Earth 202 Problem Set 3

Due Tuesday January 29, 2008

1. (5 points) Earthquake Location and Magnitude

In this problem, you locate an earthquake using S-P times and determine its magnitude, using an interactive program on the WWW. Go to:

--> http://www.sciencecourseware.org/eec/Earthquake

and do the project *Travel Time* and *Epicenter and Magnitude*. Be sure to read the text at each step. You may need to go through the *Background* section for more information on the projects. This area contains a thorough description of the exercise and will help you complete it correctly.

When you have completed a project, click on *Verify Results* in the lower corner of the *Journal* tab. This willt ake your to screen which will ask for your name, institution, institution location, and course code The course code for Winter 2008 is 1115745. When you have filled this out it will confirm that you have the correct class code (Instructor: Laura Swafford, Course: Earth 202 Earths Interior, Institution: Northwestern University). *Make sure that use the course code in order to receive credit for this exercise*. This will take you to a 5 question quiz, testing what you have learned from reading and performing the exercise. You do not need to turn anything in, the results willl be emailed to me by the site.

DO NOT wait until the last minute to complete this exercise. Several people did this last year and were unable to complete it. This is your warning, failure to have it complete by the due date will results in no points for this portion.

There are a number of other interesting links under this topic, which you are encouraged to explore.

2. (6 points) You have seismograms from different earthquakes very near each other, and observed (measured) at different places along a line as shown. You know the distance from the earthquake and the origin time of each earthquake. Use the direct (P_g) and the refracted (P_n) arrivals to find the velocities of the crust and mantle in this area. (You may assume that both earthquakes occurred at the earth's surface).

Station A:

$$X = 280km$$

$$traveltime = arrivaltime - origintime$$

$$T_{pg} = ((42 * 60)s + 7s) - ((41 * 60)s + 15.6s) = 2527.5s - 2475.6s = 51.9s$$

$$T_{pn} = ((42 * 60)s + 2s) - 2475.6s = 46.4s$$

Station B:

$$X = 456km$$

$$T_{pg} = ((22 * 60)s + 2s) - ((20 * 60)s + 35.4s) = 1322s - 1235.4s = 86.6s$$

$$T_{pn} = ((22 * 60)s - 20s) - ((20 * 60)s + 35.4s) = 1300s - 1235.4s = 64.6s$$

There are two methods to calculate the velocity of the crust and mantle in this area. The first method is a mathetical approach using the travel time equations for the direct wave and the rafcted wave. The travel time equation for the direct wave is:

$$T_{direct} = \frac{X}{V_o}$$

where X is the distance from the earthquake to the station, V_0 is the velocity of the crust, and T_{direct} is the time the direct wave arrives. The problem gives T_{direct} and X. Thus V_0 is 5.40 km/s for Station A and 5.27 km/s for Station B, which averages to 5.30 km/s. The travel time equation for the refracted wave is:

$$T_{refract} = \frac{X}{V_1} + \frac{2h\left(V_1^2 - V_0^2\right)^{1/2}}{V_1 V_0}$$

where $T_{refract}$ is the time the refracted wave arrives, X is the distance, V_1 is the velocity of the mantle, h is the thickness of the crust, and V_0 is the velocity of the crust. $T_{refract}$ and X are given. V_0 was calculated to be 5.34 km/s. There are two unknowns: V_1 and h. The equation for the arrive time of the refracted wave can be written for each station.

$$T_A = \frac{X_A}{V_1} + \frac{2h\left(V_1^2 - V_0^2\right)^{1/2}}{V_1 V_0}$$

$$T_B = \frac{X_B}{V_1} + \frac{2h\left(V_1^2 - V_0^2\right)^{1/2}}{V_1 V_0}$$

The two previous equations can be rewritten so they solve for the thickness of the crust (h).

$$h = \frac{V_1 V_0 T_A - V_0 X_A}{2\left(V_1^2 - V_0^2\right)^{1/2}}$$

$$h = \frac{V_1 V_0 T_B - V_0 X_B}{2\left(V_1^2 - V_0^2\right)^{1/2}}$$

The two equations can be combined to create one equation.

$$\frac{V_1 V_0 T_A - V_0 X_A}{2\left(V_1^2 - V_0^2\right)^{1/2}} = \frac{V_1 V_0 T_B - V_0 X_B}{2\left(V_1^2 - V_0^2\right)^{1/2}}$$

The variables in the above equation can be rearranged to solve for V_1.

$$V_1 = \frac{X_B - X_A}{T_B - T_A} = \frac{456\text{km} - 280\text{km}}{64.6\text{s} - 46.4\text{s}} = 9.67\text{km/s}$$

The second method is to graph the distances and arrival times with the distance on the x-axis and time on the y-axis. The velocity of the crust and the velocity of the mantle can be found using the slopes of the direct wave and refracted wave, respecitively.

$$\text{slopeofP}_g = \frac{86.6\text{s} - 51.9\text{s}}{456\text{km} - 280\text{km}} = \frac{1}{V_0}$$

$$V_0 = \frac{456\text{km} - 280\text{km}}{86.6\text{s} - 51.9\text{s}} = 5.07\text{km/s}$$

Using the plotting method to calculate V_0, we find that the velocity is only about 5% different from the mathematical approach.

$$\text{slopeofP}_n = \frac{64.6\text{s} - 46.4\text{s}}{456\text{km} - 280\text{km}} = \frac{1}{V_1}$$

$$V_1 = \frac{456\text{km} - 280\text{km}}{64.6\text{s} - 46.4\text{s}} = 9.67\text{km/s}$$

Both methods produce the same mantle velocity.

3. (3 points) Calculate the pressure at the bottom of 3 km high columns of each of the following;

$$\text{Pressure} = \rho * g * h$$

$$\text{Given: } g = 980\text{cm/s}^2;\ h = 3\text{x}10^5\text{cm}$$

a) ice ($\rho = 1$ g/cm^3).

$$P = 1\text{g/cm}^3\text{x}980\text{cm/s}^2\text{x}3\text{x}10^5\text{cm} = 2.94\text{x}10^8\text{dynes/cm}^2 = 2.94\text{x}10^7\text{Pa}$$

b) sediment ($\rho = 2.1$ g/cm^3).

$$P = 2.1\text{g/cm}^3\text{x}980\text{cm/s}^2\text{x}3\text{x}10^5\text{cm} = 6.174\text{x}10^8\text{dynes/cm}^2 = 6.174\text{x}10^7\text{Pa}$$

c) granite ($\rho = 2.6$ g/cm^3).

$$P = 2.6\text{g/cm}^3\text{x}980\text{cm/s}^2\text{x}3\text{x}10^5\text{cm} = 7.64\text{x}10^8\text{dynes/cm}^2 = 7.64\text{x}10^7\text{Pa}$$

4. (2 points) The diagram below shows a phase diagram for diamond and graphite, and the geothermal gradient - the distribution of pressure and temperature in the earth. Given that diamonds, which are found at the surface were formed at a depth in the mantle where diamond is stable, what is the **minimum** depth the diamonds could have come from?

To find the minimum depth that a diamond could come from, use the equation:

$$P = \rho * g * h$$

where P is pressure, ρ is density, g is gravity, and h is depth. Rearrange the equation to solve for depth.

$$h = \frac{P}{\rho g}$$

The pressure is found using the figure, and the minimum pressure is $3.8\text{x}10^{10}$dyne/cm^2. Gravity is 980 g/cm^3. Assuming the density is 5 g/cm^3, the depth is:

$$h = \frac{3.8\text{x}10^{10}\text{dyne/cm}^2}{5\text{g/cm}^3\text{x}980\text{cm/s}^2} = 7.8\text{x}10^6\text{cm} = 78\text{km}$$

Assuming the density is 3 g/cm^3, the depth is:

$$h = \frac{3.8\text{x}10^{10}\text{dyne/cm}^2}{3\text{g/cm}^3\text{x}980\text{cm/s}^2} = 1.3\text{x}10^7\text{cm} = 130\text{km}$$

5. (2 points) Mountain hikers find that at high altitudes, e.g. 14,000 ft, water boils at a temperature quite different from at sea level. This is because, as shown in the diagram below, atmospheric pressure decreases from 1 bar at sea level to less than 0.6 bars at 14,000 ft. Using the phase diagram for water, decide if boiling occurs at higher or lower temperatures at higher altitudes.

As you increase altitude to 14,000 ft, the pressure decrease from 1 bar to 0.6 bar. At 1 bar, water boils at 100^{o}C. At 0.6 bar, water boils at 70^{o}C. Thus at higher alitudes, the water boils at lower temperatures.

6. (2 points) On earth, the polar caps are made of ice (solid H_2O), while at Mars they are made, at least partially, of solid carbon dioxide (CO_2). Explain why solid CO_2 can form on Mars but not on earth using the phase diagram shown and the fact that on Mars the atmospheric pressure is 0.006 bars and temperatures in the atmosphere are well below -100°C.

The pressure and temperature conditions on the surface of mars cause the carbon dioxide to be stable as a solid. However, at the surface pressures on earth, the temperature does not decrease enough for solid carbon dioxide to be stable.

7. (3 points) The attached seismograph (next page) is from the Loma Prieta earthquake in California (17 October 1989), recorded at a station 80° distant from the epicenter. Label the phase-arrivals marked by arrows. (Hint: You will need the Jeffrey-Bullen arrival time table which is in your course readings booklet).

Calculate the travel time for each wave. On the Travel Time figure, use the travel time and the distance 80 degrees to identify the wave that the arrow is pointing to. Here are the arrival times and the waves for each arrow. Some of the waves arrive very close together in time so some arrows have more than one wave listed.

Arrow 1. Travel Time = 12.1 minutes; Wave = P, Pdiff, PcP

Arrow 2. Travel Time = 15.0 minutes; Wave = PP

Arrow 3. Travel Time = 22.7 minutes; Wave = S, Sdiff, SCS, SKS, SP

Arrow 4. Travel Time = 27.9 minutes; Wave = SS

Arrow 5. Travel Time = 32.3 minutes; Wave = PKKP, SKKP, SSSS

Arrow 6. Travel Time = 38.7 minutes; Wave = SKKS, P’P’, PKPPKP