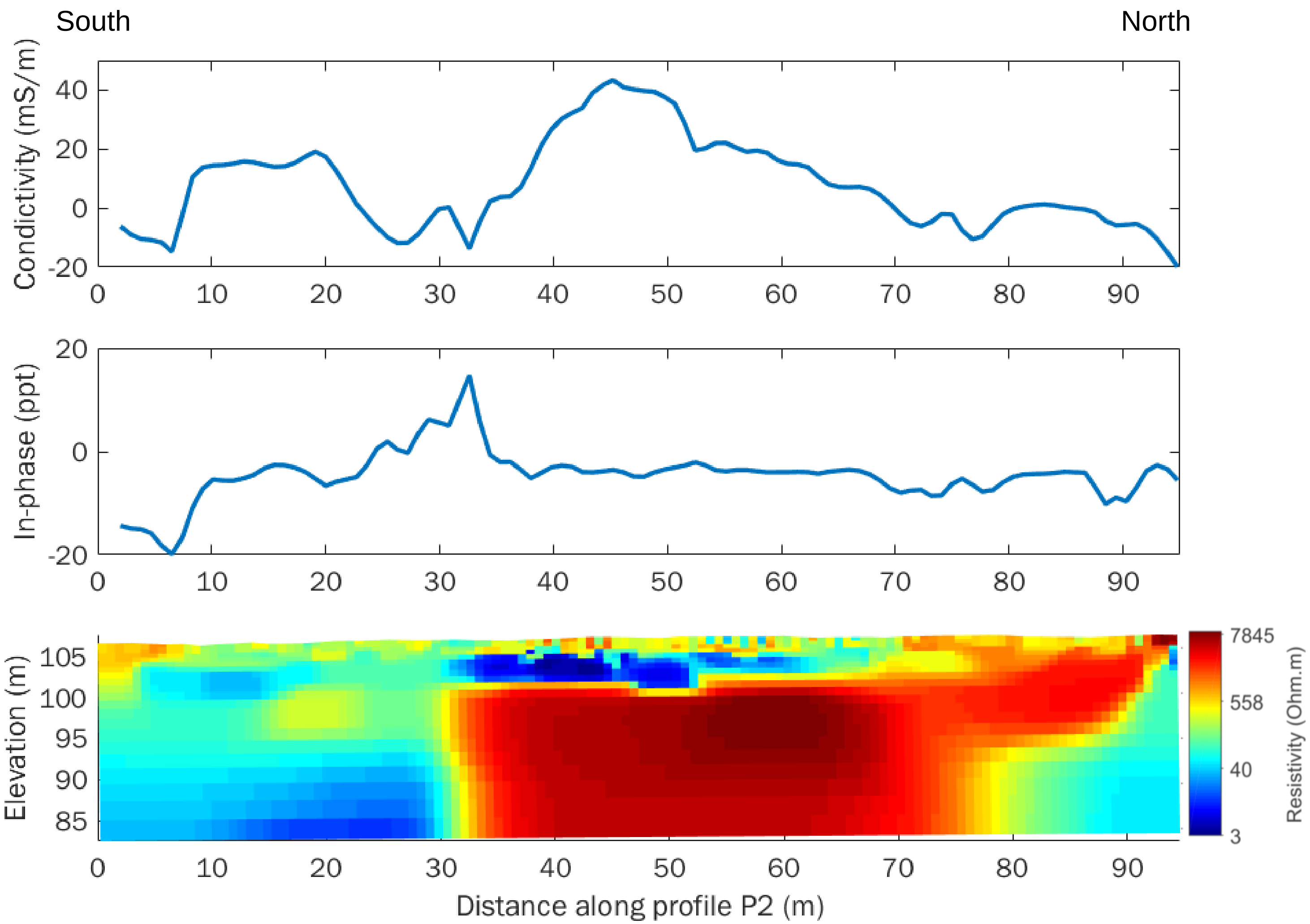
*In this contribution*

Multi-geophysical methodology using co-located data

- EMI → Profiling method at around 1 depth
- H/V → Profiling method
- Magnetometry → Profiling method after modelling or inversion

For this potential field we need a **vast** knowledge already of the geology or the landfill structure

# Profiling methods: EMI along profile P2

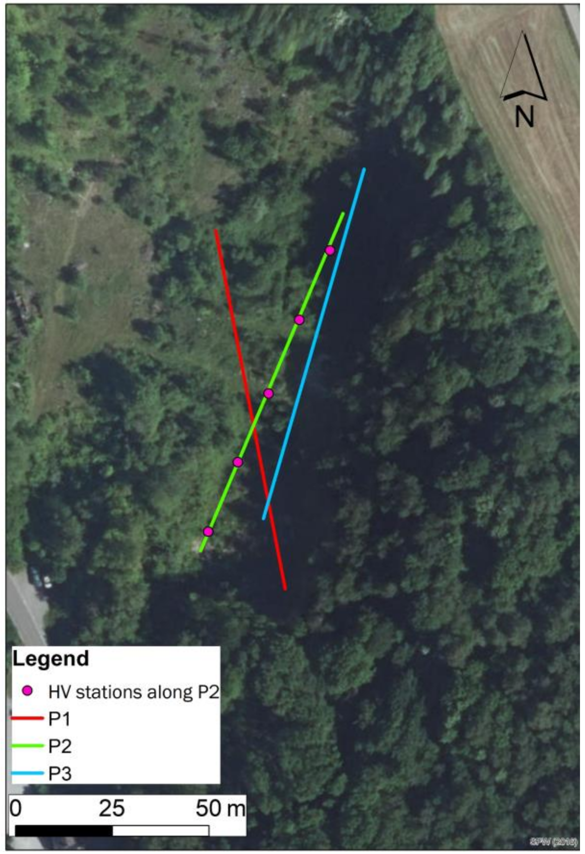


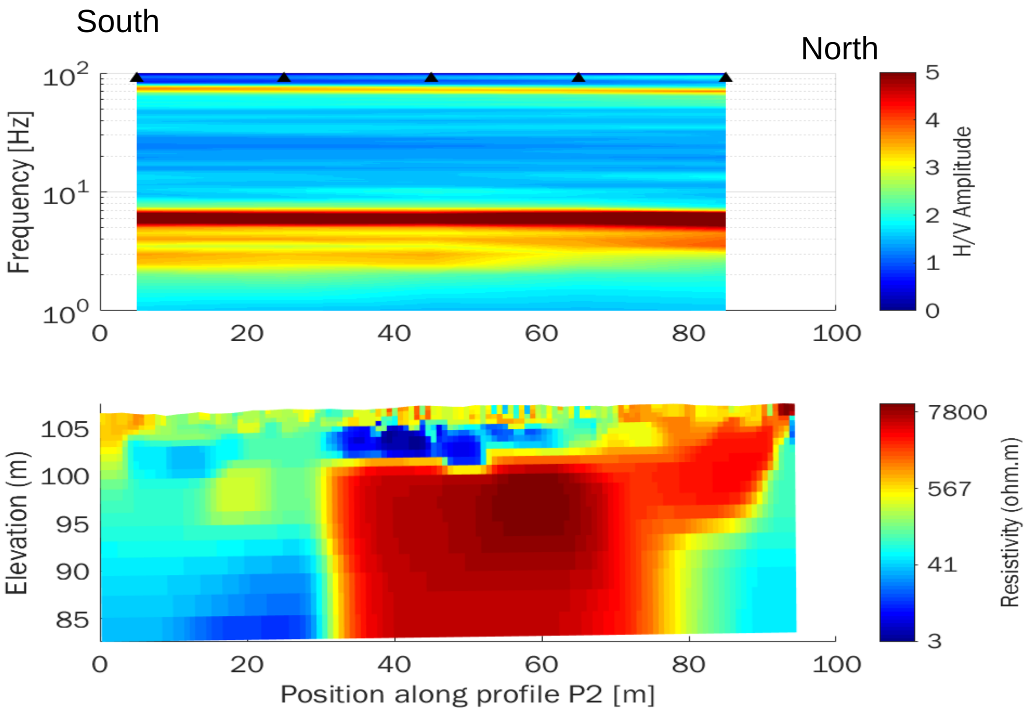

*System used: Geonics EM31 with a DOI within 3 m up to around 6 m.

## Preliminary (qualitative) observations

- The EMI quadrature component showed 3 different ranges of conductivity attributed from south to north to the lime probably combined with soil, mostly lime and backfill.
- The in-phase component present a maximum value at a distance in X of around 30 m where the ERT model shows a lateral contrast of resistivity. There is no strong difference of magnetic susceptibility along the rest of the profile, thus the material of high conductivity might be purely lime (not strongly magnetic compared to ashes).
- Negative values of quadrature and can be displayed when shallower layer (shallower depth than the DOI) have larger values of conductivity (e.g. Selepeng et al., 2017).

# Profiling methods: H/V data along profile P2



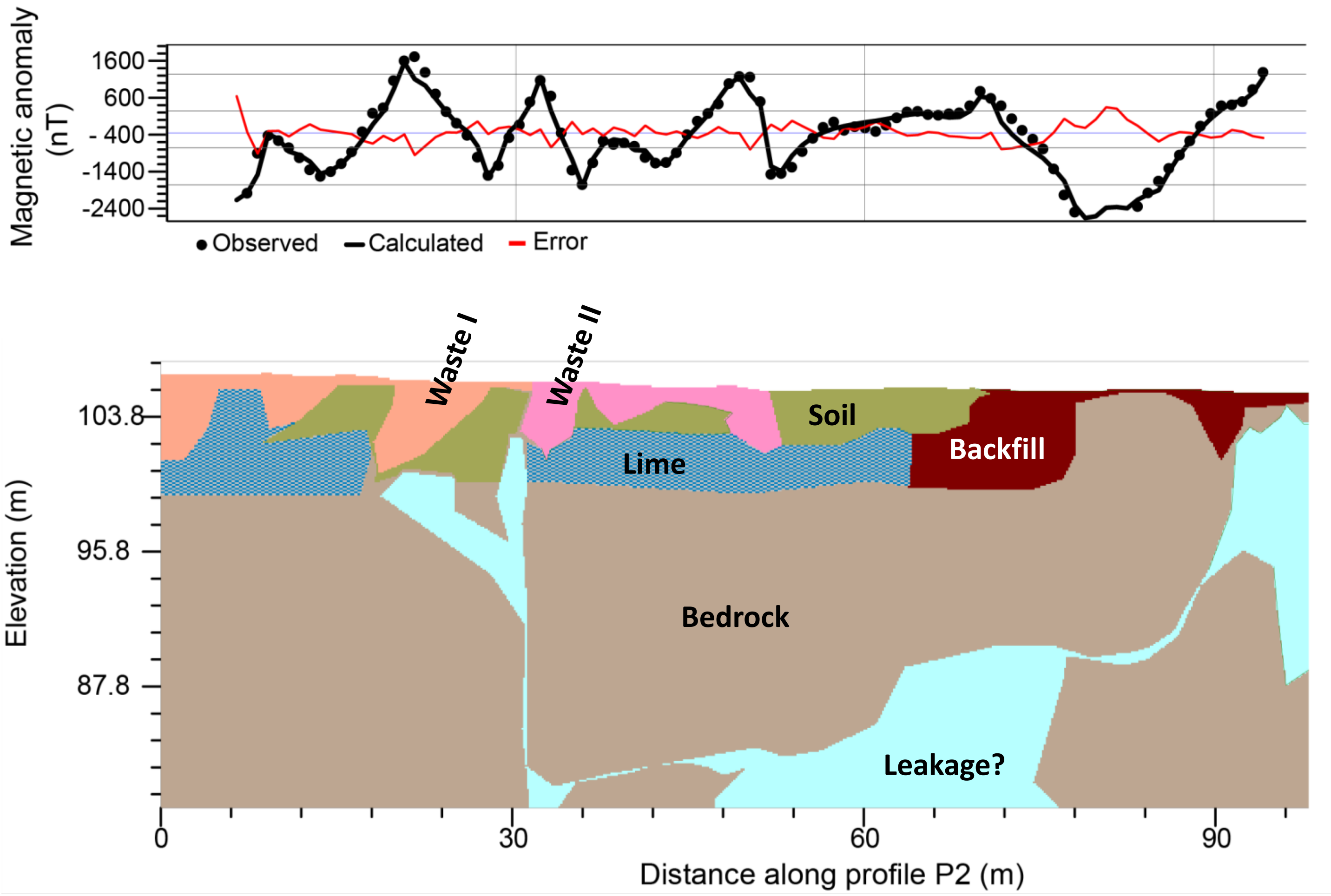

*System used: 3D component seismometer Lennartz LE-3Dlite MkIII with a low cut-off frequency of 1 Hz

*Software H/V analysis: Geopsy (SESAME European research project, deliverable D23.12, 2005)

## Preliminary observations

- There are 2 fundamental peaks (maximum H/V amplitude) at around 6 Hz and 72 Hz. Both peaks are continuous in all the H/V stations along P2.
- The fundamental peak at the largest frequency can be associated with the shallow layer of "soft soil" (combined with waste and lime) on the top of the bedrock. If this fundamental peak is continuous the thickness of this layer might also be continuous and therefore the upper limit of the bedrock too (even before 30 m, see ERT model of P2 for comparison).

# Profiling methods: magnetic modeling of P2




*System used: portable cesium magnetometer G- 858 from Geometrics.

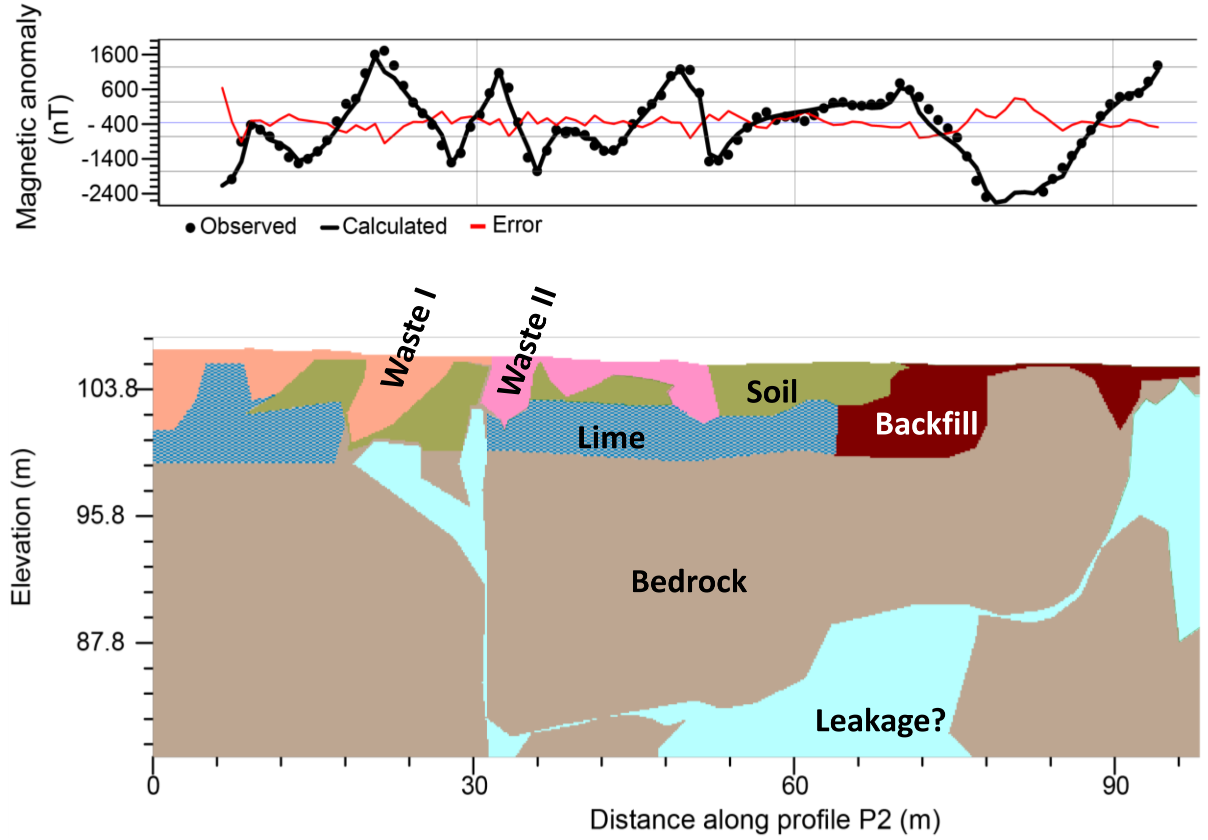
*Software for modeling: GM-SYS v 4.8

## Data processing

We computed the total field magnetic anomaly and applied a reduction to the pole. No filter was applied. The magnetic model was built based in all information presented before: continuous bedrock (H/V), shallow conductive bodies and anomaly of large magnetic susceptibility (EMI), possible infiltrations in the bedrock (ERT).

## Magnetic susceptibilities

- Waste type I = 0.1 SI (e.g. Vollprecht et al., 2019)
- Waste type II = 0.12 SI (e.g. Appiah et al., 2018)
- Soil = 1.2e-4 SI (e.g. Magiera et al., 2019)
- Backfill = 0.075 SI
- Lime = 7.9e-8 SI (e.g. Funari et al., 2016)
- Bedrock = 1.25e-5 SI (e.g. Fazzito & Rapalini, 2016)
- Leakage = 0.25- 0.37 SI (e.g. Atekwana et al., 2013)




## Preliminary observations

- After different low-pass filters, we concluded that most of the high amplitude anomalies are caused by shallow bodies of large magnetic susceptibility (MS). This can be attributed to the metallic content in scraps, IW, CDW and it could explain why the MS used here is slightly larger than the MS reported for example in MSW.
- The long-wavelength anomaly located at around 80 m can be originated by a body located at a larger depth, thus, probably an intrusive body in the bedrock.
- Following the history of the site and the results in the ERT model, it is possible to have weathered bedrock and infiltrations or leakages probably due to hydrocarbon contamination. According to the magnetic model these intrusive bodies might be dyke-like structures specially at X ~ 30m.

# Conclusions and future work

- This contribution showed that a quantitative interpretation of magnetic data can potentially contribute to better characterize a landfill if there is already a vast knowledge of the site (after boreholes, trial pits, multi-geophysical data).
- The magnetic susceptibility (MS) values used here for the magnetic modeling were taken from recent literature. However, the MS values for the possible contamination with the intrusive bodies might be overestimated. The origin of these pollutants as well as the MS must be verified, although direct measurements of magnetic susceptibility in situ can be challenging at these depths.
- For future work we will also apply the probabilistic approach exemplified for the ERT method to assess the magnetic model. However, an inversion of the magnetic anomaly might be needed first.

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