Lab 5: Seismic Reflection

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Overview

When reflection seismic data are collected, geophones are laid out, and a source (such as dynamite or a vibroseis truck) sends a wavelet into the subsurface. The wavelet reflects off of interfaces separating units with different acoustic impedances. A reflection seismic survey will consist of multiple shots over the survey area. For this lab, we will consider a 2D seismic line, where sources and receivers are positioned along a straight line.

Reflection seismology is the workhorse geophysical technique for oil and gas exploration. Seismic sections or volumes, such as the one shown in Figure 1, are interpreted for geologic structure and other geologic features. Each of the traces composing the volume is an ideal *Normal Incidence Reflection Seismogram*. In this lab, we will be investigating geologic factors that impact the character of a seismogram and walk through how a seismogram is generated from the collected data.

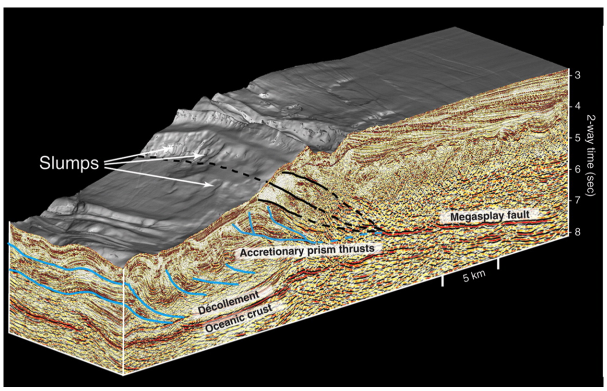

Figure 1: 3D seismic volume.

Resources

- GPG: Seismic
- Seismic Reflection app

1 Normal Incidence Seismogram

A normal incidence seismic trace simulates the time series you would observe if the source and receiver were coincident. For horizontal layers, it simulates the response you would expect for a signal that travels vertically and is reflected off of the various interfaces it encounters.

The arrival time and amplitude of the signal depend on the density, ρ, and seismic velocity, v, of the layers it travels through. Using the Seismic Reflection app, we will walk through how to construct a normal-incidence seismogram.

1.1 Reflection coefficient and Reflectivity

- The **reflection coefficient** is dependent upon the change in the acoustic impedance at an interface.
- The **reflectivity** is the amplitude of the wave (at the earth's surface) that has been reflected from that interface. That is, it incorporates transmission losses that the wave incurs as it travels from the source, to the reflecting interface, and back to the surface.

Q1. Answer the following questions related to acoustic impedance, reflection coefficients, and reflectivity (we will use the app in section 1.1 in Seismic Reflection app for this question):

a. Using the app: Start with uniform density ($\rho_1 = \rho_2 = \rho_3$) for all layers and adjust the velocity (v_1, v_2, v_3) of the layers. What is required for the reflection coefficients to be positive?, negative? What is required to have two reflection coefficients of opposite sign?

b. Using the app: Pick a constant velocity (v1=v2=v3=2150 m/s) and adjust the density of the layers. What is required for the reflection coefficients to be positive?, negative? What is required to have reflection coefficients of opposite sign?

c. Consider Figure 1 in the Seismic Reflection app. Assuming that the input amplitude is 1, use the equations provided in the notebook to calculate the reflected and transmitted amplitudes. Use $\rho_1 = \rho_2 = 2000\ kg/m^3$, $v_1 = 500\ m/s$ and $v_2 = 1000\ m/s$.

d. Consider Figure 2 in the Seismic Reflection app, which shows the reflection from the second interface. Specifying the input amplitude as 1, is the reflected amplitude from the second interface received at the surface greater or smaller than the reflection coefficient ($r_{2,3}$) at this interface?

e. Using the app: we explore the effect of transmission coefficients to reflectivity at the second interface. Turning on the "usingT" toggle in the app incorporates transmission coefficients (to yield reflectivity), and turning it off will show only the reflection coefficients. From default parameters set v2= 300 m/s and v3 = 4000 m/s, try turn off and on "usingT", can you recognize any difference? Then increase v2 to 2800 m/s, can you recognize the difference?

f. When do you think that considering transmission coefficients are important? Try a few more examples, and justify your answer.

1.2 Depth to Time conversion

We now have a series of reflectivity that tells us the amplitudes measured at the surface from reflections off of particular interfaces at depth. However, the signal we input and the data we measure are in time. Knowing the layer thicknesses and velocities, we can map from depth to time. We will use the app in section 1.2 in Seismic Reflection app. First set the parameters of the app to reproduce the model of Figure 2.

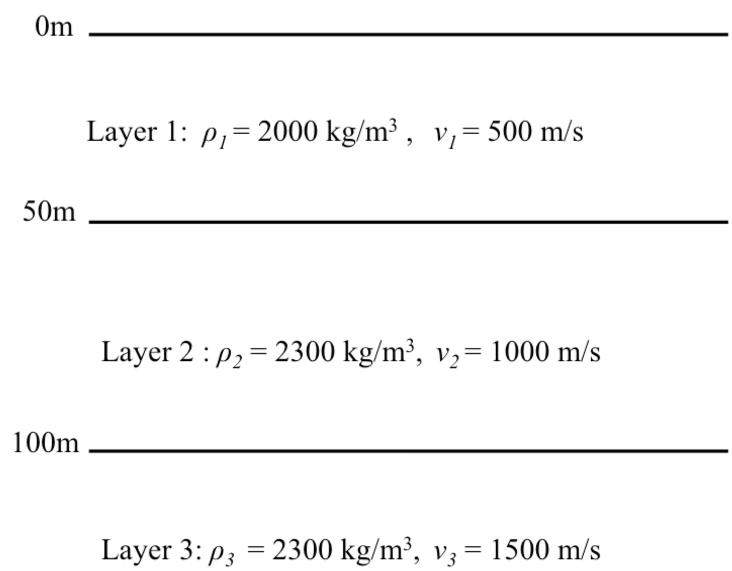

Figure 2

Q2. Answer following questions related to depth to time conversion:

a. Compute the two-way travel time for the two reflection events shown in the left panel of of the app 1.2. Show how you computed those times. Does it agree with reflection events shown in the right panel?

b. Using the app: observe changes in left and right panels while you are increasing v1 from 500 to 1900 (make the changes slowly when you increase v1 so that you can observe the changes). Do the location of the reflection events in the left panel change? How about on the right panel? What insight do you obtain from these experiments?

1.3 Modeling the ideal seismogram

By using the depth-time conversion, we can describe the reflectivity series in time. We input a source wavelet and record a seismogram in time, which is the convolution of the wavelet and the reflectivity series. We will use the app in section 1.3 in the Seismic Reflection app.

Q3. Execute the app 1.3 to define a wavelet and convolve it with the reflectivity series to construct a seismogram. For this example, we use the same model as shown in Figure 2.

a. Adjust the amplitude of the input pulse. How does this affect the resulting seismogram?

b. Adjust the frequency of the input pulse. How does the width of the wavelet change as the frequency is altered? In the space below, draw one a typical wavelet and show how you would measure the dominant period. Then, use the app to adjust the frequency of the wavelet to those listed in the table below. For each frequency, measure the dominant period of the wavelet off of the app and compare it with the theoretical value $T = 1/f$. The SEG Wiki: Ricker Wavelet webpage provides a good description of how to measure the period of Ricker Wavelet.

f (Hz)	Period (T)
5	
10	
20	
50	
100	

1.4 Vertical Resolution

Q4. Run the app for section 1.4. Now you can play with the geologic model and input wavelet frequency, as well as include noise. First, construct the model shown in Figure 3. Set the amplitude of the input pulse to 1.

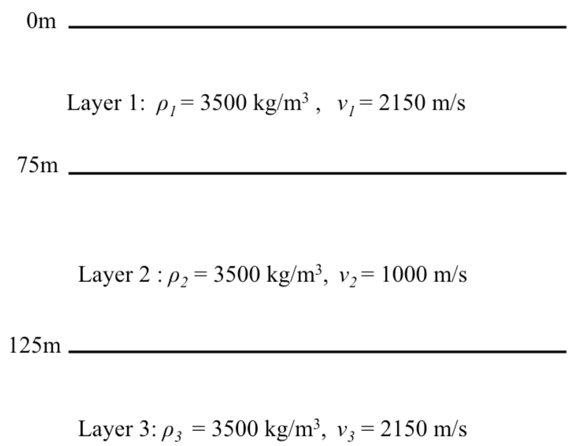

Figure 3: Three layer model.

a. Here we will investigate the impact of the wavelet frequency on seismic resolution. One question that is always of interest is "how thick must a layer be before it is detectable?". Using the model in Figure 3 as a starting point, we will fill in the following table. To compute the wavelength, λ, use the velocity of the second layer (v2) and the frequency of the input pulse. Adjust the thickness of layer 2 (h2) by adjusting the depth to the top of layer 3 (d3). For each of the frequencies listed, record the minimum h2 for which evidence of the top and bottom of the layer are visible in the seismogram.

f (Hz)	λ	**Min h2 clean**	**Min h2 noisy**
5			
10			
20			
50			
100			

b. Set the thickness of layer 2 to 1m. Set wavf = 100, and slowly decrease it. What happens to the amplitude of signal as the frequency is decreased?

2 Constructing a Normal Incidence Seismic Trace from CMP gather data

Now that we have investigated the impact of geologic factors on an ideal normal-incidence seismogram, we will examine how such a trace is extracted from the seismic data.

2.1 Sketch the Problem

There are multiple ways to sort seismic data: **common shot gather** and **common midpoint gather**:

- A **common shot gather** consists of the time-series recorded by the geophones for a single shot. The recorded time series are usually plotted with time on the y-axis and location on the x-axis.
- A **common midpoint gather** consists of the collection of traces that share the same midpoint between the source and receiver.

See GPG: Seismic or SubSurf Wiki for further explanation.

Q5. On the figure below or a separate piece of paper, sketch 4 reflection ray paths, from source to receiver for a common shot gather.

Figure 4: common shot gather

Q6. On the figure below or a separate piece of paper, sketch the ray paths for the reflections recorded on 4 source and geophone pair for a common midpoint gather.

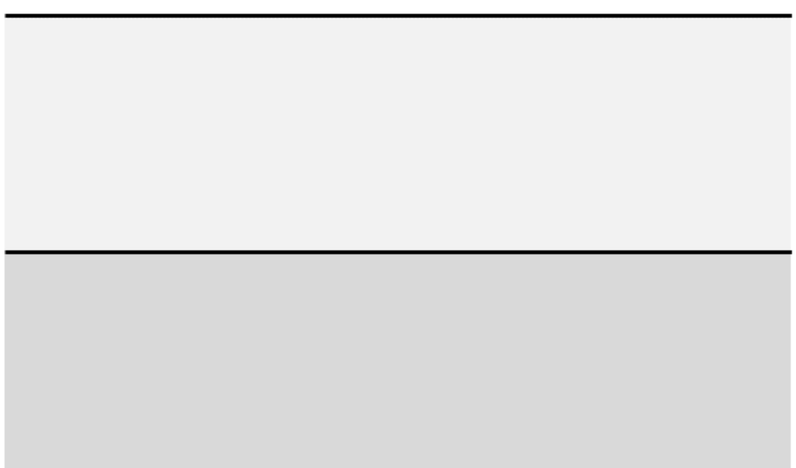

Figure 5: common midpoint gather

2.2 From CMP gather to a Seismic Trace

Here, we will walk through how to construct a normal incidence seismogram from a CMP gather. We have two data sets for you to examine. One is a clean data set, and the other is noisy. Both data sets are adapted from SeismicLab. For both, the input wavelet was a Ricker wavelet, similar to the one used in section 1 of the lab.

To estimate the geologic model and interpret structure from the seismic data, we want a single, normal-incidence trace. There are two challenges that must be considered when doing this from a CMP gather:

- For different source-receiver offsets, the arrival time of the reflection event will be different
- The data are usually contaminated with noise.

Challenge 1 will be tackled using a Normal Moveout(NMO) correction. While the second challenge will be addressed by stacking the NMO corrected traces to reduce the impact of random noise. If performed properly, the result will be a single normal-incidence trace.

Q7. The arrival time of a reflection event as a function of source-receiver offset is described by a hyperbola.

$$t(x) = \sqrt{\frac{x^2}{v^2} + t_0^2}$$

$$t_0 = \sqrt{\frac{4d^2}{v^2}}$$

The offset x is known for each trace, but we do not know the velocity v or thickness d of the first layer, so both v and t_0 must be estimated. Execute the cell corresponding to 2.2.

a. Using the app: By adjusting the intercept time t_0 and velocity v, fit a hyperbola to the reflection event in the CMP gather. The middle panel shows the NMO corrected data, that is, the data flattened on the hyperbola. Record the intercept time and velocity for the hyperbola you fit.

b. Using the app: What happens to the NMO corrected reflection event when you use a velocity which is too small? too or too large?

c. Using the app: On the right panel we provide stacked trace based t0 and v values that you fit. Assuming the input pulse has the same polarity as in the previous section (the maximum amplitude is a positive peak), what does the polarity of the event in the stacked trace tell you about the physical property contrast corresponding to that interface?

d. Compute the depth to this reflector.

Q8. Now we will work with the noisy data set. Since this data set is so noisy, we provide a hyperbola for you to fit a reflection event. The panel on the right performs the NMO correction for the hyperbola that you fit. Execute the first app of 2.3 to find a possible hyperbola to fit the reflection event in the noisy data. The second app will generate three stacked traces with the same t0 and three different velocities: v-200, v, and v+200.

a. By using the tools corresponding to section 2.3, find the intercept time and velocity that correspond to the reflection event in the noisy data. Provide the intercept time (t_0) and the velocity (v) that you used.

b. For the middle panel of the second app, can you recognize a reflected arrival in the stacked trace? How about left and right panels?

c. Estimate the depth to this reflector.

2.3 Finding the best hyperbola: Semblance analysis

Q9. One approach to estimating the hyperbolas corresponding to the reflection events is to use a semblance analysis. For a semblance analysis, we select a number of hyperbolas, with intercept time t_0 (y-axis on the semblance panels) and velocity v (x-axis on the semblance panels), and sum up the coherent energy in a window along that hyperbola (color for the semblance panels). Figures 6 and 7 show the semblance analysis for both the clean and noisy data you used in this lab. From these semblance images, which values of t0, v correspond to the reflection events in the clean and noisy data? Do these agree with the values you estimated doing "semblance by eye" in the previous questions?

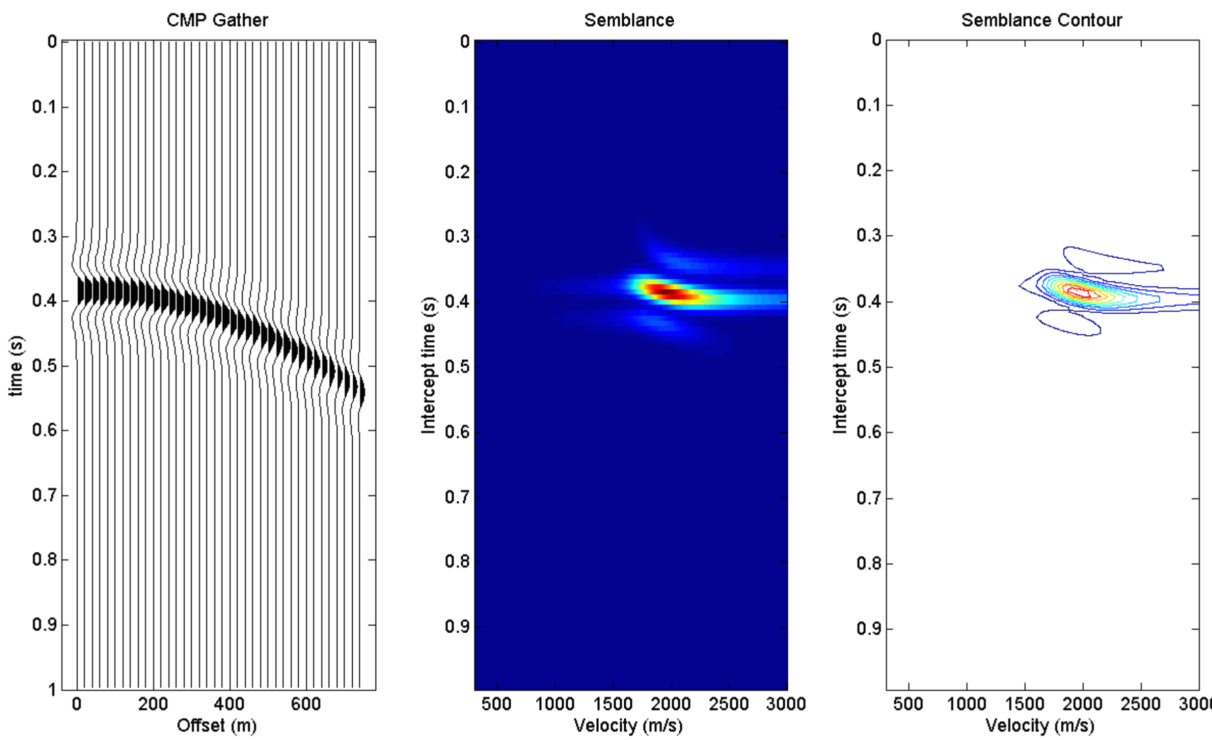

Figure 6: Semblance plots for the clean data

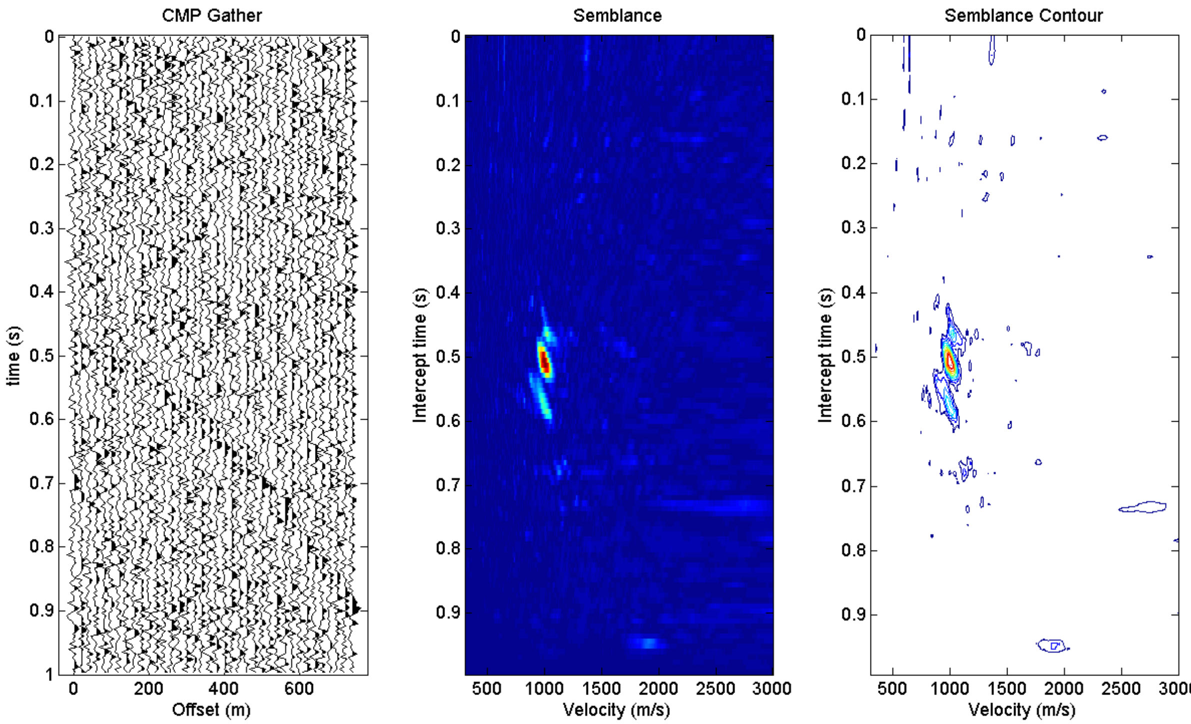

Figure 7: Semblance plots for the noisy data