# Introduction to Geophysics

Assignment: Ground Penetrating Radar

In this assignment, you will analyze several near-surface geophysics problems involving ground penetrating radar (GPR) and seismic methods.

## Problem 1: Perchlorate transport in karst

The occurrence of the perchlorate ion $ClO_4^-$ in groundwater presents a great risk to human health since perchlorate has long been known to inhibit proper functioning of the thyroid. Beneath the Naval Weapons Industrial Reserve Plant (NWIRP) in central Texas, significant concentrations of perchlorate ions derived from the manufacture of rocket propellant have been detected in groundwater and springs. A perchlorate contamination survey was conducted at NWIRP using a 50 MHz GPR system that was towed on a sled behind an all-terrain vehicle. The geology consists of weathered limestone bedrock below 0 m to 3 m of clay overburden. The survey was executed over approximately $100\,\mathrm{line} - \mathrm{km}$ covering a wide area of about 500 ha. This GPR survey in karst terrain was done with the goal of mapping subsurface structural features that might be indicative of major pathways for subsurface transport of perchlorate ions.

### Given information

- GPR frequency: $f = 50\,\mathrm{MHz}$
- Relative permittivity of weathered limestone: $\varepsilon_r = 9$
- Approximate radar velocity for part (d): $V = 0.07\,\mathrm{m/ns}$
- Lateral resolution is estimated using $\lambda/2$
- Vertical resolution is estimated using $\lambda/4$

### Questions

(a) Lateral resolution of the GPR is about 1 m. Verify this approximately using $\varepsilon_r = 9$ for weathered limestone and $f = 50\,\mathrm{MHz}$.

(b) Individual bedrock fractures are on the order of millimetres in width. Why can GPR not detect individual fractures?

(c) Why was a low frequency of 50 MHz chosen rather than a higher frequency for this survey?

(d) In the radargram, find at what time the bedrock reflection appears. Using $V = 0.07\,\mathrm{m/ns}$, calculate the depth to bedrock at this location.

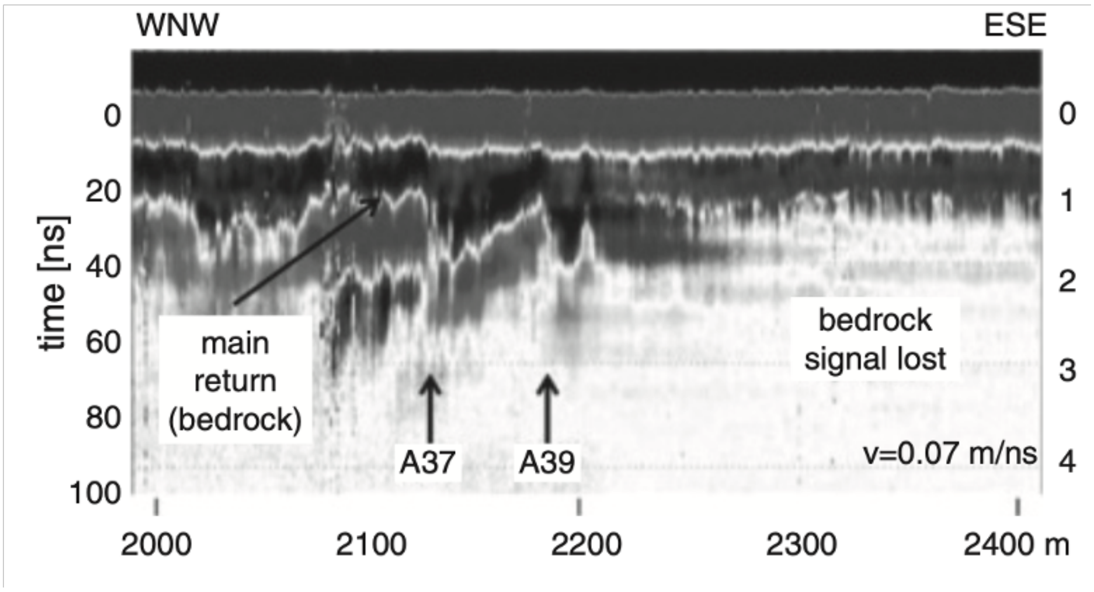


Figure 1: The radargram for Problem 1

# Problem 2: Boundary between granite and limestone

A geologist runs a GPR survey over a site and expects to detect the boundary between two rock units. The upper unit is granite ($\varepsilon_r = 6$) and the lower unit is limestone ($\varepsilon_r = 6$).

## Given information

- Upper unit: granite, $\varepsilon_r = 6$
- Lower unit: limestone, $\varepsilon_r = 6$
- Reflection coefficient formula:

$$R = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}$$

- Borehole later confirms the boundary depth is 3 m

## Questions

(a) Calculate the reflection coefficient at this boundary.

(b) The geologist sees no reflection in the radargram at the expected depth. Is this consistent with the physics?

(c) A later borehole confirms the boundary exists at 3 m depth. Why did GPR fail to detect it?

(d) What change in conditions would make this boundary detectable by GPR?

## Problem 3: Coastal barrier island and saltwater intrusion

A GPR survey is conducted over a coastal barrier island. The stratigraphy consists of aeolian sand ($\varepsilon_r = 5$, dry) overlying a beach sand deposit saturated with freshwater ($\varepsilon_r = 25$).

### Given information

- Upper layer: dry aeolian sand, $\varepsilon_r = 5$
- Lower layer initially: freshwater-saturated beach sand, $\varepsilon_r = 25$
- After saltwater intrusion: lower layer $\varepsilon_r = 20$
- Full seawater replacement case: $\varepsilon_r = 80$
- Reflection coefficient formula:

$$R = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}$$

### Questions

(a) Calculate the reflection coefficient at this boundary.

(b) A storm causes saltwater intrusion into the lower layer ($\varepsilon_r$ drops to 20 due to salinity effects on permittivity).

(c) After the storm the geologist notices that the reflection from this boundary has weakened. Calculate the new reflection coefficient and explain why.

(d) If the saltwater fully replaces the freshwater ($\varepsilon_r = 80$ for seawater), recalculate $R$ and comment.

## Problem 4: Hyperbola polarity over voids in limestone

A GPR profile over a suspected void in limestone shows a hyperbolic arrival. The wavelet at the apex of the hyperbola shows a white–black–white pattern.

### Given information

- Typical limestone permittivity: $\varepsilon_r \approx 6$
- Air permittivity: $\varepsilon_r \approx 1$
- Freshwater permittivity: $\varepsilon_r \approx 80$
- Reflection coefficient formula:

$$R = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}$$

## Questions

(a) What does this polarity tell you about the velocity contrast at the target?

(b) Is the target consistent with a water-filled void or an air-filled void? Use $\varepsilon_r$ values to justify your answer.

# Problem 5: Direct arrivals, blind zone, and shallow target detection in GPR

A GPR system has a transmitter–receiver separation of 0.5 m. The subsurface is wet clay with relative permittivity ($\varepsilon_r = 25$).

## Given information

- Transmitter–receiver separation:

$$x = 0.5 \text{ m}$$

- Speed of light in air:

$$c = 0.3 \text{ m/ns}$$

- Relative permittivity of wet clay:

$$\varepsilon_r = 25$$

- Reflection from the water table arrives at:

$$t_{\text{refl}} = 18 \text{ ns}$$

Use the following relations:

**(1) Direct air-wave velocity**

$$v_{\text{air}} = c$$

**(2) Direct ground-wave velocity**

$$v_{\text{ground}} = \frac{c}{\sqrt{\varepsilon_r}}$$

**(3) Travel time**

$$t = \frac{x}{v}$$

**(4) Approximate blind-zone depth**

$$z_{\text{blind}} \approx v_{\text{ground}} \frac{t_{\text{ground}}}{2}$$

### Questions

(a) At what time does the direct air wave arrive at the receiver?

(b) At what time does the direct ground wave arrive?

(c) A reflection from the water table arrives at 18 ns. Is this reflection obscured by the direct arrivals? Comment on the implications for shallow target detection.

(d) If you move the antennas closer together to 0.1 m separation, what happens to the direct wave arrival times and the blind zone?

## Problem 6: Why GPR and seismic methods are complementary

The seismic and GPR techniques are somewhat complementary in the sense that poor GPR field conditions (wet clays) are actually good seismic conditions while ideal GPR conditions (dry sands) are unfavorable for the acquisition of high-quality seismic data.

### Questions

(a) Explain physically why wet clay is poor for GPR but good for seismic.

(b) Explain physically why dry sand is good for GPR but poor for seismic.

(c) You are asked to image a 5 m deep boundary in an unknown soil. A quick GPR profile shows almost no signal penetrating below 0.5 m. What does this imply about the ground conditions, and what method should be used instead?

## Problem 7: Seismic and GPR reflection coefficients at a water-saturation boundary

A boundary exists at 3 m depth between two geological units. Unit 1 above is dry sandstone. Unit 2 below is the same sandstone but water-saturated.

### Given information

- Boundary depth:

$$z = 3 \text{ m}$$

- Dry sandstone:

$$V_1 = 2000 \text{ m/s}, \qquad \rho_1 = 2200 \text{ kg/m}^3, \qquad \varepsilon_1 = 5$$

- Water-saturated sandstone:

$$V_2 = 3500 \text{ m/s}, \qquad \rho_2 = 2350 \text{ kg/m}^3, \qquad \varepsilon_2 = 30$$

Use the following formulas:
**(1) Seismic reflection coefficient**

$$R_{\text{seis}} = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

**(2) GPR reflection coefficient**

$$R_{\text{GPR}} = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}$$

## Questions

(a) Calculate the seismic reflection coefficient.

(b) Calculate the GPR reflection coefficient.

(c) Which method gives a stronger reflection at this boundary?

(d) What fundamental difference in physics does this illustrate?