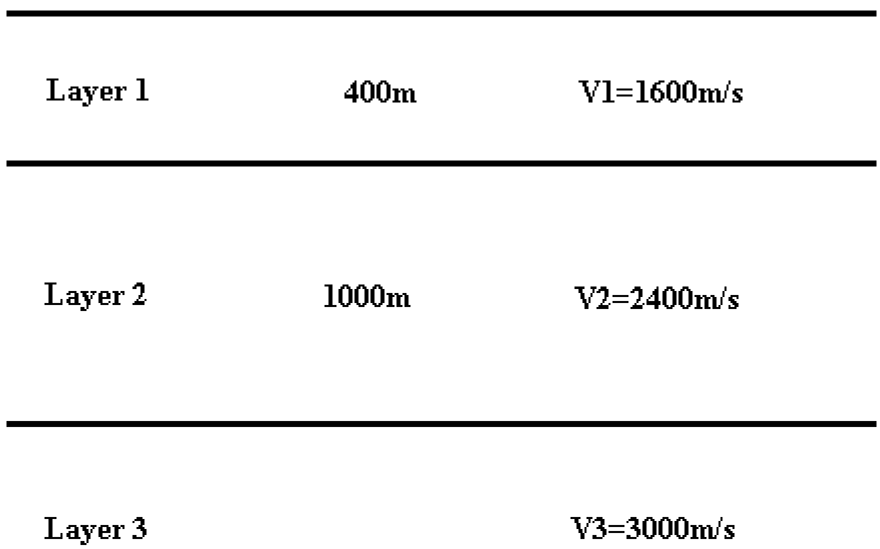
Geol 335.3

Lab #1 – Geometrical Seismics

Part 1: Wavefront Diagram

Wave front diagrams provide a unique method for visualizing both quantitatively and qualitatively, wave propagation underground when a charge of explosive is fired at or near to the surface. A wave front is defined as the surface passing through the most advanced position reached by a specific disturbance <u>at any given time</u>. Thus, each wavefront is characterized by a constant travel time. By drawing wavefronts at times increasing by a constant increment Δt, you will obtain a wavefront diagram showing at what time any point within the subsurface is reached by the wave.

Using the following geological section, you will construct a wavefront diagram <u>for the first arrival</u> passing from the source and through the subsurface. You will find that parts of the model can be reached by waves traveling through different layers. The first-arrival diagram means that only the earliest arriving wavefronts at any given point should be plotted.



The entire construction should be based on the <u>Huygens' principle</u> and the simple <u>rules of geometrical optics</u>. The Huygens' principle states that the wavefront at time $t + \Delta t$ can be constructed by propagating the wavefront at time t by distance $V\Delta t$, where V is the wave velocity.

Thus, the simple rules for drawing wavefronts are:

A. The spacings between any two adjacent wavefront are <u>constant everywhere within any given layer</u> n and equal $V_n\Delta t$. Thus, you simply need to draw sequences of equispaced lines within the layers.

B. Wavefronts are <u>continuous across any boundaries</u>.

C. <u>Rays are always orthogonal</u> to the wavefronts. In fact, this is the definition for rays.

D. Because of the rules A – C above, wavefronts and rays change directions at the interfaces (but remain continuous).

Make sure you enforce these rules in the following drawing, and the resulting diagram will automatically be correct.

Assignment:

1) Use scale of 1cm = 150m and **draw the layers as shown above**. Make sure your plot area covers at least 5000 m horizontally and 1600 m in depth.
2) Using the expressions at the end of this text, **calculate**: (a) values of ray parameters for the rays refracting critically <u>at each of the two interfaces</u>, (b) positions (X) and times (T) of the refraction points on these rays. Mark the times at the refraction points.
3) **Draw the two critical rays**, label them CRR_1 and CRR_2.

Assuming an isotropic medium, wave fronts in the first layer can be represented by spherical surfaces. The spacing of the wave fronts is chosen to be.
Δt = 0.05 s. Therefore, the spacing of the wave fronts in the first layer is $\Delta S_1 = V_1\Delta t$.
Note that in an isotropic medium, wave fronts are perpendicular to the ray paths.

4) In layer 1, plot circular wave fronts about the shot point, with spacing ΔS_1. Label the times on some of the wavefronts, in terms of Δt increments or ms.

   The spacing between successive wave fronts in the horizontal part of ray CRR_1 (traveling below the boundary) is now $\Delta S_2 .= V_2\Delta t$. **Mark these points on the interface**.

   The ray path may not intersect the interface at the same place as the wave front, and so make sure to determine the proportion of the Δt spent in each of the two layers. This can be done in two ways:

   a) by calculating the exact time of the ray to the refraction point using equation (5) at the end of this text;
   b) graphically, by measuring the portion of spacing ΔS_1 remaining from the last wavefront to the refraction point.

As the critically refracted waves propagate horizontally below interface, they generate waves traveling upward (and still away from the source) into the lower-velocity medium above. These waves are called <u>head waves</u>.

5) For time $T = 10\Delta t$, **build the head wave front** using the Huygens' principle. To do this, plot circular wave fronts about each of the points on the interface marked in Step 2. The radii will be increasing toward the source, with increments of ΔS_1.

   Note that the envelope of these circular wavefronts forms a planar wavefront propagating at the critical angle upward. This is the head wave front for time T. Is it orthogonal to the critically refracted ray CRR_1?

6) **Plot the rest of the head wave fronts**. They will be parallel to the one you have just built, with spacings of ΔS_1.

   The head wave fronts intersect the corresponding direct wave fronts at points of equal propagation time. Connect these intersection points to give a contact surface of equal propagation time. Label this surface CS_1. The point where this contact surface reaches the surface gives the **crossover distance.** Label the crossover distance CD_1.

Wave fronts are circular only in the first layer. The change of velocity of the disturbance, in passing through the boundary, distorts the wave front.

7) Use the Huygens' principle to **draw these non-circular fronts** within the second layer. To do this, for each value of $T = n\Delta t$ (use only *even* values of n, to make the plot not so busy), draw circular arcs within Layer 2 about each of the timed points on the first interface. Again, the radii should increase by ΔS_2 as you move toward the source, so that the total time equals T. An envelope of these arcs will be the wavefront at time T.

   Note that as the distance from the source increases, the shape of the wave fronts becomes less curved.

8) As in Steps 2-3, **draw the wave fronts of head waves** resulting from the critical refraction along the second interface. They are similar to those for the first interface, except that their spacing along the interface equal $\Delta S_3 = V_3\Delta t$., and the dip corresponds to the critical angle in layer 2 (see formulae below).

9) The intersections between these head waves and the downgoing wave fronts in the second layer form a contact surface of equal time propagation, as for the first layer. Draw the surface and label it CS_2.

10) The head waves from the second interface are further refracted into the upper layer. **Draw these refracted head wave fronts**. They will be planes with spacing $\Delta S_1 = V_1\Delta t$, dipping at constant angle (see expressions below) and propagating upward.

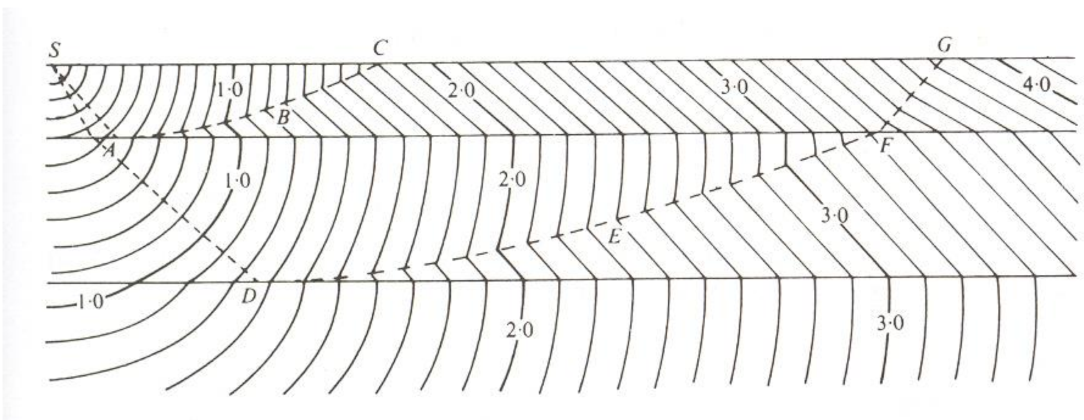
11) **Connect the intersection points** between these newly refracted head waves and the head waves from the first interface. This is a continuation of the equal-time contact curve of the second layer; label it CS_2. The crossover distance occurs when this contact curve reaches the surface. Label this point CD_2.

Question 1: In general, can distance CD_2 be smaller than CD_1? What would happen in such a case?

Question 2: What is the spacing between the refracted head wave fronts in Layer 1? Why?

12) Using the same horizontal scale, **draw another plot with a first-arrival travel-time curve**. Label the segments corresponding to the <u>direct wave</u> and the two <u>head waves</u>. Mark on the *X* axis the critical distances and crossover distances.

Your final plot should look similar to this (labeling may be different):



Question 3: Using this plot, if seismographs are located at 1200 m, 3000 m, and 6000 m from the shot point, indicate which wave (direct, first or second head wave) will arrive first at each of these locations.

Question 4: Calculate the ratio of the minimum required offset range (CD_2) to the depth of the second refracting boundary. Can you guess how this ratio would change if the velocity contrasts are reduced?

Useful expressions

Rays are characterized by *ray parameters*, *p*, measured in the units of *slowness*, [s/m]. Ray parameter is constant along the ray and is related to the angle of incidence i_k and velocity V_k in each layer:

$$p = \frac{\sin i_k}{V_k}. \qquad (1)$$

For a ray that is critical at the bottom of *k*-th layer (that is, $\sin i_{k+1}=1$), its ray parameter is

$$p_k^{critical} = \frac{1}{V_{k+1}} . \tag{2}$$

For a given p, the incidence angle of the ray in k-th layer is given by

$$\sin i_k = pV_k , \tag{3}$$

its raypath length through the layer (h_k is the thickness):

$$l_k = \frac{h_k}{\cos i_k} = \frac{h_k}{\sqrt{1-(pV_k)^2}} , \tag{4}$$

and its travel time is accordingly:

$$t_k = \frac{l_k}{V_k} = \frac{h_k}{V_k\sqrt{1-(pV_k)^2}} . \tag{5}$$

The horizontal distance to which the ray travels as it crosses the layer is:

$$x_k = l_k \sin i_k = \frac{h_k(pV_k)}{\sqrt{1-(pV_k)^2}} . \tag{6}$$

For multiple layers, one only has to sum the times and distances in order to get the position of the ray bottoming in the n-th layer:

$$T_n = \sum_{k=1}^{n} t_k , \tag{7}$$

$$X_n = \sum_{k=1}^{n} x_k . \tag{8}$$

For $p = p^{\text{critical}}$, the last two formulas give *half* of the critical time and distance, respectively.

Hand in, in a binder, or in a Word or PDF file by email:

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