Lab 5: Reflection Seismology I (35 points)
Simple models, Reflection coefficients, NMO, Dipping layers I

This lab will help you think critically about what seismic reflection data represents. You will be considering travel time curves and how they relate to the raypaths of reflected waves in a layered media.

Part I: Reflection coefficient, NMO for flat-layer model (Group)
Consider the diagram below, which shows a three-layered earth model. It does not extend very deep (25 meters) and the p-wave velocities and densities given are typical for unconsolidated sediments and sedimentary rocks very near the earth's surface. The star designates the point of a small dynamite blast. Geophones are shown as triangles, laid out every 10 meters. Investigate this structure by considering the following problems.
1. Reflection and Transmission Coefficients (4 pts)

The reflection coefficient shows what percent of the elastic energy incident on a reflecting surface will be reflected and the transmission coefficient shows what percent will be transmitted. From these coefficients, we can gain insight into the expected amplitudes of reflected waves and waves transmitted through the layer. The reflection coefficient is given by:

\[ C_R = \frac{(I_2 - I_1)}{(I_2 + I_1)} \]

where the subscripts denote the velocity model layers, 
\( I \) is the acoustic impedance and 
\( I = \rho V \), 
\( V \) is seismic velocity (here, the velocity of the p-wave or \( V_p \)) 
\( \rho \) is density

The transmission coefficient is similar, and is given by:

\[ C_T = \frac{(2I_1)}{(I_2 + I_1)} \]

Note that all energy which is incident on (i.e. comes in contact with) a layer must be either transmitted or reflected, therefore:

\[ C_R + C_T = 1 \]

Both of these formulas assume normal incidence of the incoming wave (or \( \theta = 90 \)).

a. First, calculate \( C_R \) and \( C_T \) for the boundary A between layers 1 and 2. Convince yourself that you have done the calculation correctly by checking that their sum = 1.

b. Next, calculate \( C_R \) for boundary B between layers 2 and 3. Is it smaller or larger than for boundary A? Take a moment to consider how this relates to the acoustic impedance contrast (\( I_1 \) compared to \( I_2 \)) for each layer.

c. Use the coefficients calculated in a and b above to figure out what percentage of energy originally sent out from the source gets reflected from boundary B. Hint: This energy must be transmitted across boundary A before it is reflected off layer B.
d. Use your results to explain how you think the amplitudes of reflected waves compare between i) boundaries that have different impedance contrasts and ii) boundaries that are deeper and shallower (e.g. why are deeper layers harder to see on a reflection profile?).

2. Normal Incidence Two-Way Travel Time, \( t_0 \) (4 pts)
A normally incident ray is one which has an incidence angle of 90° (vertical); energy travels directly down from the source and is reflected directly back to the surface. For a flat reflector, the minimum two-way travel time \( t_0 \) is observed at a geophone at the source (or \( X = 0 \)).

a. Compute \( t_0 \) for a reflection off of boundary A.

b. Compute \( t_0 \) for a reflection off of boundary B.

3. Normal Moveout (11 pts)
Now you will consider several ray paths that originate at the source, are reflected off of boundary A and are received at each of the five geophones shown on the diagram on page 1. You have already made a calculation of the travel time of the ray received at a geophone at the source.

a. On page 1, draw the ray paths for the reflected rays from boundary A received at each geophone, including the ray to a geophone at the source. Determine the length of each raypath and record it in the table below. Hint: Note the scale on the diagram if you want to avoid some trigonometry!

<table>
<thead>
<tr>
<th>Geophone</th>
<th>Raypath Length (m)</th>
<th>2-Way Travel Time (msec)</th>
<th>NMO (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<tr>
<td>1</td>
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</tbody>
</table>
b. Calculate the two-way travel time for each of the reflected rays drawn in a. Record this in the table above.

c. The difference between the two-way travel time for each reflected ray and $t_0$ is the normal moveout (NMO). Compute the normal moveout for each reflected ray drawn in a and record it in the table above.

d. Plot the two-way travel time curve for boundary A on the graph below.
Part II: Comparisons between flat and dipping layer NMO (Individual)
We have seen in detail how an NMO curve is constructed for a single, flat geologic boundary. In this part of the lab, you will use an Excel spreadsheet to investigate NMO curves for both flat and dipping layers. The spreadsheet Reflection.xls is located here: http://www.geo.arizona.edu/~andyf/Lab5/

1. Travel Time Curves and Horizontal Reflecting Interfaces (8 pts)
Using the Question 1 section of Reflection.xls, observe the changes in the two-way travel time curve as you change layer thickness and velocity of a single-layered model.

a. First vary the layer thickness, keeping the velocity at 1500 m/s. It is suggested that you start with a thin layer of 2 m and then progress to 5, 10, 15, and 20 m.

Describe what happens to the curve shape and the intercept ($t_0$) as you vary the thickness. Which layer thickness produces a curve that becomes a straight line closest to the source?

How does the change in shape and intercept of the NMO curve relate to the raypaths of the reflected rays within the layers (such as you drew in Part I)? *Hint:* It might help your thinking to draw a picture of some hypothetical raypaths through a very thin and a much thicker layer.

b. Now change the velocity values, leaving the thickness constant at 10 m. It is recommended that you start with a velocity of 1000 m/s and then progress to 1500, 2000, 3000, and finally 6000 m/s.

Describe the change in curve shape and $t_0$ with changing velocity.

Describe how NMO relates to the velocity of the layer through which the reflected rays travel.
2. Travel Time Curves and Dipping Interfaces (8 pts)
Using the Question 2 section of Reflection.xls, observe the changes in the two-way travel time curve as you change the dip of the reflecting layer. Note that this spreadsheet shows calculations for geophones on both sides of the source.

a. Making sure to keep the velocity constant (1500 m/s is a good value to use), describe what happens to the shape of the travel time curve as the dip of the reflecting layer is increased. It is recommended that you start at 0 and increase the dip at 5- or 10-degree increments. *Hint:* Pay attention to the apex of the curve.

b. Use the diagram below to think about how raypaths are reflected off a dipping layer. The key is that the angle of incidence \((\theta_i)\) is equal to the angle of reflection \((\theta_r)\) as illustrated in the raypaths drawn for you on the diagram. Attempt to sketch in the raypaths from the source to the other receivers, keeping these angles in mind. Avoid the temptation to whip out a calculator, simply use your intuition (or trial and error!) to draw in approximate raypaths.

c. What do you notice about the raypath from the source to geophone 2? Is it longer or shorter than the normal incidence raypath (to geophone 3)?

d. Use your observations in c to speculate as to why the apex of the curve changes the way it does in part a.

**BONUS (3 pts.)** Which direction (left or right) is the reflecting layer dipping in the spreadsheet? Explain your reasoning.