Geol 335.3

Lab #1 – Geometrical Seismics

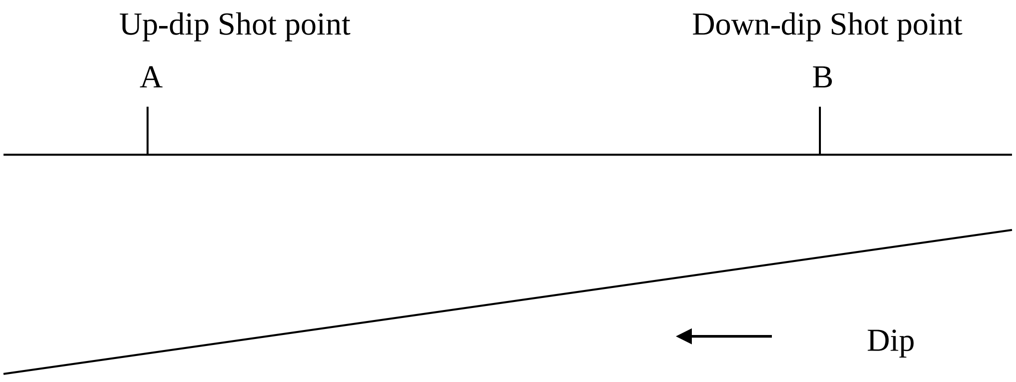
Part II: Inverse problem - Locating a Refracting Interface

If first-arrival travel-time data are available, the wavefront method can be used to determine the seismic velocities and the depths and position of refracting boundaries. This is about how you would interpret refraction seismic records that you collect in the field.

Consider the following first-arrival travel-time data given in terms of apparent velocities and crossover distances. Apparent velocities are simply the slopes of the travel-time curves on the (*distance*, *time*) plane: $\tan\left(angle\right)=\frac{\Delta t}{\Delta x}=\frac{1}{V}$, and from Part 1a, the crossover is the point after which the head waves become the first (earliest) arrivals. This parameterization is the easiest for graphing and calculation:

Up-dip Profile	Down-dip Profile
$V_1 = 1800$ m/s	$V_1 = 1800$ m/s
$V_{2u} = 3400$ m/s	$V_{2d} = 2700$ m/s
$X_{12u} = 820$ m	$X_{12d} = 210.6$ m

Here, X_{12u} and X_{12d} are the crossover distances from the up-dip and down-dip shot points, and $V_{2u,d}$ are the corresponding apparent velocities. For a dipping interface, the shot points are often referred to as follows:



Shot point spacing AB = 2300m.

Question 1: Before we proceed, how do we know from the travel-time profile data above that the interface is dipping to the left?

1) Using scale of 1 cm = 150 m = 0.1 s, **draw a plot of the travel-times**. Use 2500 m for the length of your horizontal axis and 1 s for the time axis. **Label** the shot points and crossover distances. On the time axes for each of the shots, **indicate and label** the intercept times. **Indicate and label** the reciprocal times.
2) Using the graphs, measure the intercept times for each of the two head waves. To do this, simply continue the head wave graphs back to the positions of the respective sources.
3) Using the same spatial scale, prepare **two copies** of (X, Z) plot area for your depth models.

You will use two complementary methods to identify the position of the refracting interface.

<u>Method 1: Using the contact surfaces</u>

The critical incidence angle α and the dip angle θ of the dipping refracting horizon can be found as follows:

Critical angle: $$\alpha = \frac{1}{2}\left(\sin^{-1}\frac{V_1}{V_{2d}} + \sin^{-1}\frac{V_1}{V_{2u}}\right),$$

Boundary dip angle: $$\theta = \frac{1}{2}\left(\sin^{-1}\frac{V_1}{V_{2d}} - \sin^{-1}\frac{V_1}{V_{2u}}\right).$$

To locate the refracting interface of a dipping bed, <u>the process used in Part 1a of this lab is reversed</u>:

4) Starting from crossover points located in step 1) and <u>moving backward</u> to the sources, **draw concentric direct-wave wavefronts** for the two shot points. Use some arbitrary constant spacing ΔS_1 between the wavefronts.
5) Also starting from the crossover points and moving backward, **draw the head wave fronts**. This is done by laying off an angle of $(\alpha - \theta)$ from the horizontal line through the up-dip crossover point distance. An angle of $(\alpha + \theta)$ is used for the down-dip

crossover point distance. Next, draw a set of lines with perpendicular spacings equal ΔS_1 and in parallel to these two initial lines.

Question 2: What are the spacings between the intersections of the head wave fronts with the surface? These spacings give the apparent velocities in the down-dip and up-dip directions.

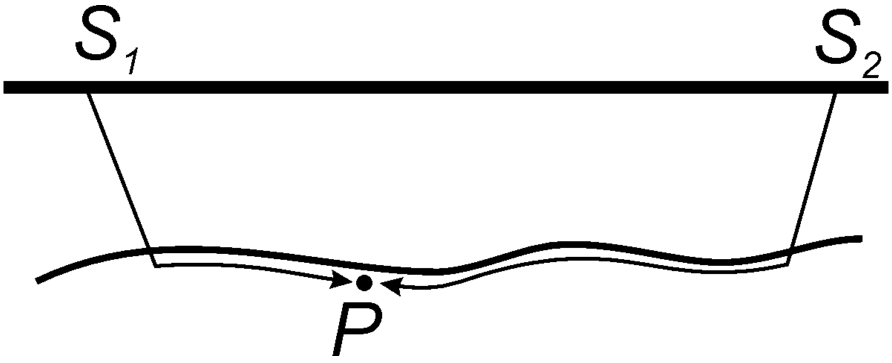
6) As in part I of this Lab, the points of the intersection of the corresponding head waves form an equal-time contact line. **Draw and label** them CS_1 and CS_2 for the first and second shot point, respectively.
7) **Draw the refracting surface** by joining the points of maximum depths on the up-dip and down-dip contact lines. You should see that these points will be located where the direct waves from the sources approach the refracting boundary at the critical angle α.

Method 2: Downward travel-time continuation

This method introduces the concept of "migration" in application to refractions. In seismic imaging, "migration" means moving the wave arrivals recorded in (receiver coordinate, time) coordinates into the (profile distance, depth) coordinates of the actual subsurface image. As a result of migration, the recorded data ((x,t) travel-time curves in this case) start looking as the desired geological section.

A nice feature of the downward-continuation method is in using the entire offset extents of the head waves. Also, it can be used to map the refracted *waveforms* onto the interface, thereby providing additional information about the detailed properties of the interface.

The method employs the fact that for any point (P in Figure below) on a refracting interface, with reversed coverage (i.e., covered by two shots in opposite directions) the sum of travel times to each of the two shots is constant:



$$t_{S_1 \to P} + t_{S_2 \to P} = t_{S_1 \to S_2} = t_{S_{21} \to S_1} = T\ ,$$

which is the reciprocal travel time corresponding to wave propagation from one source point to another. Note that this method works even for varying interface depth between the shot points. You will obtain not only positions of two points on the contact surfaces but also the complete shape of the interface between them.

To build the interface:

8) **Calculate the reciprocal times**, *T*, in both directions.

Question 4: Are these times equal?

Reciprocal times are the principal tool for quality control of refraction travel-time data. In field data, the reciprocal times would often be mismatch each other due to the differences in time picking, measurement errors, and also because the source and receiver positions are not exactly the same. If these mismatches are small, source times are slightly adjusted to make the reciprocal times equal. Large mismatches in reciprocal times indicate significant errors in experiment geometry, identification of arrivals, or travel-time picking.

9) Choose a time increment of approximately $\Delta t = T/20$.
10) **Build a system of head wave fronts** for shot S_1. Start with a wave front passing through S_2 and progress backward toward the source. The wave fronts will intersect the surface at intervals equal $V_{2u}\Delta t$, and the distance between the wave fronts will be $V_1\Delta t$.
11) On the resulting mesh of travel time fronts, **locate nodes** for which the combined time to both source points equals *T*. Connect these nodes. This is your refracting interface.

Hand in or submit by email:

1. Plots, including labels, as described above.
2. Write-up including all calculations and answers to all questions.