
## Geophysical techniques

# Introduction to Seismic methods

ULiege & BGS

## Seismic methods

# Application on landfills

Interreg North-West Europe RAWFILL

European Regional Development Fund

Co-funded by the Walloon region

Mapping

Profiling

Active Seismics

Passive Seismics

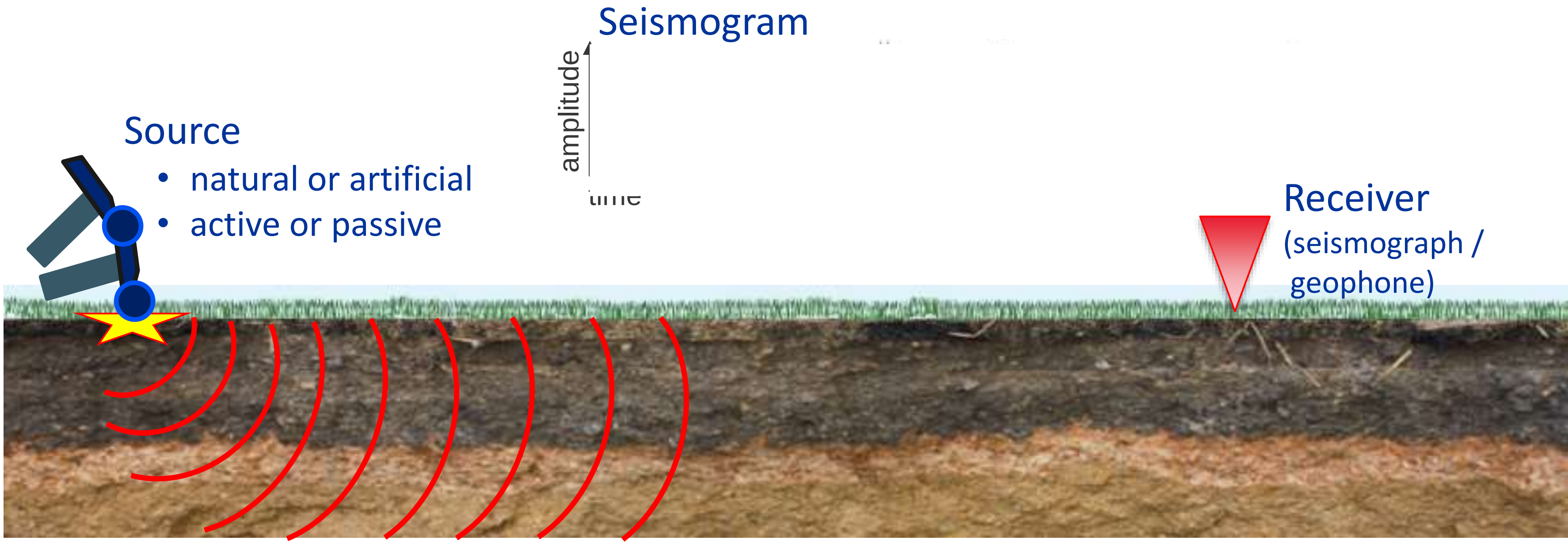
| | | EMI | MAG | ERT | IP | MASW | SRT | GPR | HVSRN | SP | GRA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Landfill structure | Lateral extent | | | | | | | | | | |
| | Cover Layer thickness | | | | | | | | | | |
| | Vertical extent | | | | | | | | | | |
| | Utilities | | | | | | | | | | |
| Landfill characterization | Waste zonation | | | | | | | | | | |
| | Leachate content | | | | | | | | | | |
| Environmental conditions | Geology | | | | | | | | | | |
| | Groundwater table | | | | | | | | | | |
| Staff required for survey | | | | | | | | | | | |
| Required time for survey | | | | | | | | | | | |
| Required time for processing | | | | | | | | | | | |

# What is studied?

→ propagation (velocity) of seismic waves

## What is a seismic wave?

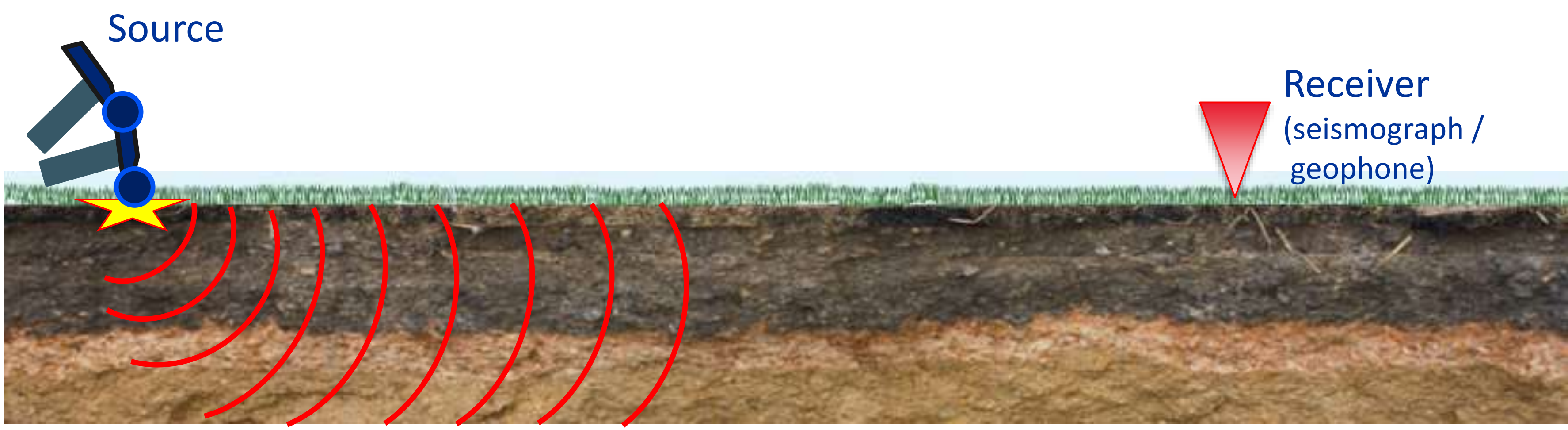
"Seismic waves are pulses of strain energy that propagate in solids and fluids." (Knoedel et al. 2007)



Seismic methods

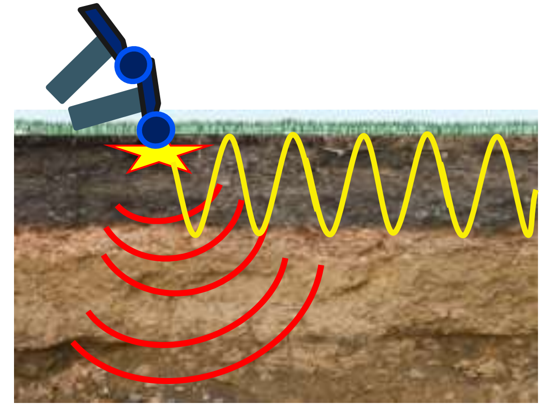
# What is studied?

**propagation velocity of seismic waves** → relevant physical properties: ground **stiffness**, **elasticity** and **density**



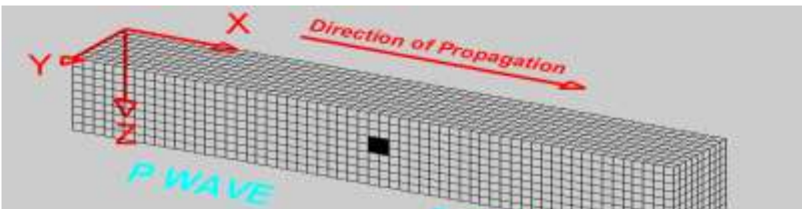
Seismic methods

# Types of waves

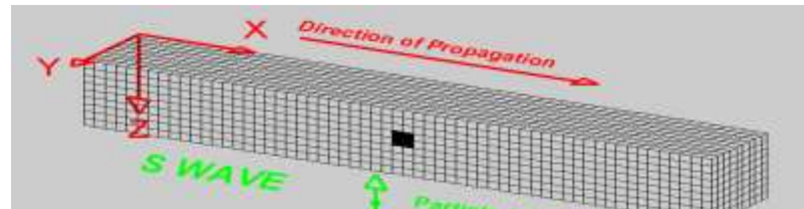


## Body waves

Pass through the bulk of a medium



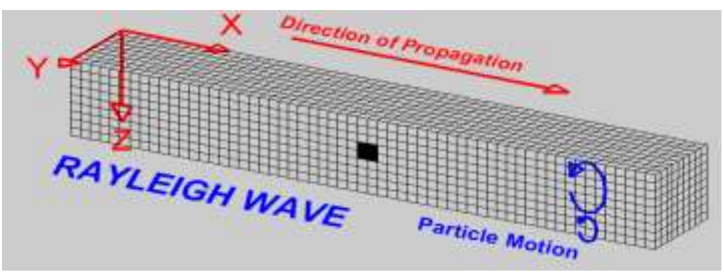

P-Wave
[or Pressure Wave]




S-Wave
[or Shear Wave]

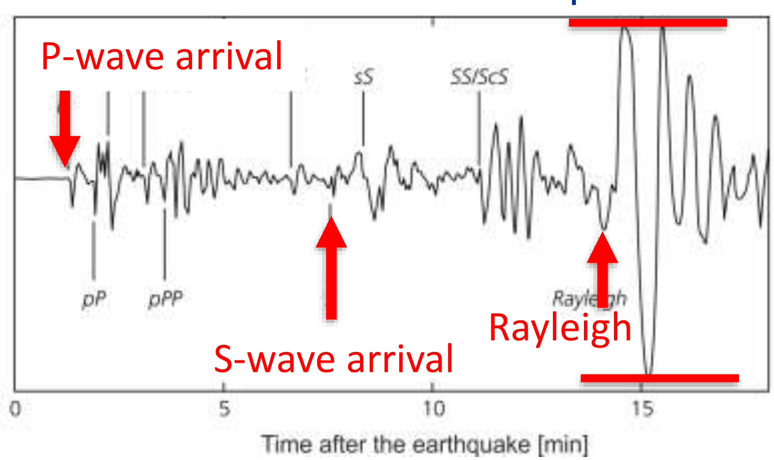
## Surface waves

Travel along the ground surface




Dispersive: different frequency components travel at different velocities

different velocities and amplitudes




(Stein and Wysession, 2003)

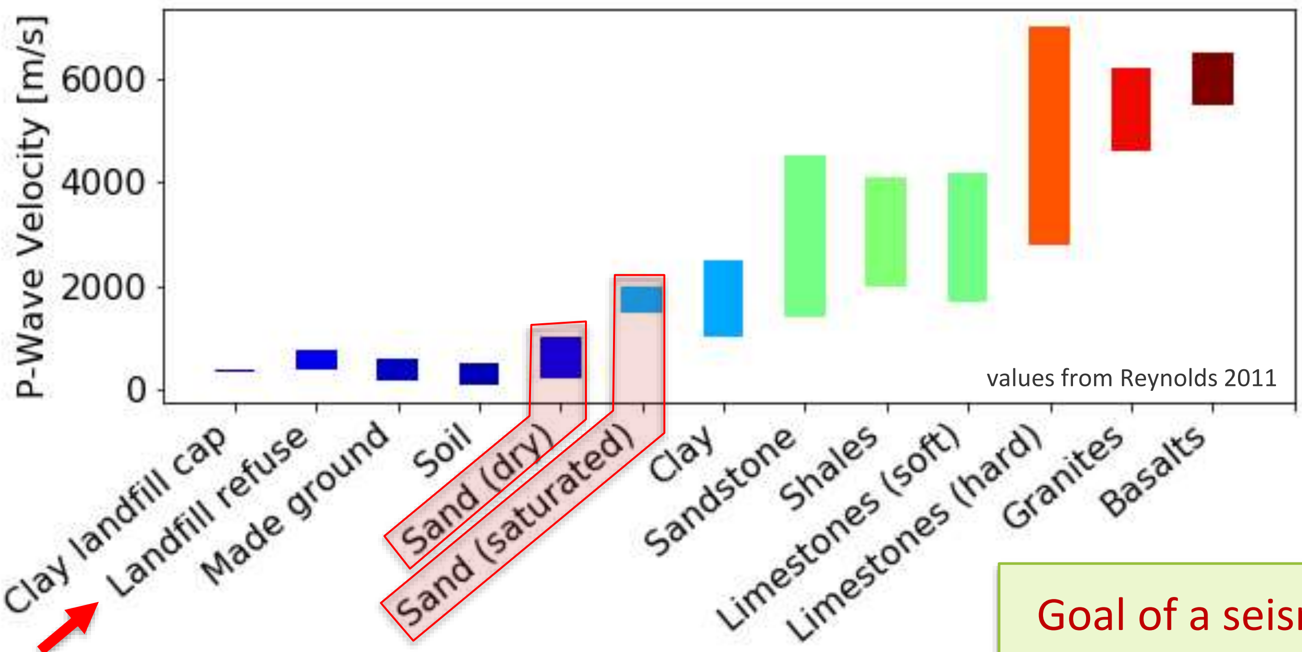


https://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/seismicWaves.html

Seismic methods

# Seismic velocities

Seismic velocity depends on the **bulk density** and the **elastic properties** and **varies with mineral content, lithology, porosity pore fluid saturation and degree of compaction**.




Different seismic wave types exhibit different velocity characteristics

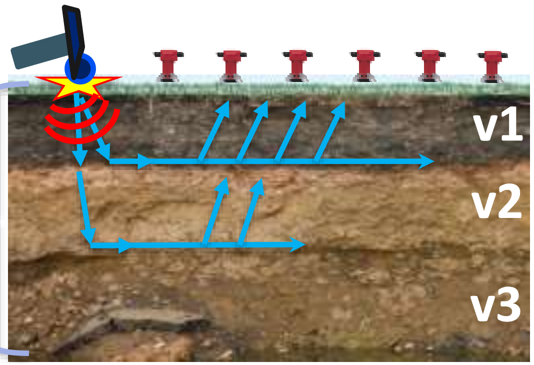
Goal of a seismic survey: create a material specific velocity model of the subsurface

# Active Seismic methods

## Looking at different propagation "paths"

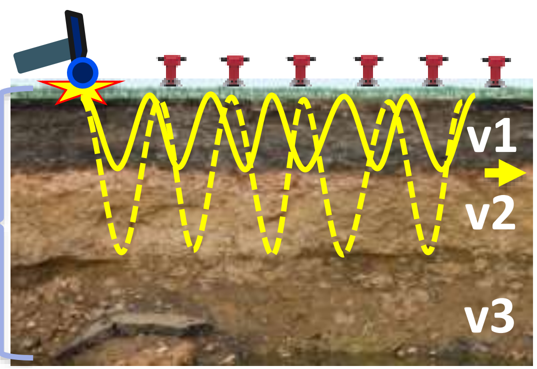
- The processing steps for the two methods are different
- Result looks similar but are often given as different velocities.

Body waves (P and S)




Refraction seismics (SRT)

Surface waves (Rayleigh)

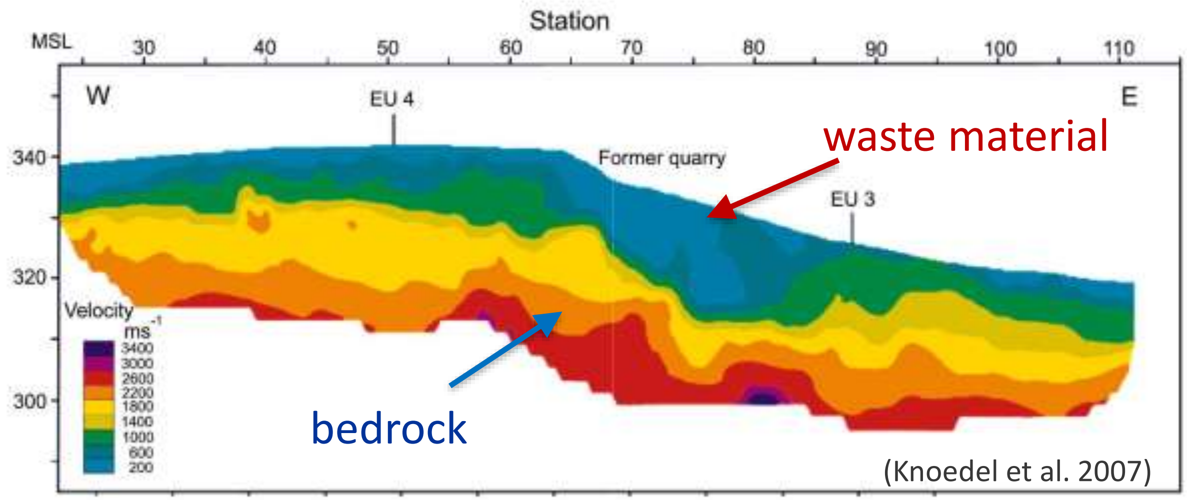



Multi-channel Analysis of Surface Waves (MASW)

## Active Seismic methods

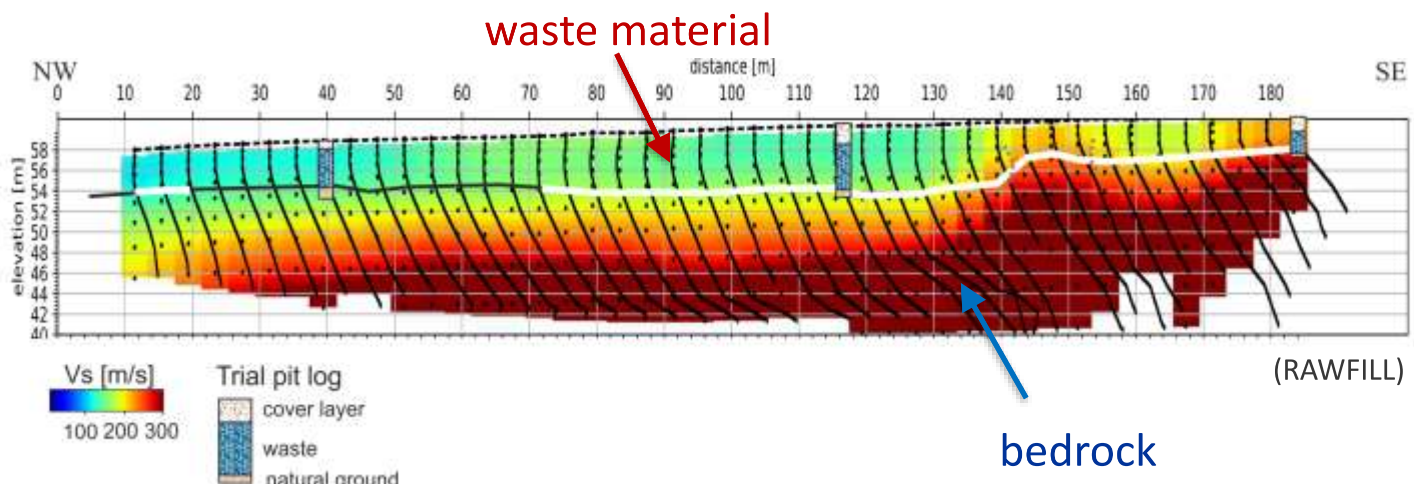
# Example results

Refraction seismics (SRT)




(Knoedel et al. 2007)

Multi-channel Analysis of Surface Waves (MASW)



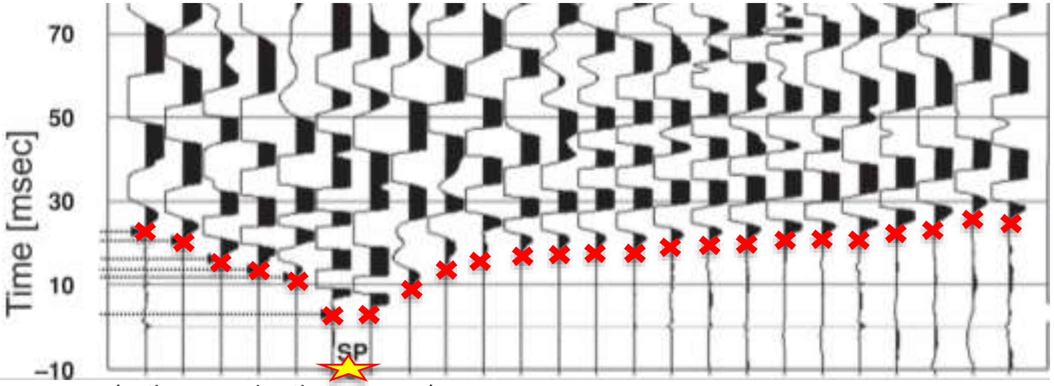

(RAWFILL)

Active Seismic methods

# Basic data processing

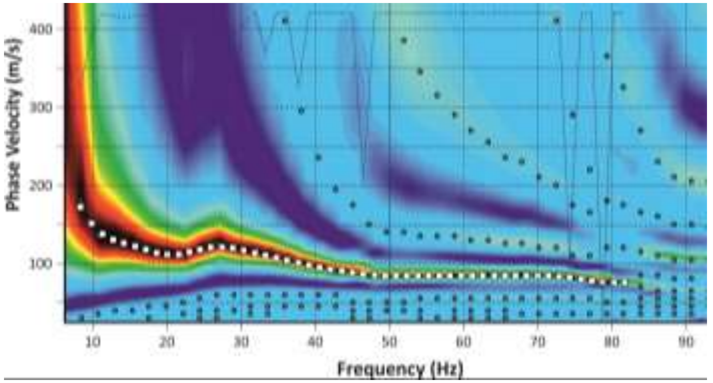
1) Assign survey geometry and check field record

2) First-arrivals picking (SRT)

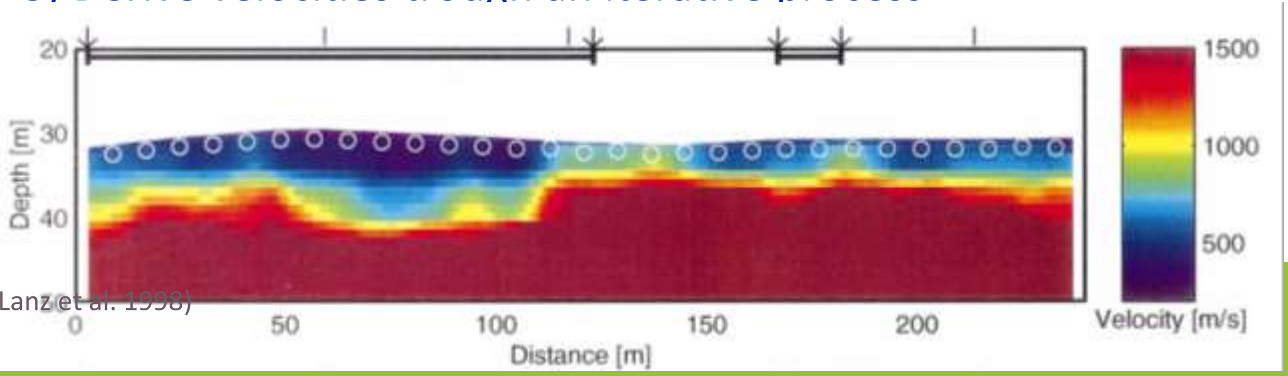



(Milsom and Eriksen, 2011)

2) Transformation to dispersion curve and picking (MASW)




3) Derive velocities trough an iterative process



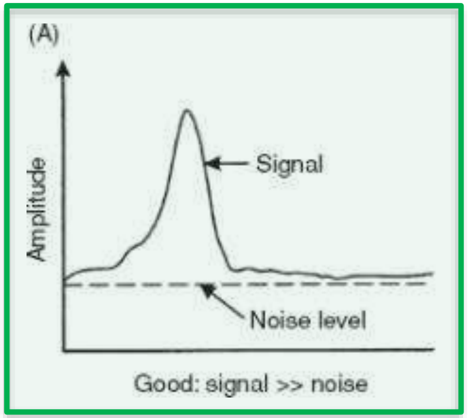

(Lanz et al. 1998)

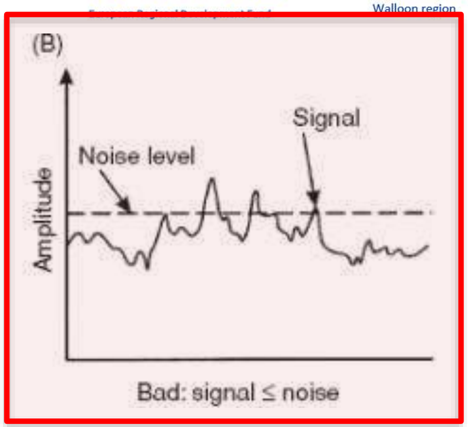
Seismic methods

# Challenges: Noise

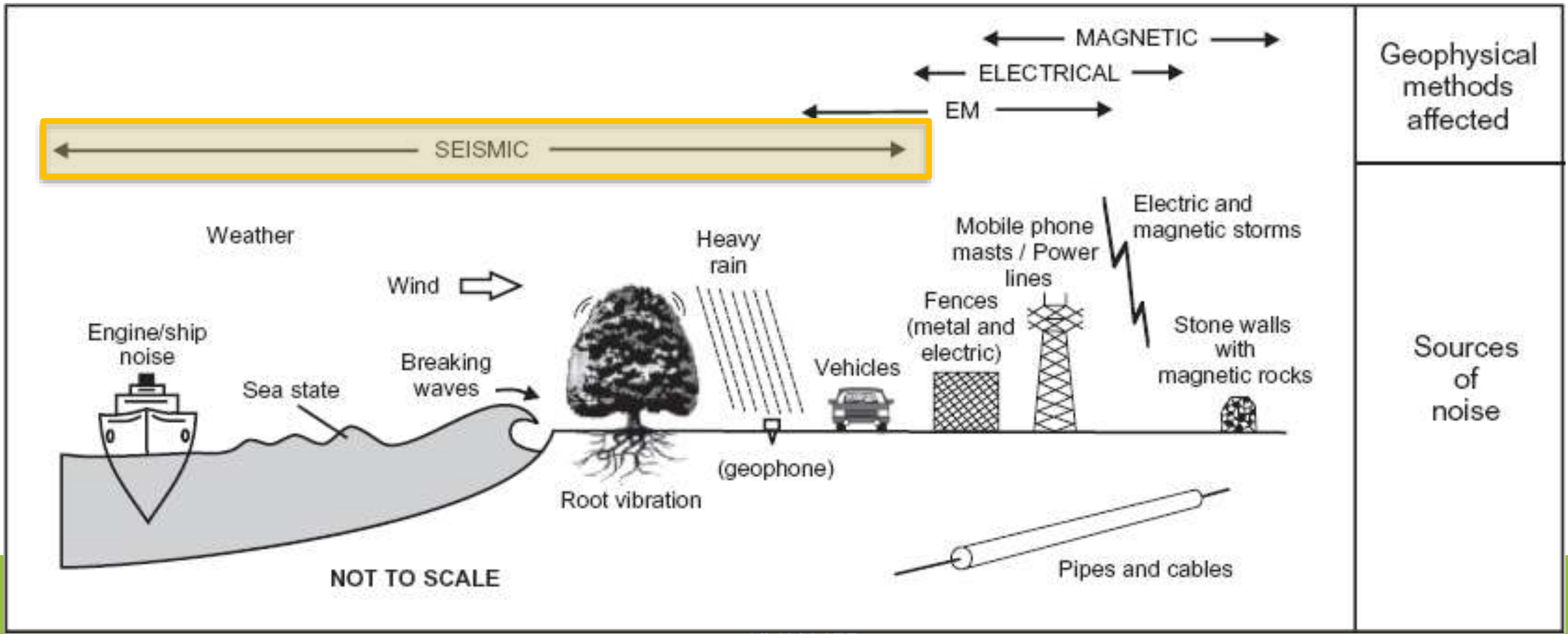
High noise levels could mask the target signal

Plan a seismic survey such that potential noise sources can be limited to a minimum




Sources of noise



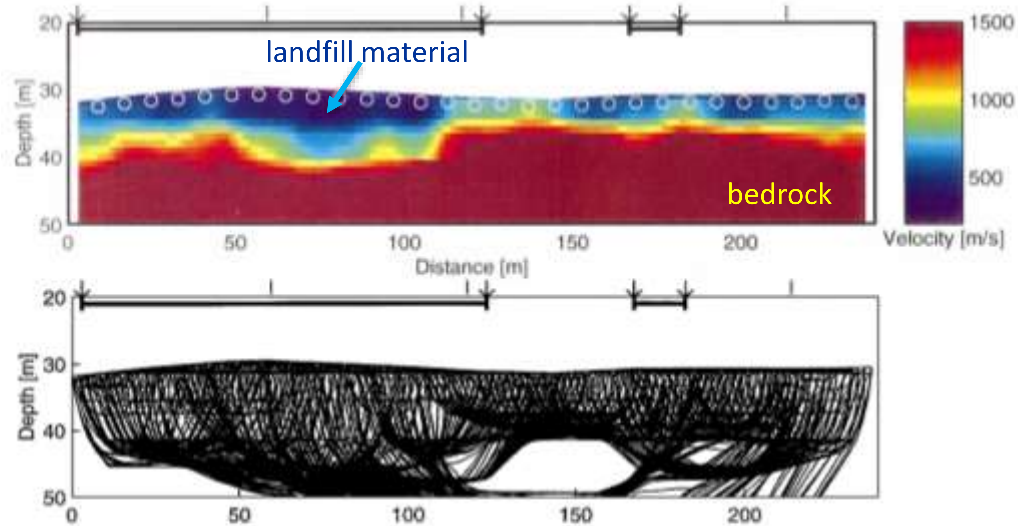

(Reynolds 2011)

Seismic methods

# Resolution and investigation depth

**Seismic refraction:**
Areas with low ray coverage are poorly resolved
→ Requires an adequate survey design

Depth of investigation:
About 5 to 10 times of profile length




(Lanz et al. 1998)

**MASW**:
Geophone spacing defines the minimum detectable layer thickness

Depth of investigation: About half the wavelength of the recorded lowest frequency surface wave. For landfills this is often about 15m.

A seismic survey needs to be designed in accordance with the required depth coverage and expected subsurface heterogeneities

# Passive Seismic method: H/V



## Basic principle and acquisition

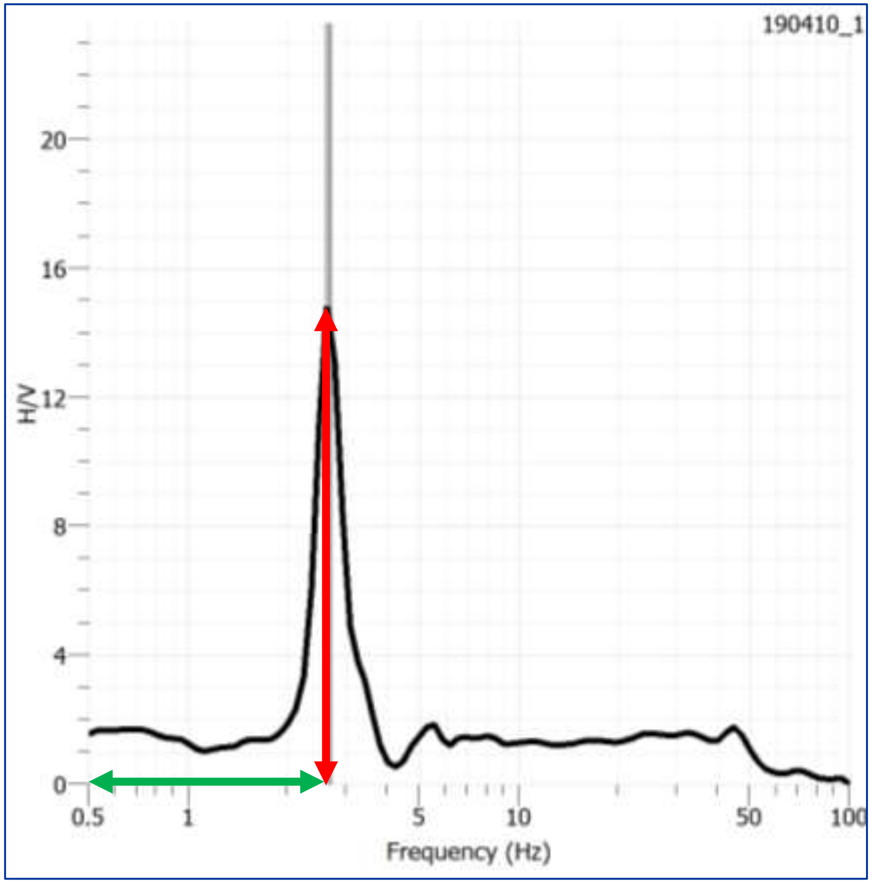
By recording seismic ambient noise, this method aims to estimate the dominant frequency induced by local layering of stratigraphy (Piña-Flores et al., 2017).

DATA LOGGER

SEISMOMETER
SET ON THE SURFACE

# Data processing/ interpretation






- **Frequency of H/V peak → thickness**
- **Peak amplitude → Contrast in S-wave velocity**
- **For one surficial layer over a half-space (e.g. bedrock):**

$$\boxed{f_0} = \frac{\boxed{V_s}}{4\boxed{H}}$$

**Resonance frequency**

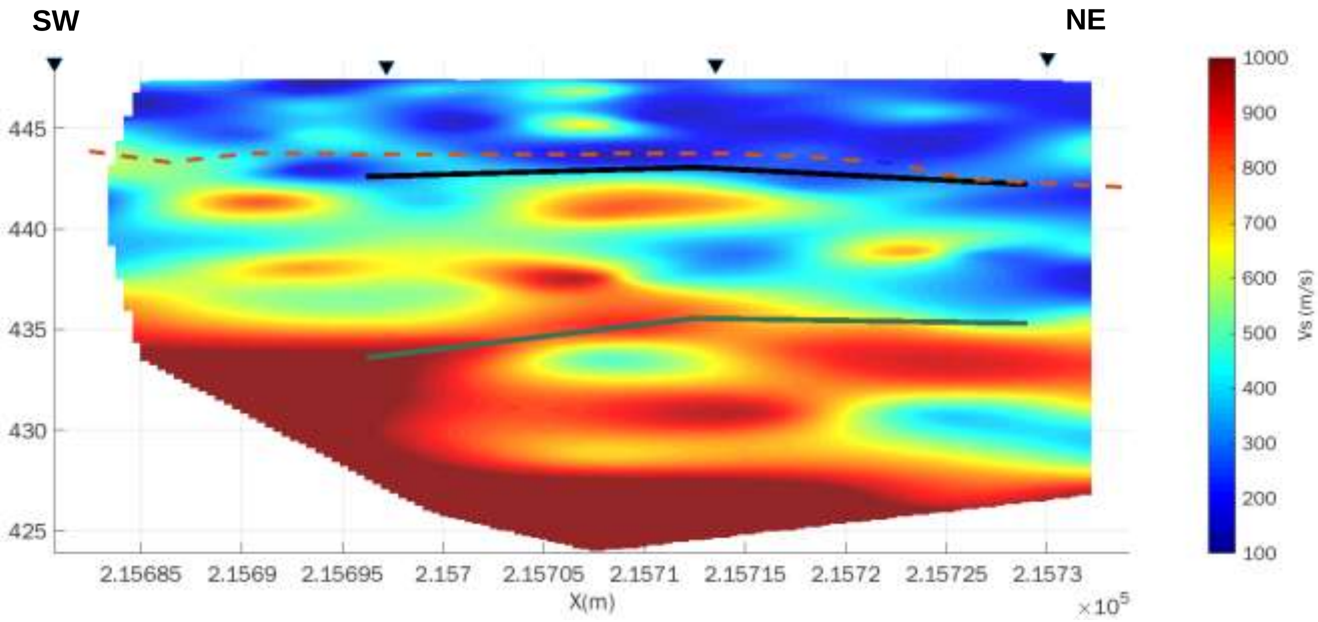
**Thickness**

**S-wave Velocity**

# Example results

Interreg North-West Europe RAWFILL
European Regional Development Fund
EUROPEAN UNION
Co-funded by the Walloon region

## 1) **Bertrix landfill**- MASW model & HVSRN




- HVSRN stations
- Estimated bottom limit of shallow layer
- Estimated bottom limit of deepest layer
- Topography before landfilling (1969)

**Proved useful to estimate the thickness of the waste**

# Example results

Interreg North-West Europe
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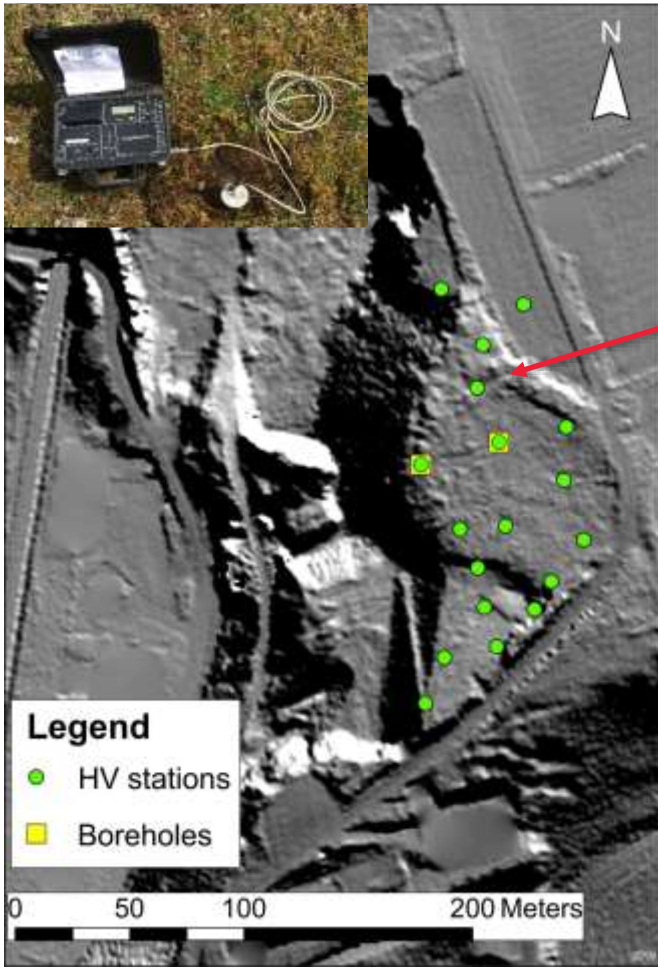
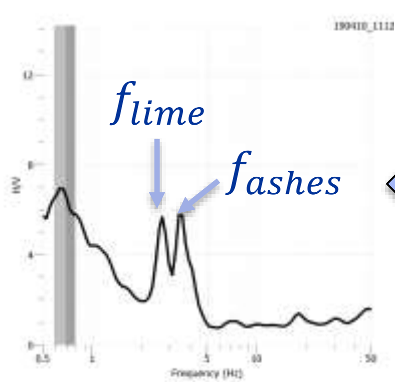
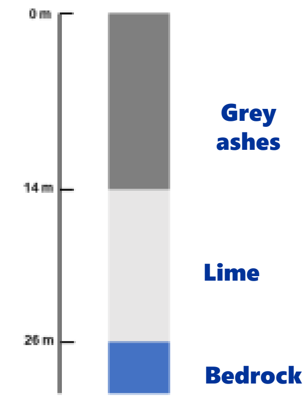
## 2) Onoz landfill- HVSRN + boreholes




H/V measurement




Borehole log




$$V_{s\,lime} = 318\,\frac{m}{s}$$

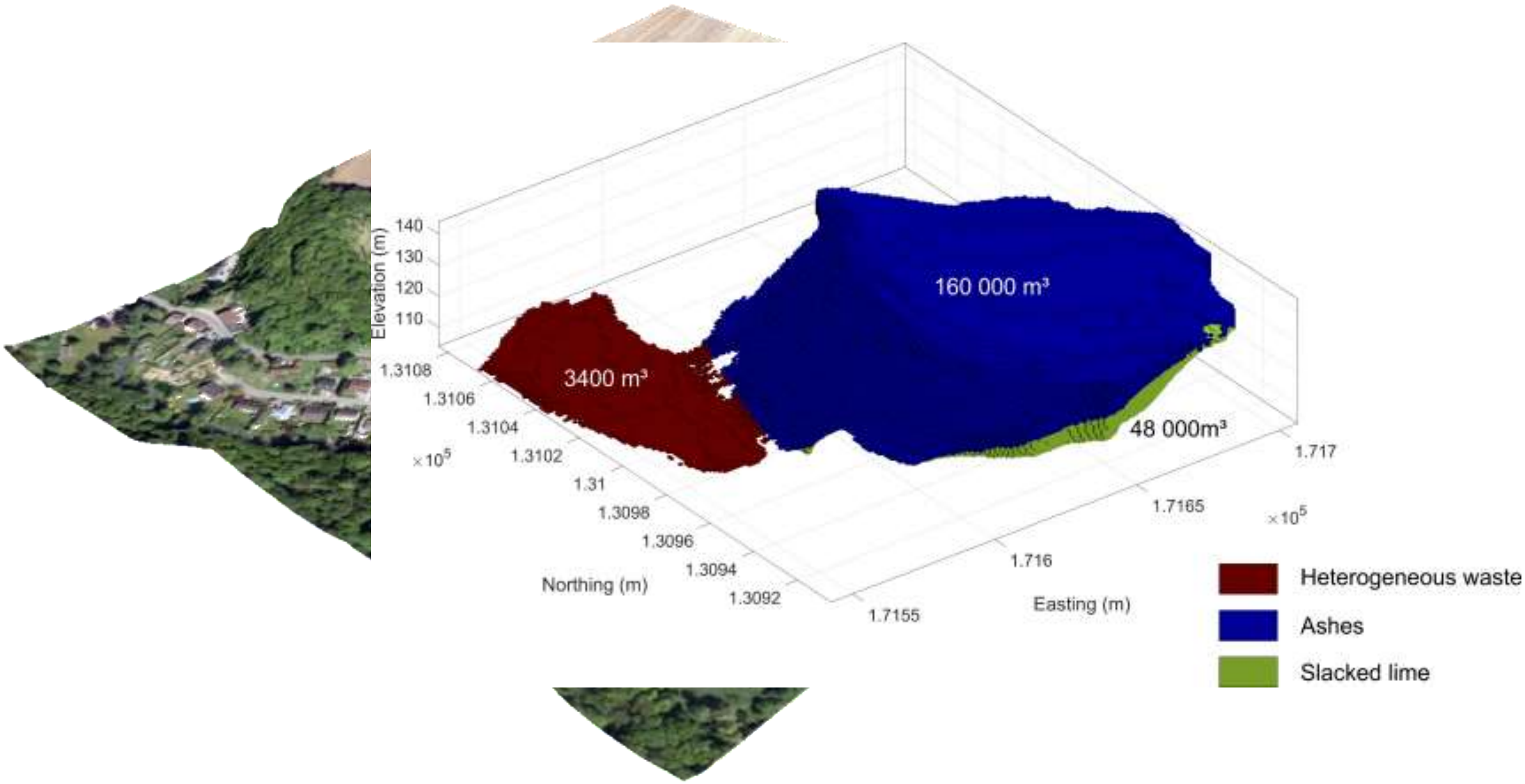
$$V_{s\,ashes} = 271\,\frac{m}{s}$$

Possible to estimate the thickness of ash and lime at other HV stations

(Debouny, 2019)

# Example results

## 2) **Onoz landfill**- resource distribution model



Seismic methods

# Advantages and limitations

| | | Active | | Passive |
|---|---|---|---|---|
| | | MASW | SRT | HVSRN |
| Landfill structure | Lateral extent | | | |
| | Cover Layer thickness | | | |
| | Vertical extent | | | |
| | Utilities | | | |
| Landfill characterization | Waste zonation | | | |
| | Leachate content | | | |
| Environmental conditions | Geology | | | |
| | Groundwater table | | | |
| Staff required for survey | | | | |
| Required time for survey | | | | |
| Required time for processing | | | | |

## Seismic refraction:

- Main method to delineate bottom of waste at greater depth
- Unable to detect a low velocity layer below a higher velocity layer
  - ➢ potential difficulties for waste zonation and cover layer thickness

## MASW:

- Main method to delineate bottom of waste and waste zonation for medium waste thickness (limited depth of investigation)

## HVSRN:

- Efficient method to delineate bottom of waste at greater depth

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# Thank you!

# Raw materials recovered from landfills

Interreg North-West Europe RAWFILL
European Regional Development Fund
EUROPEAN UNION
Co-funded by the Walloon region

The Interreg North-West Europe Project is coordinated by SPAQuE and unites 8 partners from 4 EU regions.

SPAQuE.be

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