Lab 6: GPR

TA: Devin Cowan

e-mail: devinccowan@gmail.com

office: ESB 4021

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Overview

During ground penetrating radar (GPR) surveys, an antena is used to send a pulse of electromagnetic waves into the Earth. As the GPR signal propagates, it is reflected, transmitted and refracted at interfaces where the Earth's physical properties change. Some of the GPR signal returns to the Earth where it is measured by a receiver.

In this lab, you will be working with GPR data collected near UBC. You will begin by examining how GPR signals propagate through the earth. You will then explore GPR responses for several geologic models and interpret field collected data.

Running the iPython Notebook

For this lab, you will not have to write any code. You will only be running it.

- *Shift + Enter* runs the code within the cell (so does the forward arrow button near the top of the document)
- You can alter variables and re-run cells by changing the values and doing *Shift + Enter*
- If you want to start with a clean slate, restart the Kernel either by going to the top, clicking on *Kernel: Restart*, or by *esc + 00*

Resources

- GPG: GPR Section
- Zip File containing the notebook

Identifying the Ray Paths of GPR Signals

Consider the model shown in Figure 1. This model consists of three layers: air, layer 1, and layer 2. The layers have relative permittivities $\epsilon_{r,air}$, $\epsilon_{r,1}$ and $\epsilon_{r,2}$ respectively. The distance between the source and the receiver is given by x. The source and receiver antennas are oriented in y-direction.

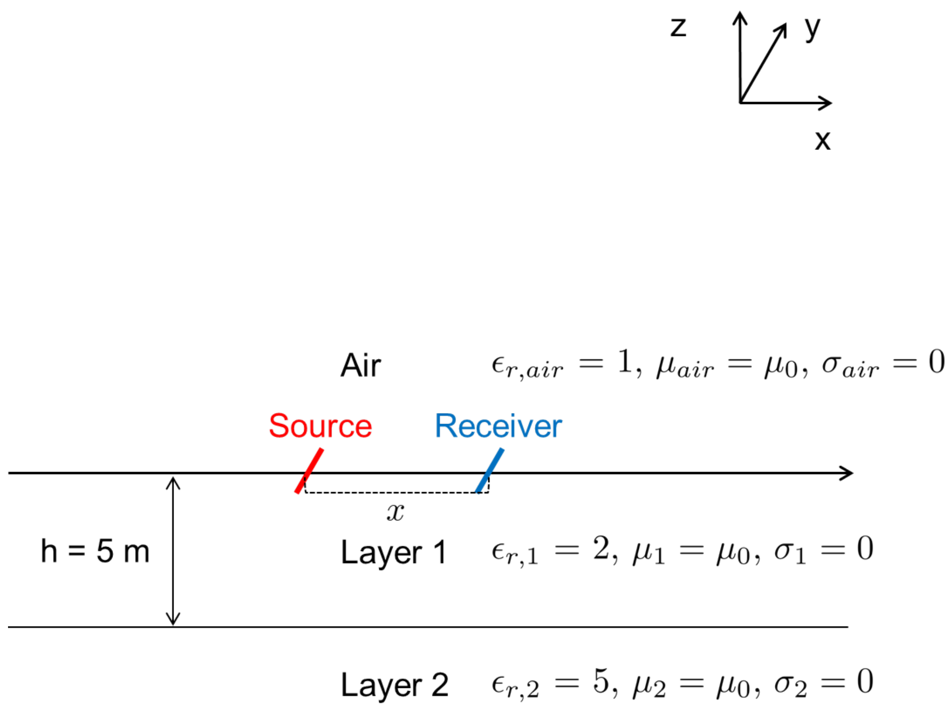

Figure 1: Conceptual diagram of GPR source antenna and receivers.

Q1. For the model shown in Figure 1, there are a number of ways in which portions of the GPR wavefront (or waves) can reach the receiver. The different travel paths are called ray paths. Answer the following questions about GPR signals and ray paths.

a. There are two direct paths which GPR signals can take from the transmitter to the receiver. Where do each of these waves propagate? Sketch the two ray paths on your own diagram below.

A: direct air wave and direct ground wave

b. Which of the two direct signals will arrive first? Justify your answer by considering the physical properties of each medium.

A: air wave, $v = c/\sqrt{(}\epsilon_r)$ when $\mu_r = 1$, and $\epsilon_{r,air} < \epsilon_{r,1}$ always

c. If the transmitter and receiver are separated by a distance x, what is the expression for the travel time for a direct wave?

A: t = x/v, where v = c/sqrt(eps)

d. Suppose the operating frequency of the GPR system is 200 MHz. What is the spatial length (wavelength) of the GPR wavelet as it travels through the ground. Assume the ground has a relative permittivity of $\varepsilon_r = 4$. Sketch a typical wavelet below.

A: $\lambda = c/f_c\sqrt{\varepsilon_r} = 0.75$ m

e. For layer 1, what is the smallest separation distance which two buried object could have and still be visible with a zero-off survey? Assume the objects are buried at a depth of 4 m. The operating frequency is still 200 MHz.

A: $D > \sqrt{\frac{Vd}{2f_c}} = 1.22$ m

f. Plot the radargrams for the direct air wave and direct ground wave on the t-x plot in Figure 2. Recall that we know the relative permittivity of air and that the relative permittivity of layer 1 is $\varepsilon_r = 4$.

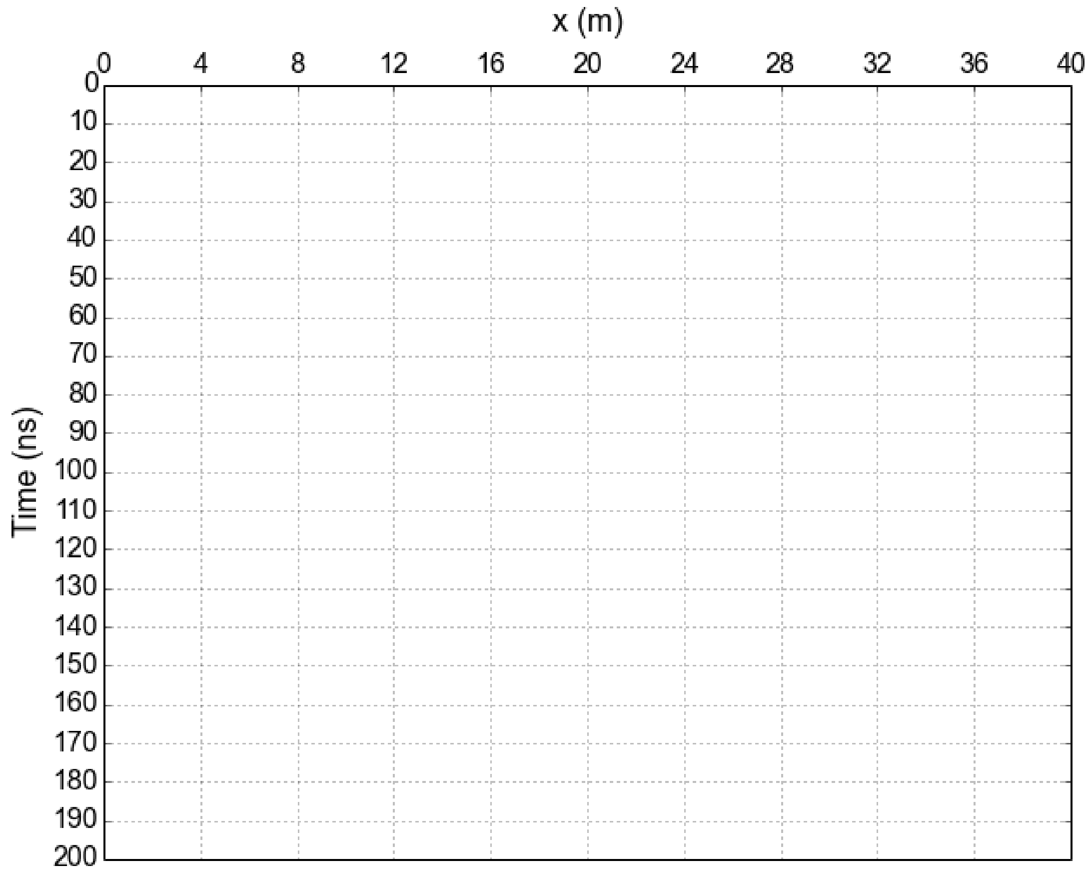

Figure 2: T-X plot

g. When the GPR signal sent into the Earth reaches the interface between layers 1 and 2, some of it is reflected and some of it is refracted.

(i) Add the reflected ray path to your diagram in Question 1a.

(ii) The formula for the travel time as a function of offset is given by $t = \sqrt{(x^2 + 4h^2)}/v_1$. Use this forumla to fill in the table below.

(iii) Add the reflected wave signal to the T-X plot in Figure 2.

x (m)	arrival time from the reflected wave at 1st interface (t)
0	
1	
2	
4	
8	
16	
24	

A: 67 ns, 67 ns, 68 ns, 72 ns, 85 ns, 126 ns, 173 ns

h. For the geologic model we are considering, is it possible for there to be a critically refracted wave? Along which interface would the critically refracted wave travel if possible? Explain.

A: Yes. It would travel along the surface interface. Because $V_{air} > V_1$ always.

i. Given that $\varepsilon_{air} = 1$ and $\varepsilon_1 = 4$, what is the angle for the critical refraction at the surface.

A: $\theta_c = \sin^{-1}(v_1/v_{air}) = 30$ degrees

j. At what offset (x_c) will the critically refracted ray first be detected by receivers at the surface? Add the critically refracted wave to the T-X plot in Figure 2.

A: $x_c = 2h \tan\theta_c = 5.77$ m

Q2. Using the GPR widget (contained in the Zip File), we will estimate the unknown earth parameters, $\epsilon_{r,1}$, h from the given data. For each of the following questions, record the value(s) you find. Before executing any of the codes be sure you have run "Step 0: Import necessary packages."

a. Identify the direct air wave in the data and fit the arrival tmes with a straight line (blue) by adjusting epsrL and tinterpL. Record these values.

A: interpL = 15, epsrL = 1

b. Identify the direct ground wave and fit the arrival times with a straight line (blue) by adjusting epsrL and tinterpL. Record these values.

A: interpL = 15, epsrL = 9

c. Identify the reflected wave from the interface between the first and second layer and fit it with a hyperbola (red) by adjusting tinterpH and epsrH. Since the reflected wave travels through the first layer, you may use the relative permittivity you found for the direct ground wave for epsrH. Record the estimated tinterpH and esprH values.

A: interpH = 115, epsrH = 9

d. What is the velocity of the wave in the first layer?

A: 0.1 m/ns

e. What is the thickness of the first layer, h?

A: $d = \dfrac{Vt}{2} = 0.1m/ns \times 115ns/2 = 5.75$ m

Sketch ray paths on a profile line

In this section, we sketch ray paths for the GPR survey configurations and models provided. By drawing the ray paths, we can then infer the features we would expect to see in the corresponding radargram.

Q3. Consider the thick slab model in Figure 3. Let the black dots represent the Tx-Rx locations for a **zero offset** configuration.

a. Sketch the reflected ray paths for the slab model given below. Recall that rays which reflect off a point will reflect in all directions.

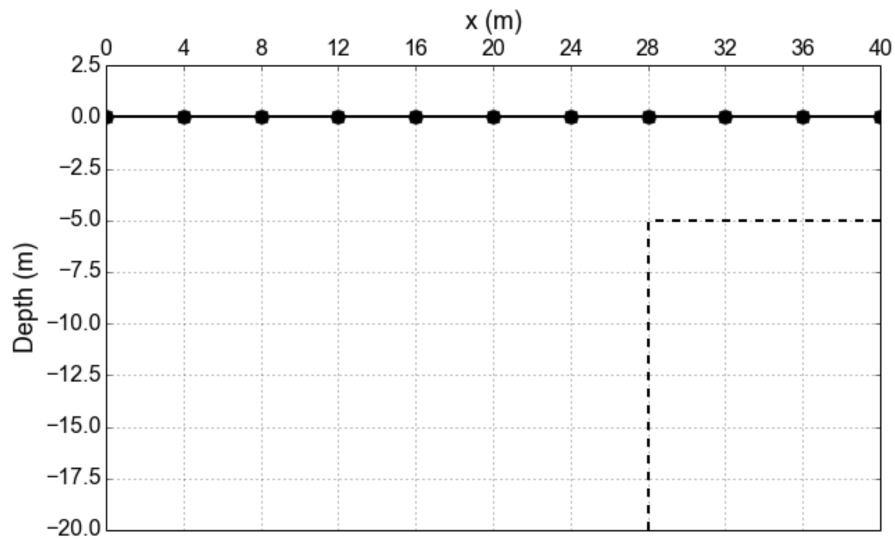

Figure 3: Ray paths for the slab model.

b. If the slab was very thin, would the ray paths change? Why?

A: No. None of the reflected waves from the vertical face will reach a receiver.

c. Based on ray paths you drew on Figure 3, sketch the corresponding radargram on the figure below. You will first need to determine the top-layer velocity. This can be done by looking at the arrival time to depth conversion between Figures 3 and 4.

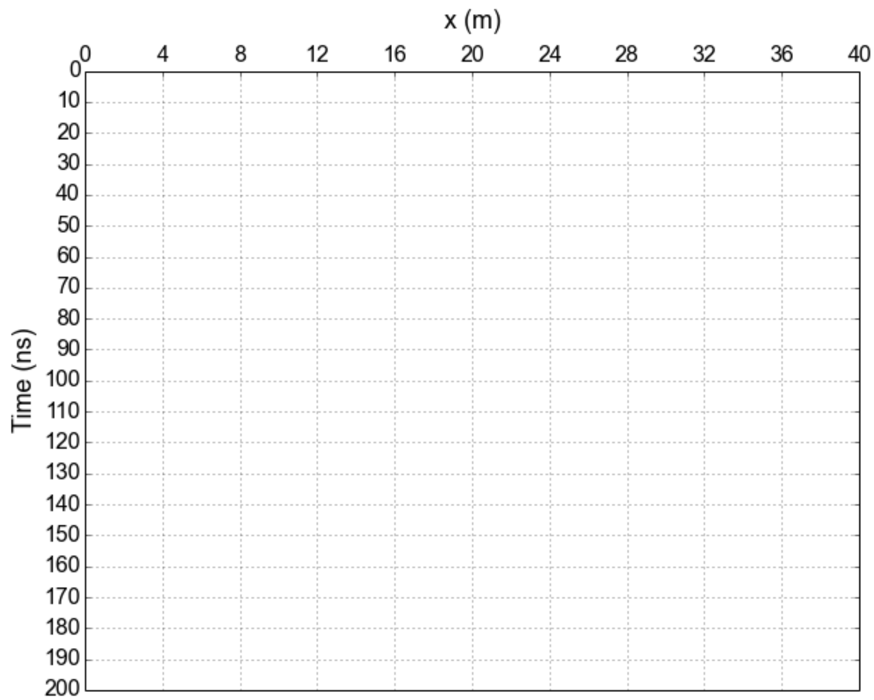

Figure 4: Arrival times for the slab model

Q4. Consider the concave interface in Figure 5. Once again, we will use a zero offset survey configuration.

a. Sketch the reflected ray paths for the syncline model given below when the GPR unit is at x=8, x=16 and x=20m

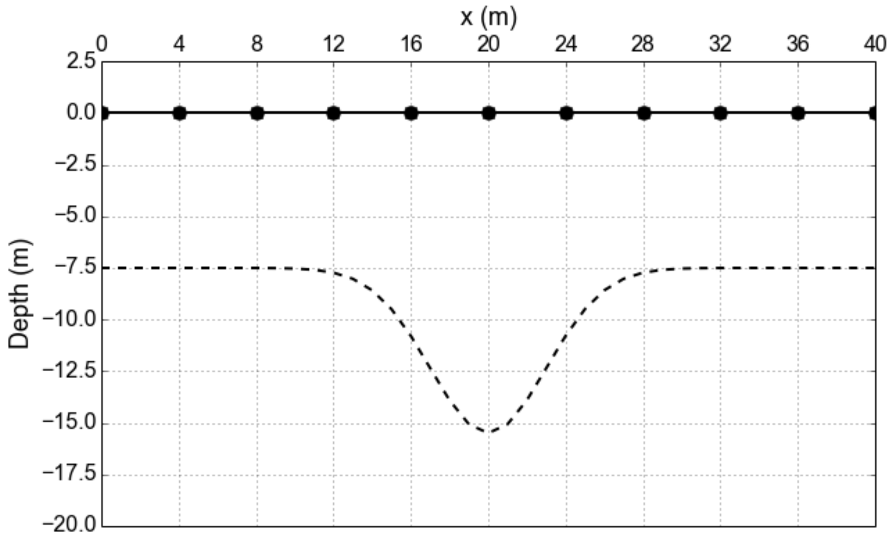

Figure 5: Ray paths for the syncline model

b. Why might it be more difficult to infer the shape of this interface from radargram data?

A: Because we will see multiple reflected signals for the same interface.

Interpretation of Field Data

In this section, we will interpret two field GPR data sets collected at the University of British Columbia. Applications in the GPRWidget will help you answer following questions.

Q5. The data shown in Figure 6 were collected using the common midpoint survey configuration. In this case, the smallest offset distance was 2.4 m (not 0 m). For the following questions, use Steps 2-4 of the GPR widget.

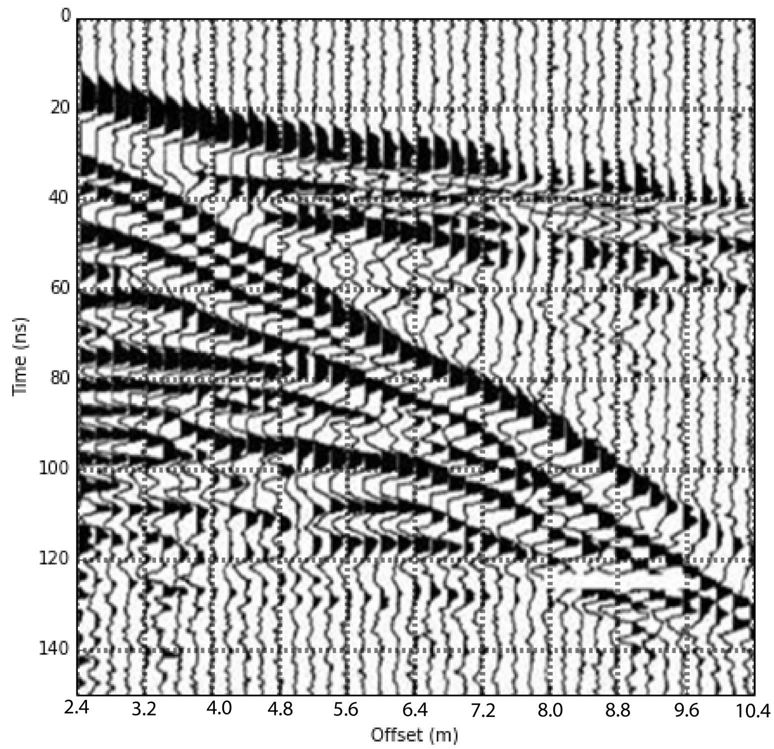

Figure 6: Common Midpoint data collected by UBC.

a. Pick out the air wave and estimate its velocity.

A:

b. Identify the direct ground wave and estimate its velocity.

A:

c. The radargram is not easily interpreted but there is a distinct flattening out of the reflections at small offsets. This is characteristic of a reflection hyperbola. Pick a possible candidate for this reflective event and extrapolate back to zero offset. What is the depth of the layer that gives rise to this reflection?

Q6. We consider the line profile data shown in Figure 7. Let us assume that we know that there are three different types of objects present:

- Layered Earth
- Buried pipes
- Concrete utilities casing

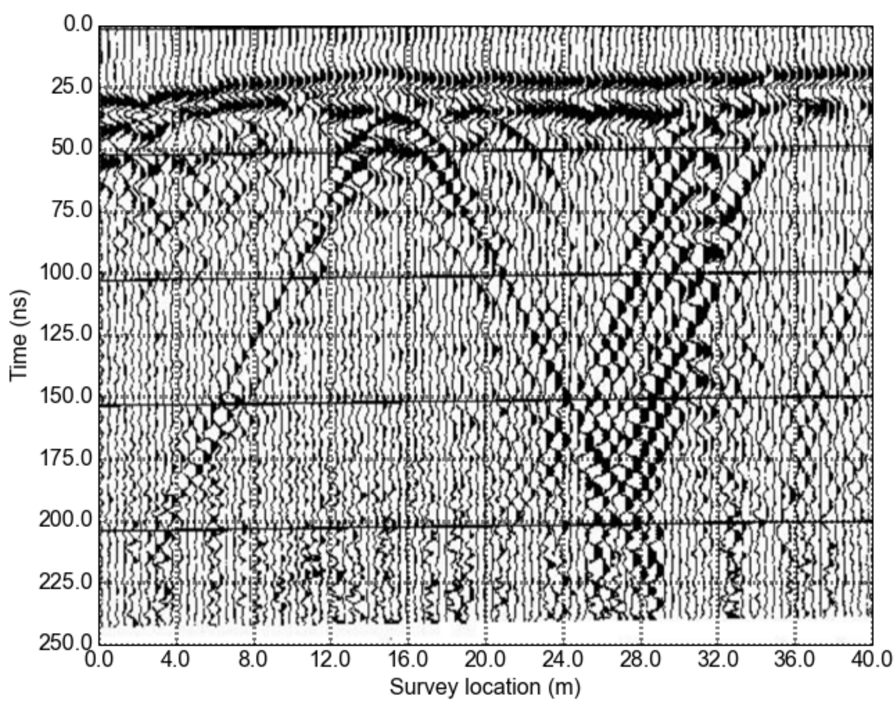

Figure 7: Common offset profile collected by UBC

a. On Figure 7, draw a line where you observe a layer boundary. Estimate the depth of this layer using the velocity of the ground that you estimated from Question 5b.

A: ...

b. On Figure 7, identify responses due to the pipes (there are two), and fit those responses with GPRWidget by adjusting the provided parameters. Record the best parameters for both pipes. There are four parameters that you need to estimate: epsr (relative permittivity), h (distance of the pipe center from the surface), xc (the pipe center location), r (radius of the pipe).

A: ...

c. Choose one of the hyperbolic responses you attributed to a pipe (because you can find a couple of them). Fix the radius of the pipe as 0.5 m and 1.5 m, respectively. Then fit the hyperbolic responses so that you can find two different sets of parameters for $r = 0.5$ and 1.5 m. If you were in charge of interpreting these data, how would you characterize the pipe?

A: ...

d. Compute the velocity of the GPR signal using the estimated relative permittivity. Compare this velocity with one that you computed in Question 5b (based on the CMP gather shown in Figure 6. The CMP gather data were acquired near the location of the profile line data). How do the velocities compare? Can you find a relative permittivity for the top layer that was satisfactory for both data sets? If you can't, can you suggest any reason for the discrepancy or could you reconsider any of your analysis to find a relative permittivity value?

A: .I got epsr=11 for the CMP gather and epsr=25 for the pipe. The direct wave for the CMP gather is sensitive to the velocity right at the surface. In the COG (Common Offset Gather) the waves are travelling through the upper meter or more of the ground. If the moisture level is increasing with depth then so will epsr. This might be a possible explanation. ..

e. Identify the response due to the concrete casing (similar to a slab), and fit those with GPRWidget adjusting provided parameters. Record the parameters that you find.

A: ...