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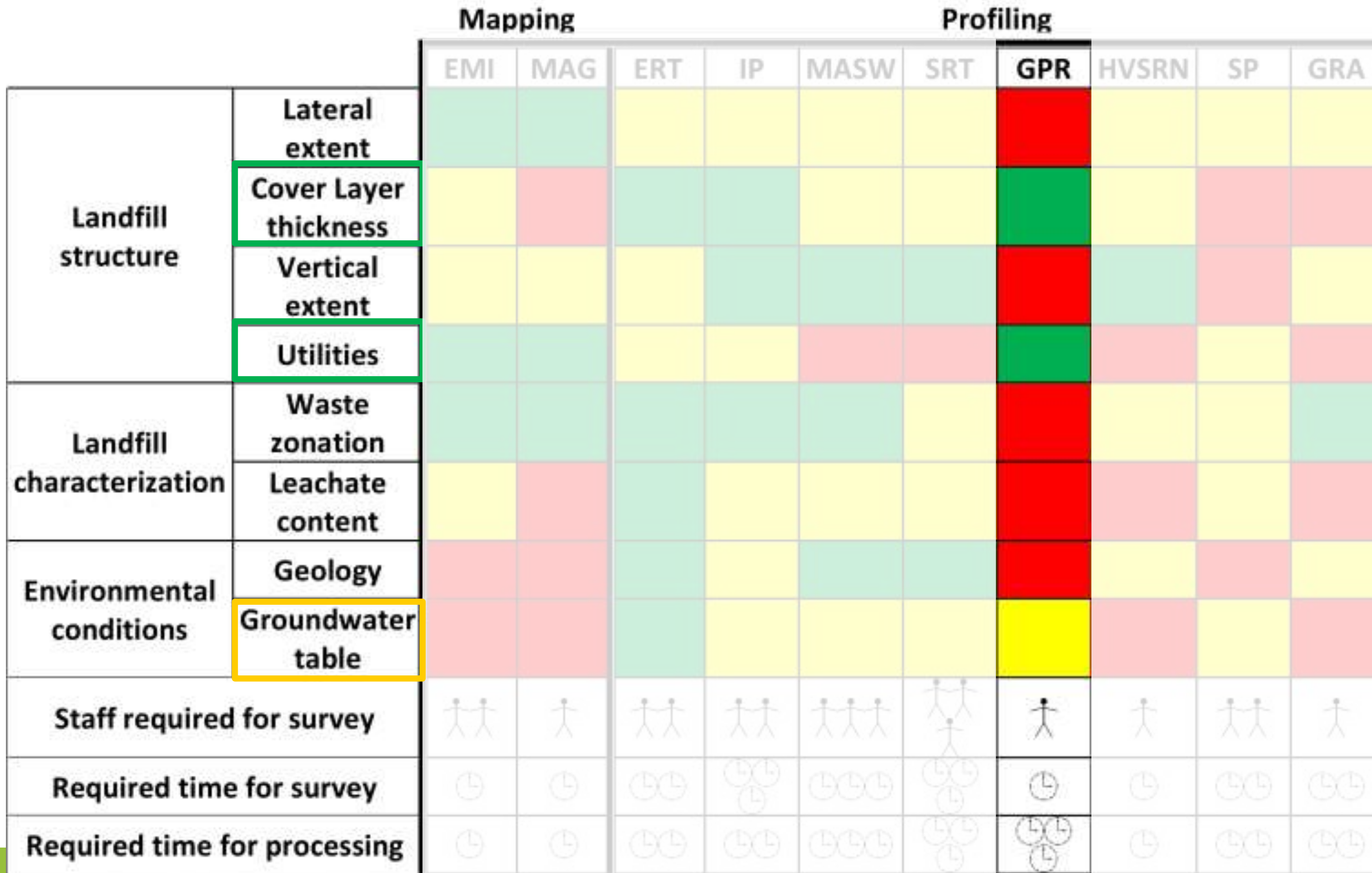
Introduction to Ground Penetrating Radar (GPR)

ULiege & BGS

Ground Penetrating Radar (GPR)

Method – basic concepts



Ground Penetrating Radar (GPR)
Method – basic concepts

RAdio **D**etection **A**nd **R**anging

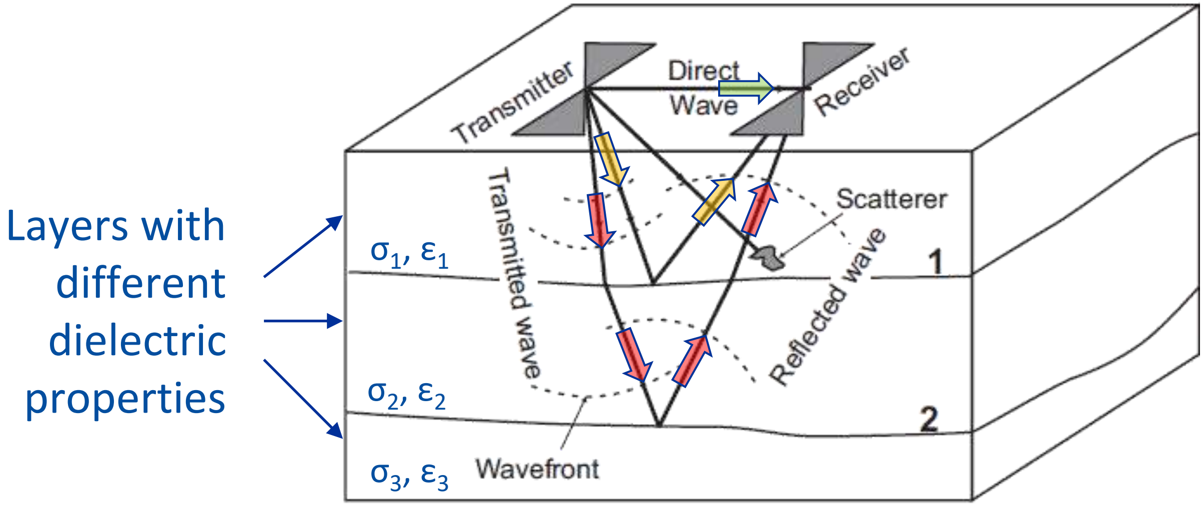
- Used to determine range, angle, or velocity of objects
- Radio wave signals
- Frequencies 10 - >4000 MHz thought to be too high for ground penetration → used in plane altitude measurement

- … however, in the 1950’s US Air Force pilots were crash landing on ice fields in Greenland.
- Radar altimeter reflections from the base of the ice were misread as reflections from the surface.

Ground Penetrating Radar (GPR)

Method – basic concepts

- Operates by transmitting pulses of EM waves of frequencies 10 MHz – 4 GHz through a transmitting antenna
- Changes in dielectric properties cause parts of the signal to be reflected back to the surface, where it is recorded and amplified by the receiving antenna
- The amount of reflected energy is dependent on the contrast in electrical properties



Ground Penetrating Radar (GPR)

Method – basic concepts

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Material	Permittivity (ε_r) -	Resistivity (ρ) [Ωm]
Air	1	> $1 \cdot 10^{16}$
Ice	3–4	$1 \cdot 10^{5}$
Fresh water	80	$2 \cdot 10^{4}$
Salt water	80	0.3
Dry sand	3–5	$1 \cdot 10^{5}$
Wet sand	20–30	$1 \cdot 10^{3}$ - $1 \cdot 10^{5}$
Shales and clays	5–20	1 - $1 \cdot 10^{3}$
Silts	5–30	1 - $1 \cdot 10^{2}$
Limestone	4–8	500 - 2000
Granite	4–6	$1 \cdot 10^{3}$ - $1 \cdot 10^{5}$
(Dry) salt	5–6	$1 \cdot 10^{3}$ - $1 \cdot 10^{5}$

Dielectric permittivity

- Defines how strongly a material becomes electrically polarized under the influence of an electric field
- Determines the reflection and refraction of radiowave signals
- Impacts the velocity and then the wavelength of radiowave signals

Resistivity

- Inverse of conductivity
- Impacts the attenuation of radiowave signals

Ground Penetrating Radar (GPR)

Method – basic concepts

- Radar wavelength given by:

$$\lambda = \frac{wave\ speed}{frequency}\sqrt{rel.permittivity}$$

- Wavelength (and thus frequency) determines resolution.

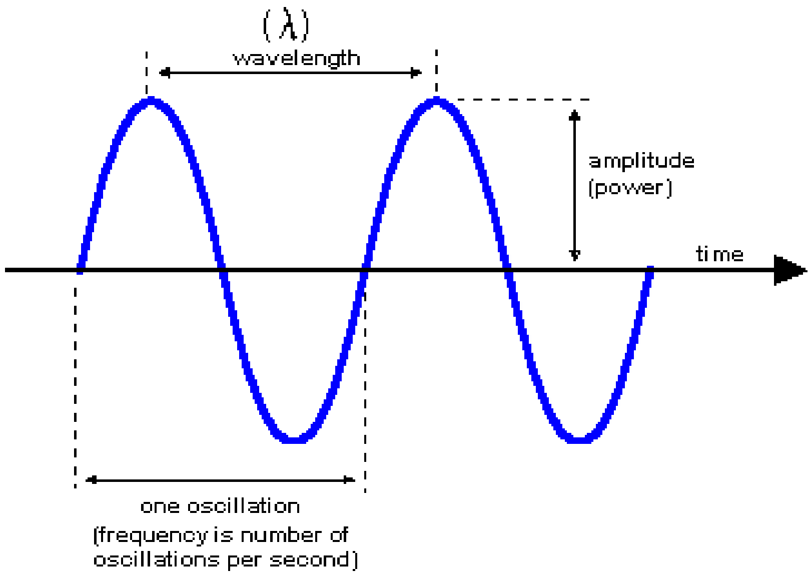
Wavelength ↓ ↑ Resolution, Frequency

- **Example:**

EM waves travel with the speed of light in air (c = 300 000 km/s)

100 MHz signal:
Air: 3 m
Rock: 2.4 m
Salt water: 0.9 m

500 MHz signal:
Air: 0.6 m
Rock: 0.5 m
Salt water: 0.2 m

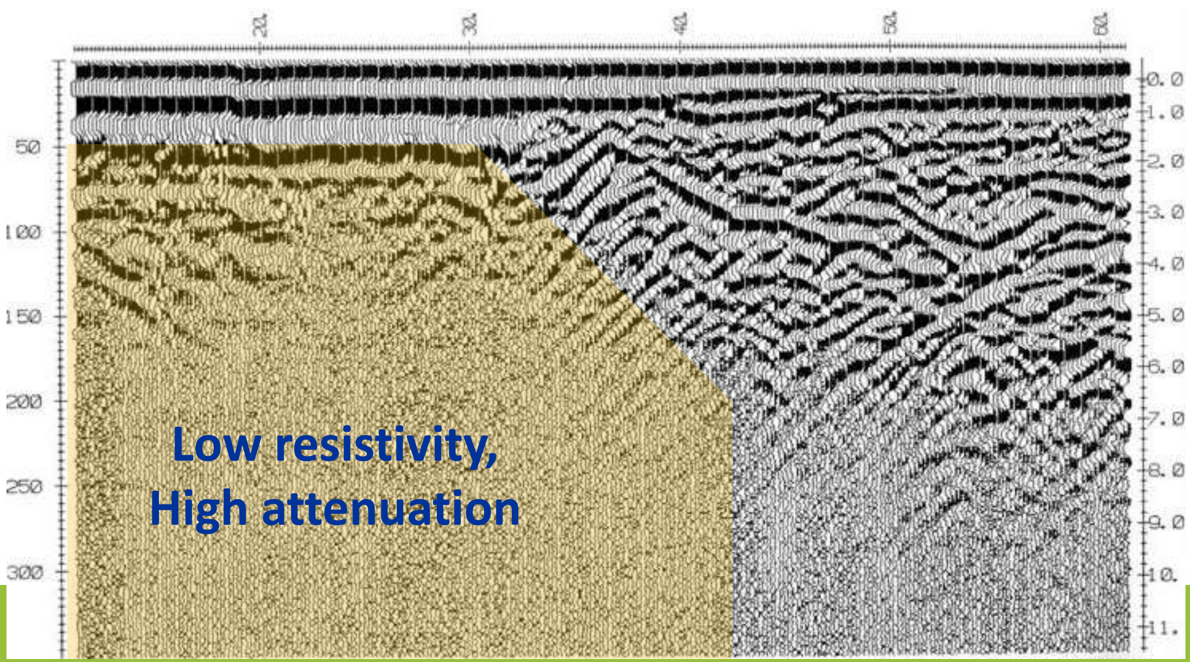


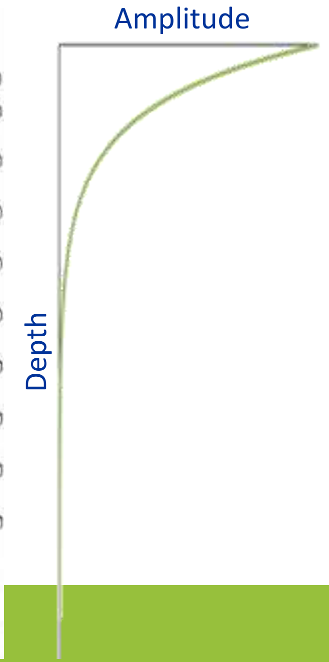
Ground Penetrating Radar (GPR)
Method – basic concepts

In the ground, radar waves cause currents to flow → loss of energy = attenuation

Radar signal amplitude shows an **exponential decay** with depth, which is proportional to an **attenuation constant**

Frequency, Resistivity ↓ ↑ Attenuation factor





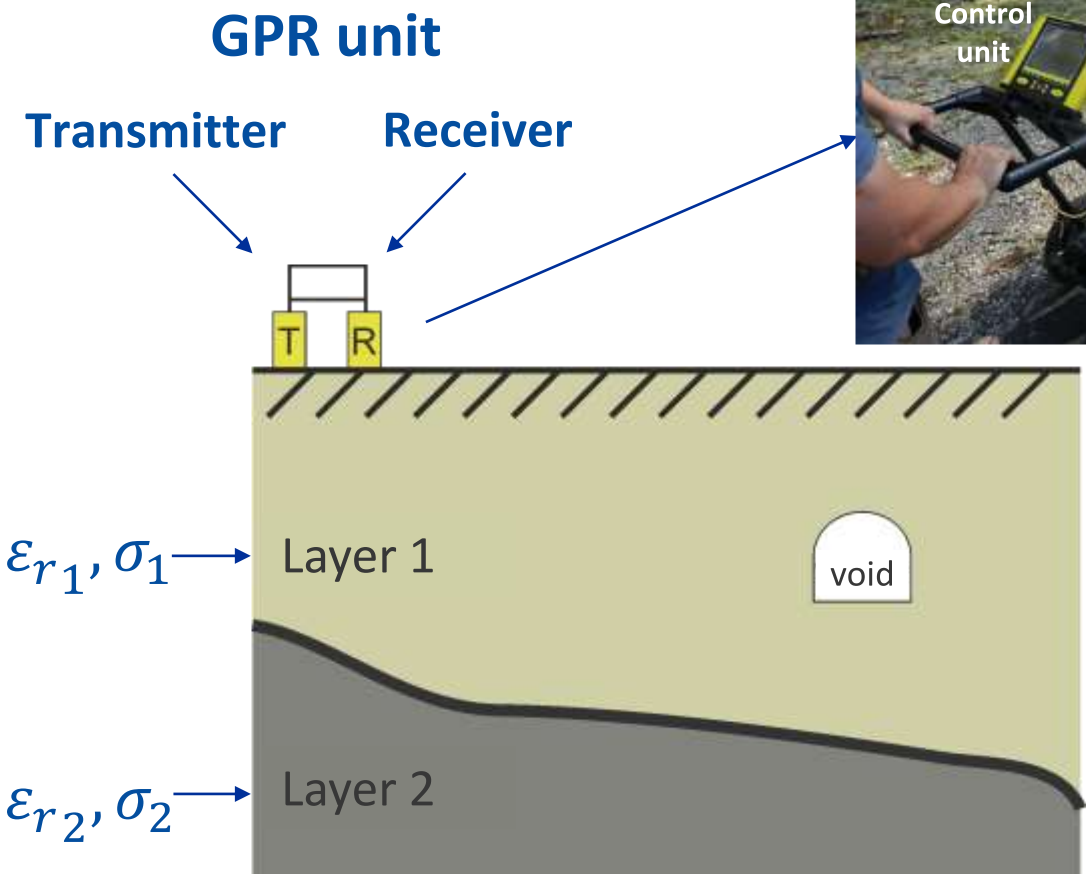
Ground Penetrating Radar (GPR)
Method – basic concepts

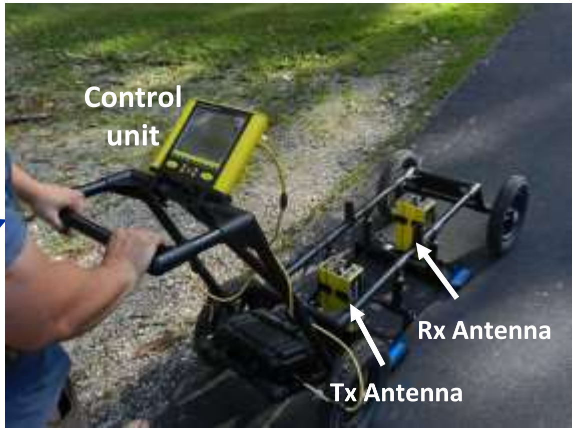
Material	Permittivity (ε_r)	Resistivity (ρ) [Ωm]	Velocity (V) [m/ns]	Attenuation constant (α) [dB/m]
Air	1	$> 1 \cdot 10^{16}$	0.3	0
Ice	3–4	$1 \cdot 10^{5}$	0.16	0.01
Fresh water	80	$2 \cdot 10^{4}$	0.033	0.1
Salt water	80	0.3	0.01	1000
Dry sand	3–5	$1 \cdot 10^{5}$	0.15	0.01
Wet sand	20–30	$1 \cdot 10^{3}$ - $1 \cdot 10^{5}$	0.06	0.03–0.3
Shales and clays	5–20	1 - $1 \cdot 10^{3}$	0.08	1–100
Silts	5–30	1 - $1 \cdot 10^{2}$	0.07	1–100
Limestone	4–8	500 - 2000	0.12	0.4–1
Granite	4–6	$1 \cdot 10^{3}$ - $1 \cdot 10^{5}$	0.13	0.01–1
(Dry) salt	5–6	$1 \cdot 10^{3}$ - $1 \cdot 10^{5}$	0.13	0.01–1

The **smaller** the resistivity, the **higher** the attenuation, the **smaller** the return signal.

Ground Penetrating Radar (GPR)

Method – Data acquisition





Changes in dielectric properties

Common Offset acquisition

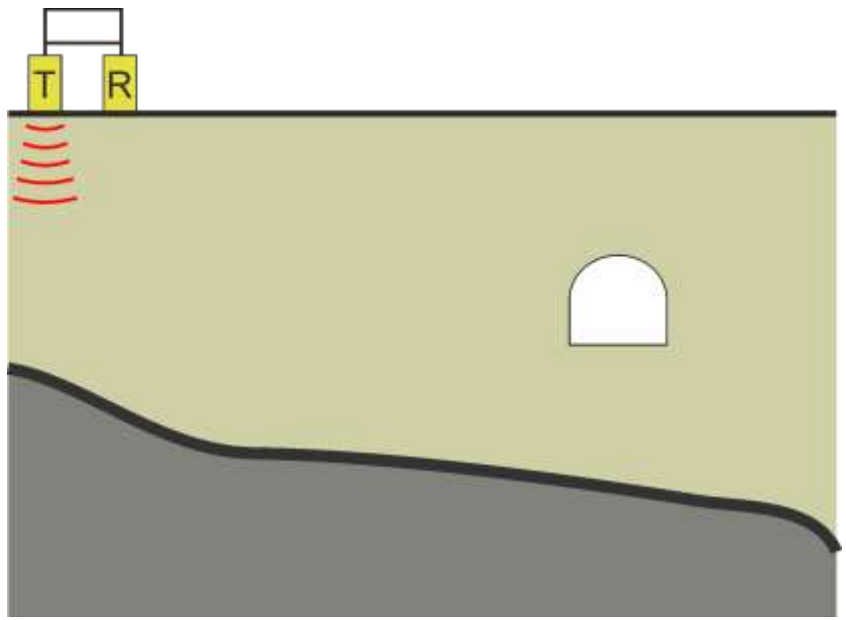
Static Tx-Rx distance

Ground Penetrating Radar (GPR)

Method – Data acquisition

- Operates by **transmitting pulses** of EM waves of frequencies 10 MHz – 4 GHz through a transmitting antenna
- Waves travel through the ground and parts of the signal is **reflected** on **discontinuities** of dielectric properties (**permittivity**, **resistivity**)

EM pulse emission at Tx



Common Offset acquisition

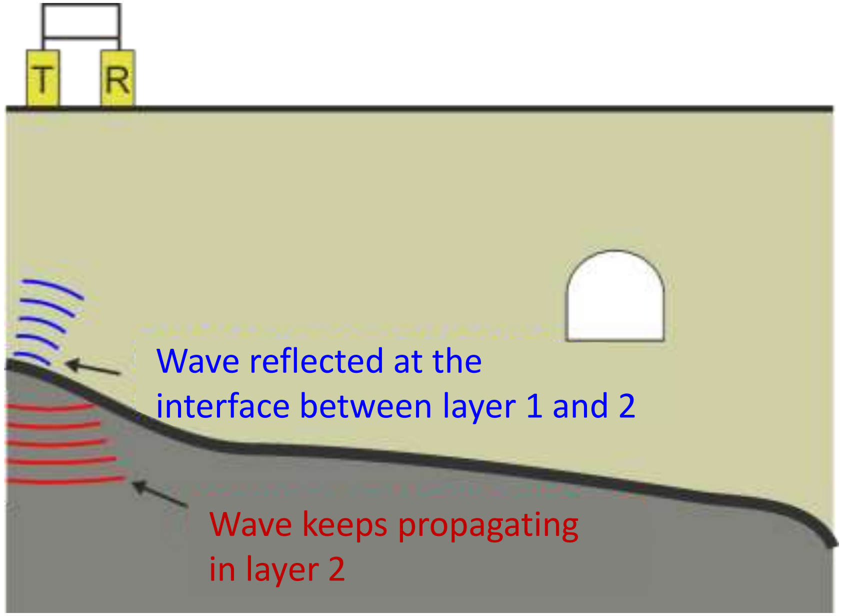
Static Tx-Rx distance

Ground Penetrating Radar (GPR)

Method – Data acquisition

- Operates by **transmitting pulses** of EM waves of frequencies 10 MHz – 4 GHz through a transmitting antenna
- Waves travel through the ground and parts of the signal is **reflected** on **discontinuities** of dielectric properties (**permittivity**, **resistivity**)
- Reflected waves are recorded at the surface by the **receiver antenna**

Pulse is reflected if presence of a contrast in resistivity or permittivity

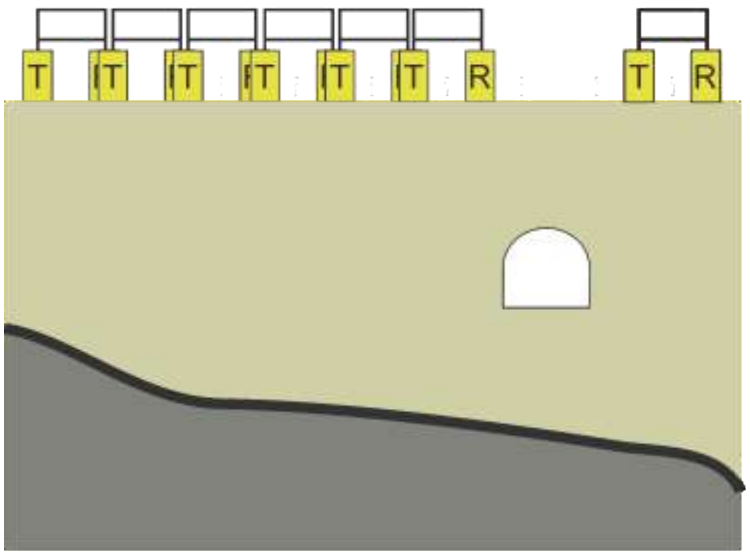


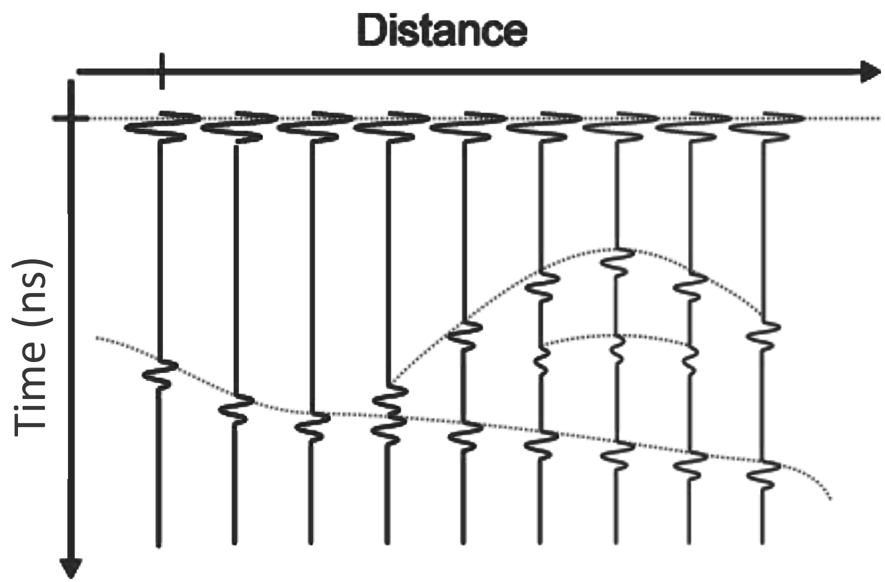
Common Offset acquisition

Static Tx-Rx distance

Ground Penetrating Radar (GPR)
Method – Data acquisition

- As the antennas move, multiple traces are recorded
- These traces show peaks in amplitude coming from the reflected waves
- They typically display **layers** and **hyperbolas**





Ground Penetrating Radar (GPR)
Method – Data acquisition

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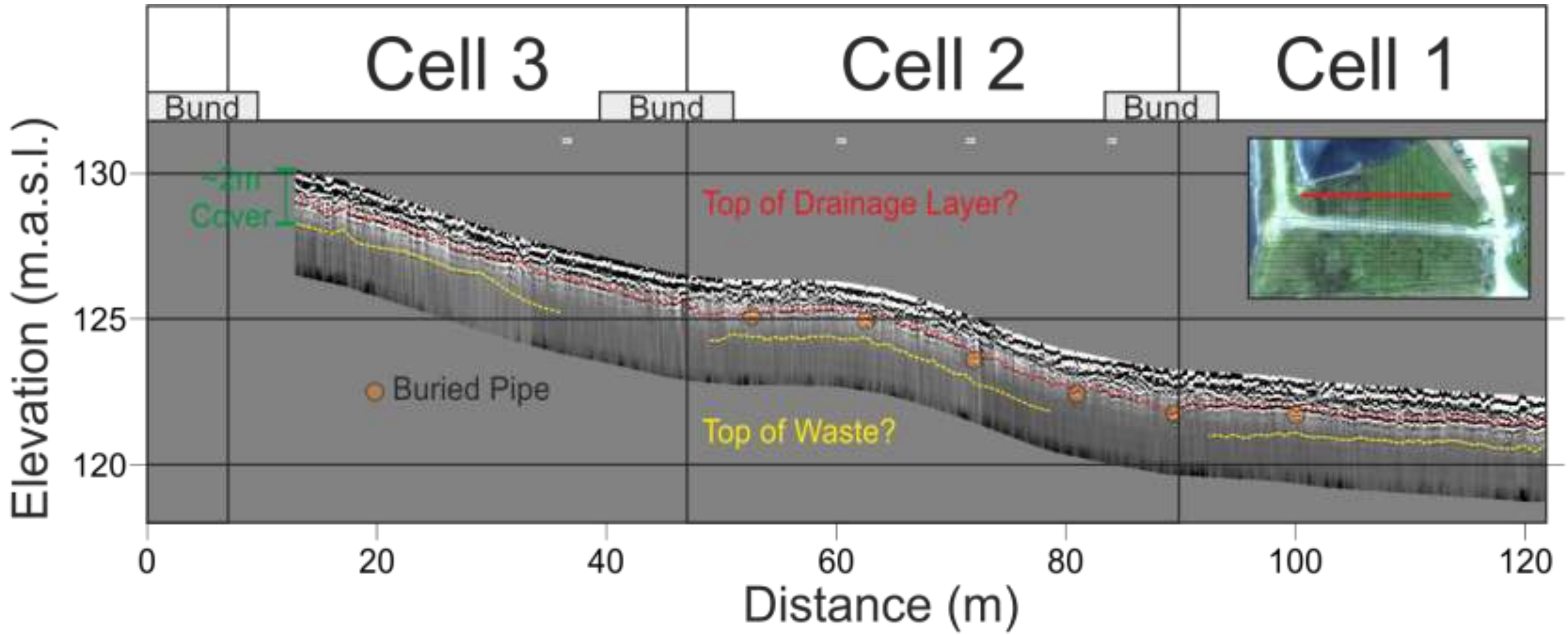
- A … , V in th…
  - …
  - … f light

Ground Penetrating Radar (GPR)

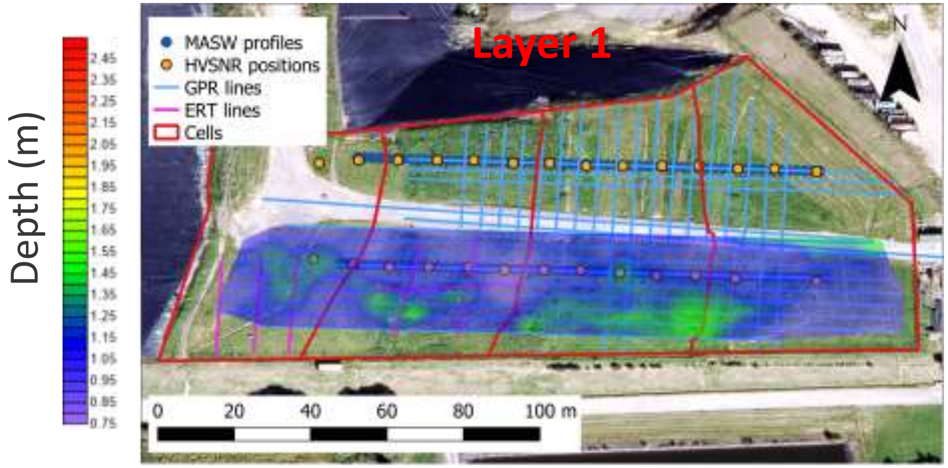
Case histories – Les Champs Jouaults

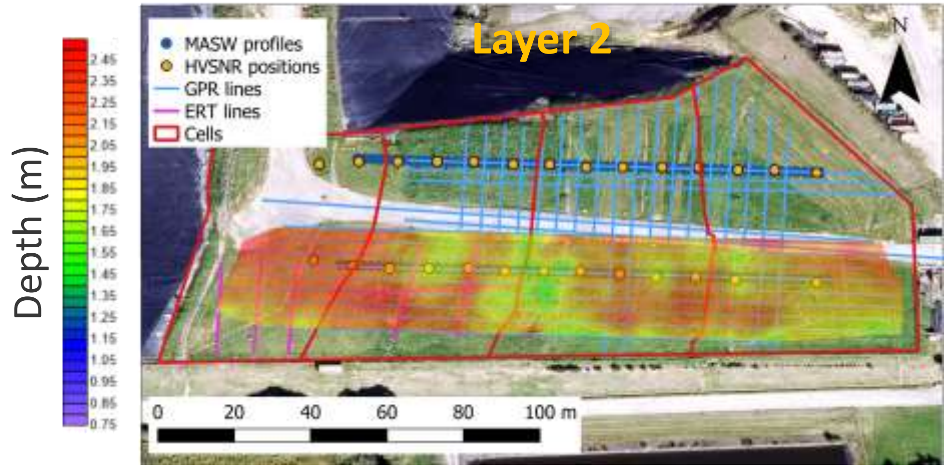
- Imaging buried pipes
- Two interfaces corresponding to:
  - Boundary between 2 type of material in the cover layer
  - The top of the waste



Ground Penetrating Radar (GPR)

Case histories – Les Champs Jouaults





- Picking the 2 layers in data from parallel surveys (3D grid)
- Interpolation gives a map (isosurface) of the 2 interfaces retrieved from the GPR data

Ground Penetrating Radar (GPR)

Method – summary

- Operates by transmitting pulses of EM waves of frequencies 10 MHz – 4 GHz through a transmitting antenna
- Waves travel through the ground and are reflected at discontinuities of dielectric properties (permittivity, resistivity)
- Reflected waves are recorded at the surface by the receiver antenna
- EM waves are attenuated in the ground; attenuation controlled by the grounds resistivity
- Resolution is a function of wavelength/frequency; the higher the frequency, the smaller features can be resolved
- But the higher the frequency, the higher the attenuation too…

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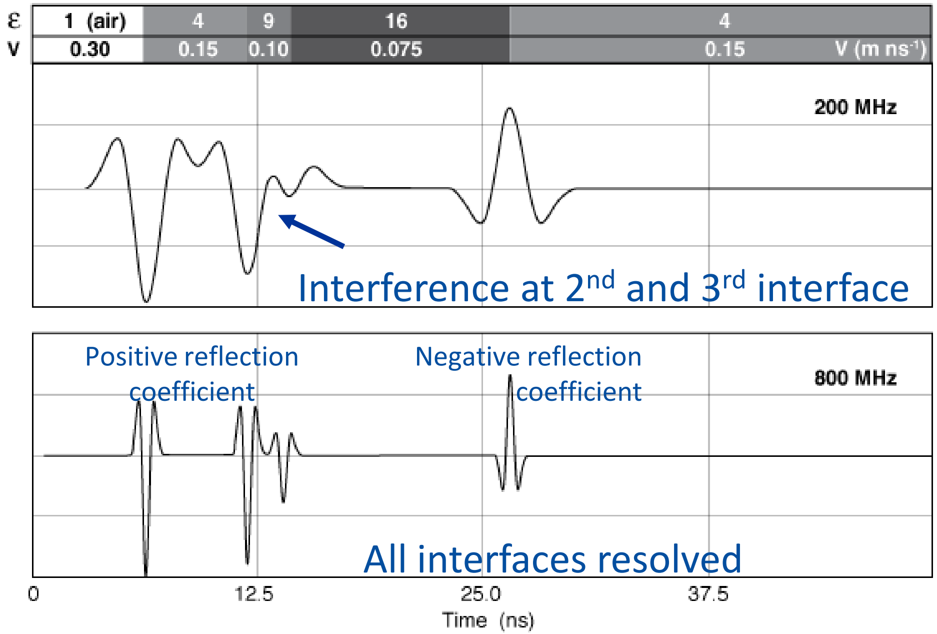
Thank you!

Ground Penetrating Radar (GPR)
Method – basic concepts

- If a GPR signals encounters a **discontinuity** in **resistivity** or **permittivity** a part of the signal will be reflected.

- The **wavelength** must be **smaller** than any given layer to **resolve** its thickness.
- If the layer is thinner **interference** occurs
- Importance of choosing the appropriate frequency for the antenna



Ground Penetrating Radar (GPR)
Method – Data acquisition

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- Depending on attenuation, reflection coefficient, interference, etc., these waves show different amplitudes, informing on different layers, or objects
- When displayed altogether, next to each other, these traces form an image called radargram