Assignments

Due: October 10, 2014

1. What is the isotropic material in seismology? Why is the isotropic assumption mostly valid in seismology? What kind of research in seismology forces us to consider other assumptions instead of the isotropic one?

2. Derive the isotropic wave equation (equation 1.22) from equations 1.8, 1.11, and 1.21. Also, explain what assumptions is the isotropic wave equation applied (e.g., material, dimension, elastic moduli)?

3. Give an example of a strain tensor for which there is 1) an increase in volume, b) a decrease in volume, c) shear strain but no volume change. Which of these strains could result from a P wave, and which could result from an S wave?

4. Figure I.4 is an observed waveforms of the Northridge earthquakes on January 17, 1994. When we assume that the incoming waves are $\mathbf{u} = (0, 0, A\sin(\omega(t - x/c)))$ (where A is the amplitude, ω the angular frequency, c the wave velocity), compute the maximum strain tensor given by the Northridge earthquake at the observation point. We know the wave velocity is $3.2 km/s$ from other data.

5. Figure I.5 shows a profile of a borehole. Draw the shear and bulk moduli in the entire borehole (0–100 m). You can use the densities (kg/m^3) following: granite 2.6, clay 1.6, sand 2.4, and quartz 2.65.

bonus

Show that we can reduce the components of the elastic moduli from 21 (general anisotropic) to 2 (isotropic) with isotropic assumptions.

no point

I (Nori) need some feedback from you. Write down to tell me about your opinion for the class. What are good and what are needing to be improved? What can I do in this class to better help you understand the material or improve your skills? What do you want to learn more? How about the speed of the class? My English?

(If you mind to put your name on this question, you can write down it on a scratch paper without your name and hand it to Clara. Then she can give me it as an anonymous.)

Figure 1.4: Vertical displacement of the Northridge earthquake (Jan 17, 1994). The frequency range is 0.5–1.5 Hz.
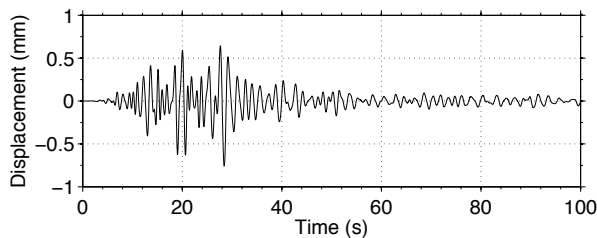
Figure 1.5: Borehole profile estimated from logging data (in Osaka, Japan).

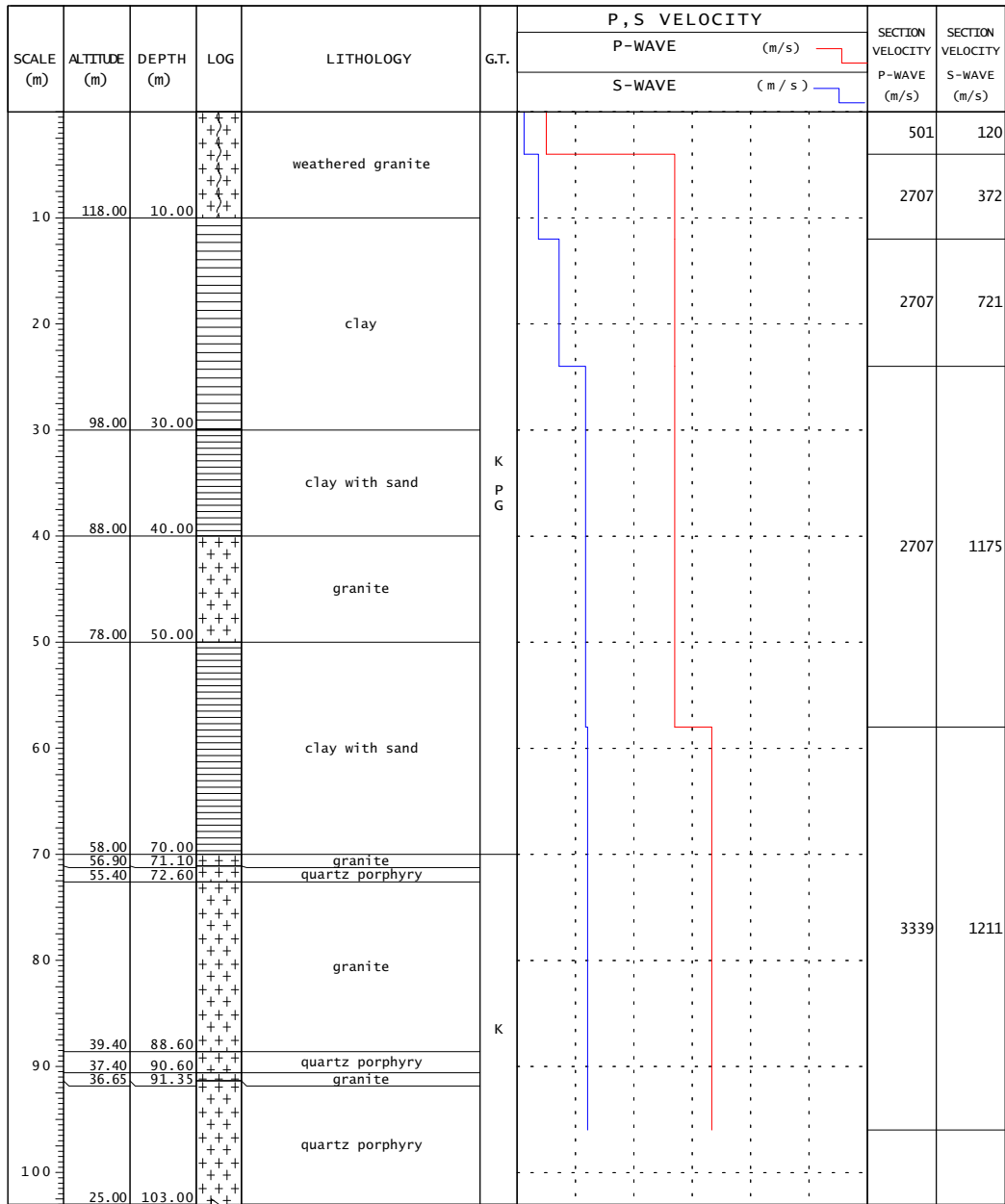# Soil &Rock Condition

Station Point: TAISHI

Location : OSAKAFU MINAMIKAWACHIGUN TAISHICHO YAMADA 1221

Latitude : 34 deg 31 ' 17.0 "

Altitude : +128m

Station Code: OSKH03

Longitude : 135 deg 39 ' 47.0 "

Depth : 103.00m

SCALE (m)	ALTITUDE (m)	DEPTH (m)	LOG	LITHOLOGY	G.T.	P,S VELOCITY	SECTION VELOCITY P-WAVE (m/s)	SECTION VELOCITY S-WAVE (m/s)
				weathered granite			501	120
10	118.00	10.00					2707	372
20				clay			2707	721
30	98.00	30.00		clay with sand	K P G			
40	88.00	40.00		granite			2707	1175
50	78.00	50.00						
60				clay with sand				
70	58.00	70.00						
	56.90	71.10		granite				
	55.40	72.60		quartz porphyry			3339	1211
80				granite				
	39.40	88.60			K			
90	37.40	90.60		quartz porphyry				
	36.65	91.35		granite				
100				quartz porphyry				
	25.00	103.00						

P-WAVE (m/s)

S-WAVE (m/s)

Assignment 1 (addition)

Due: October 10, 2014

For simplicity, let us consider a 2D case. When a stress tensor is given by

$$\underline{\sigma} = \left(\begin{array}{cc} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{array} \right) = \left(\begin{array}{cc} -30 & -12 \\ -12 & -50 \end{array} \right) MPa,$$

and there is a fault oriented at 30° clockwise from x_1 axis, answer problems below.

1. compute the deviatoric stress of the given stress.

2. compute the normal and shear tractions on the fault.

3. explain why the normal and shear tractions on the fault is important for studies of earthquake.

Assignment 2

Due: October 23, 2014

I. For a 3D isotropic medium, a wave equation can be given as

$$
\rho \begin{pmatrix} \frac{\partial^2 u}{\partial t^2} \\ \frac{\partial^2 v}{\partial t^2} \\ \frac{\partial^2 w}{\partial t^2} \end{pmatrix} = (\lambda + 2\mu) \begin{pmatrix} \frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \\ \frac{\partial}{\partial y}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \\ \frac{\partial}{\partial z}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \end{pmatrix} - \mu \begin{pmatrix} \frac{\partial}{\partial y}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) - \frac{\partial}{\partial z}\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \right) \\ \frac{\partial}{\partial z}\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \right) - \frac{\partial}{\partial x}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) \\ \frac{\partial}{\partial x}\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \right) - \frac{\partial}{\partial y}\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \right) \end{pmatrix}. \tag{1}
$$

Solve problems below.

1) Start from equation 1 and show a wave equation which is for P-SV waves.

2) For the wave equation in problem 1), we can write a plane-wave solution in medium 1 in Figure 1 as

$$
u = \epsilon e^{-i\omega(t - px - \gamma z)}, \quad w = e^{-i\omega(t - px - \gamma z)}, \tag{2}
$$

where $p = \sin\theta_1/\alpha_1$. Find ϵ and γ for P and SV waves.

3) Let us consider reflection and transmission at the free surface (medium 2 is air and the boundary is the free surface, called *halfspace*). Use the solutions in problem 2), and show the reflection and transmission coefficients at the free surface are given by

$$
\begin{pmatrix} \acute{P}\grave{P} & \acute{S}\grave{P} \\ \acute{P}\grave{S} & \acute{S}\grave{S} \end{pmatrix} = \begin{pmatrix} \dfrac{-(\eta_1^2 - p^2)^2 + 4p^2\xi_1\eta_1}{(\eta_1^2 - p^2)^2 + 4p^2\xi_1\eta_1} & \dfrac{\beta_1}{\alpha_1}\dfrac{4p\eta_1(\eta_1^2 - p^2)}{(\eta_1^2 - p^2)^2 + 4p^2\xi_1\eta_1} \\ \dfrac{\alpha_1}{\beta_1}\dfrac{4p\xi_1(\eta_1^2 - p^2)}{(\eta_1^2 - p^2)^2 + 4p^2\xi_1\eta_1} & \dfrac{(\eta_1^2 - p^2)^2 - 4p^2\xi_1\eta_1}{(\eta_1^2 - p^2)^2 + 4p^2\xi_1\eta_1} \end{pmatrix}, \tag{3}
$$

where the P and S indicate P and SV waves, respectively, and accents on top of them show the direction of waves (e.g., $\acute{P}$ is upgoing P waves). Vertical slownesses are given by $\xi_1 = \cos\theta_1/\alpha_1$ and $\eta_1 = \cos\phi_1/\beta_1$.

4) To solve the reflection coefficients at the boundary in Figure 1 when medium 2 is also an elastic material, describe the boundary condition we need to consider.

5) Back to the problem in halfspace (medium 2 is air and the boundary is the free surface). Different from Love waves, Rayleigh waves can exist in medium 1 (note that for Love waves, we need a layer with thickness H). For the solution of Rayleigh waves, what are the conditions for the vertical slownesses (ξ_1 and η_1) (*hint* do surface waves propagate vertically?)?

6) Why do not Love waves exist in a half-space (no layer)?

II. You have an earthquake record observed at 103 m below the free surface in a horizontal component (Figure 2). When you assume the incident angle of the wave is almost vertical, the waves are dominated by S waves. The borehole profile is given by logging data (Figure 3). Make a reasonable two-layer velocity model from the borehole profile and estimate the maximum amplitude at the surface given by this earthquake. Note that because of the slower layer near the surface, some amplification occurs, and let us assume the medium has no intrinsic attenuation (*hint* you can find the peak frequency from the right panel of Figure 2 and maximum amplitude from the left panel.)
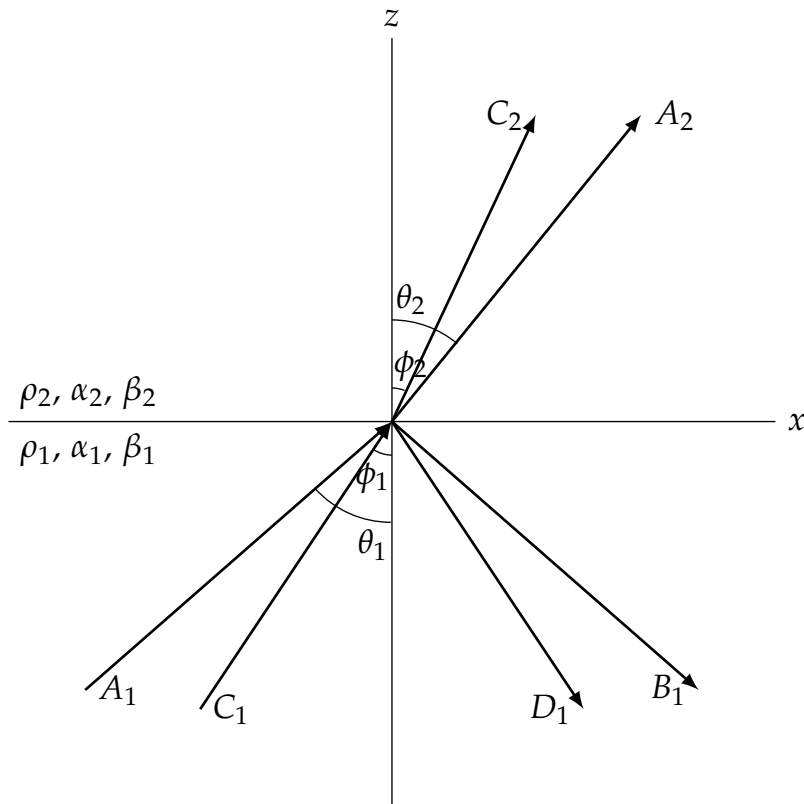
Figure 1: Geometry of reflection and transmission for P-SV waves. A_i, B_i, C_i, and D_i are the amplitude of upgoing P, downgoing P, upgoing SV, and downgoing SV waves in medium i. Waves with amplitudes A_1 and C_1 are incoming waves.
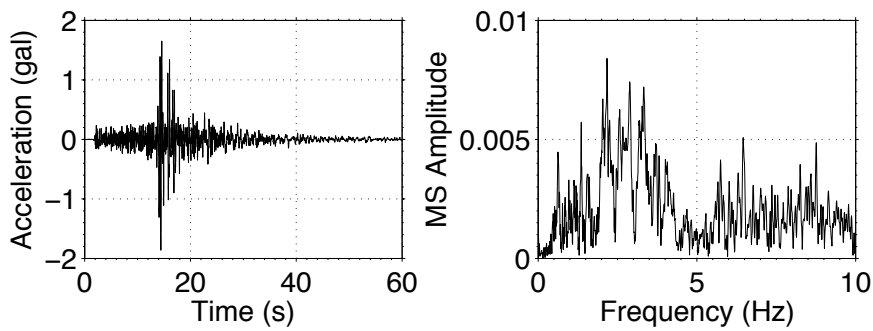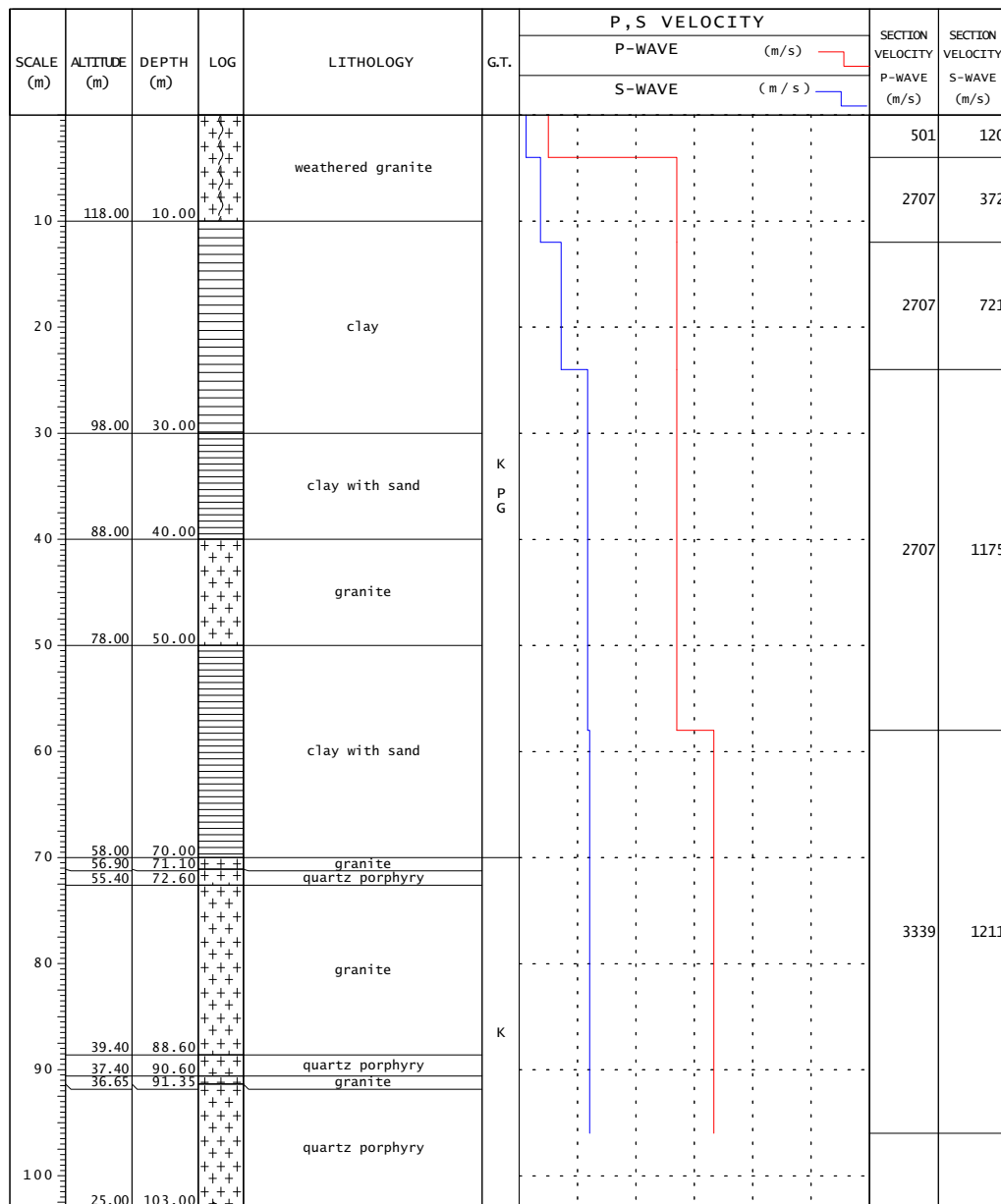

Figure 2: Earthquake record at 103-m depth (left panel is time series and right is the mean-square power spectra of the waveforms).

Figure 3: Borehole profile estimated from logging data (in Osaka, Japan).

Soil & Rock Condition

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Geophysics 130 Homework – Signal Processing

You have been provided with one hour of continuous waveform data, vertical component, recorded near the Calaveras Fault in California, southeast of San Jose. The seismogram includes several earthquakes between magnitude 0 and 4.1. The sampling rate is fs = 20 Hz (samples per second).

Please use MATLAB to do this homework, and turn in your MATLAB code with your answers.

1. Read in the seismogram data into MATLAB, using the `fget_sac.m` script:

```
[t,x,SAChdr] =
fget_sac('2011.008.00.00.00.deci5.1hr.NC.CCOB.EHZ.D.SAC');
```

The input is the name of the file containing the data. It is in SAC format, which is widely used by seismologists. There are 3 outputs. "t" contains the time (in seconds) for each data sample. "x" contains the seismogram amplitude (don't worry about units). "SAChdr" has other information associated with the data, which you don't need for now.

Make a plot of the seismogram amplitude as a function of time. The time axis should range from 0 to 3600 seconds, and the amplitude axis should range from -500 to 500. Label the axes and give the plot a title. Submit your plot and your MATLAB code. (Hint: use `xlim` and `ylim` to set the axis limits.)

2. What is the sampling time interval (Δt) in seconds? (You can use either the sampling rate fs, or look at the contents of the "t" array.)

3. To avoid aliasing, an anti-aliasing filter was applied to this data. What is the highest frequency (Nyquist) of the seismogram data? (Hint: you know the sampling rate fs.)

4. You will look at the frequency content of the seismogram data. Compute the Fourier transform of the seismogram amplitudes, using the MATLAB function `fft`. Then compute the amplitude spectrum (magnitude of the Fourier transform).

In this step, you will plot the amplitude spectrum as a function of frequency. You will only plot the amplitude spectrum at the positive frequencies (since the seismogram signal is real, the Fourier transform at the negative frequencies is symmetric).

First, set up the frequency spacing: $\Delta f = 1/T$, where T = length of data (seconds) = 3600 s (= 1 hour).

Next, set up an array with frequency values (in Hz), call it "freq". The original time (and seismogram amplitude) arrays have N = 72001 elements, so this frequency array should have fix(N/2)+1 = 36001 elements. The first element of freq should be 0, the last element of freq should equal your answer to Problem #3, and the difference between adjacent

elements should be Δf.

Now you are ready to plot the amplitude spectrum as a function of frequency. Plot it on a log-log scale (use the MATLAB function `loglog`). The frequency axis should range from 10^-3 to 10^1 Hz, and the amplitude spectrum axis should range from 10^-2 to 10^6. Label the axes and give the plot a title. Submit your plot and your MATLAB code.

5. Repeat Problem #1 and #4, but this time using the seismogram data that has been bandpass filtered 2-8 Hz:

```
[t,x,SAChdr] =
fget_sac('2011.008.00.00.00.deci5.1hr.NC.CCOB.EHZ.D.SAC.bp2to8');
```

You should only need to change the filename to use the version that is bandpass filtered. You don't need to make any other changes to your code.

a) Submit your plot of the seismogram amplitude as a function of time, and the amplitude spectrum as a function of frequency, for the bandpass filtered data.

(Hint: you can look at slides 45 and 46 of the "Seismograms as Signals" lecture to make sure you have the correct plots for this homework.)

b) What is the effect of the bandpass filter on the seismogram amplitude in the time domain?

c) What is the effect of the bandpass filter on the amplitude spectrum in the frequency domain?

d) What is one possible reason why you might want to apply a bandpass filter?

e) You have two other components (EHN: north horizontal, EHE: east horizontal). What can you do with three components?

f) Interpret the waveforms of the main (largest) earthquake. (hint: amplitude and/or frequency changes over the time, P or S waves, etc)

g) What else can you find from waves? (you can answer whatever you find.)

Assignment 4

Due: December 2, 2014

I. Explain how anisotropy leads to splitting of shear waves?

II. Explain why Fermat's principle is important for conventional refraction seismology? (the conventional refraction seismology means what you learned in the class.)

III. Figure 1 shows travel times of direct and refracted waves. The model contains two horizontal layers on top of the half space. Answer the questions below.

    1) Estimate the layer thicknesses of the first and second layers.

    2) Estimate the velocities of each layer (first and second layers, and half space).

    3) Compute the travel times of reflected waves from the second layer and the half space. (*hint*: you can use the rms velocity for the reflected waves from the half space. Also, you do not need to consider multiples.)

IV. Assume that a 24-fold seismic survey records data sampled every 40 milliseconds, and that each trace is 10 s long. For a source spacing of 25 m, how many data points are recorded in a 100 km-long 2D survey? (problem 11 on p.213)

V. Explain what the migration is for reflection seismology. Why is it important?

VI. When a large earthquake occurs at California, can people at California observe 1) direct P waves, 2) PP, 3) PcP, 4) ScS, 5) SKS, 6) $SKiKS$, 7)$P'P'$?
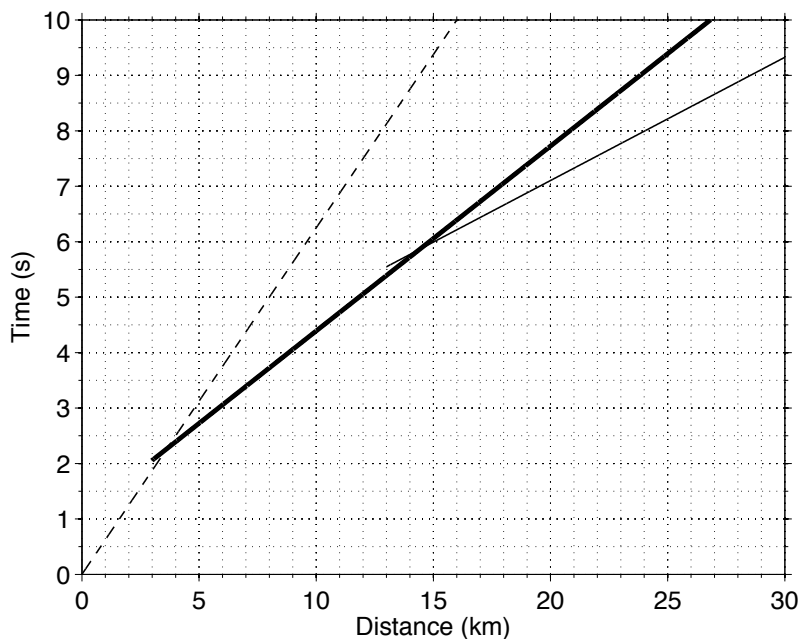

Figure 1: Travel times of direct and head waves obtained from the two-layer model.

Assignment 5

Due: December 2, 2014

I. Explain why we sometimes need to use Moment tensors instead of using strike, dip and rake to characterize earthquakes?

II. Explain what is CLVD and what kinds of fractures cause CLVD.

III. Characterize earthquakes shown in Figure 1. (*hint*: what kind of faulting, is the dip shallow or steep, is the mechanism deviatoric, what is the horizontal direction of faulting, etc?)

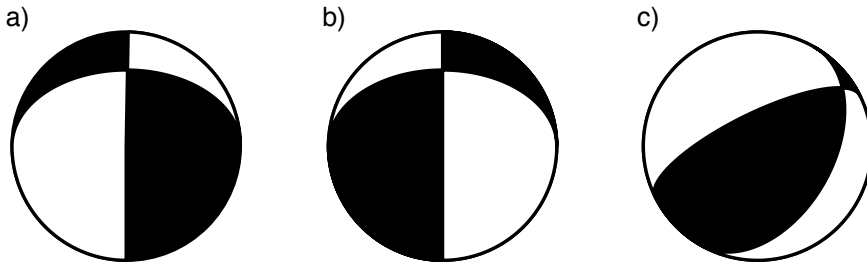**IV.** Characterize earthquakes shown in Figure 2.

Figure 1: Focal mechanisms. Angles of strike, dip and rake are a) $[270°, 30°, 0°]$, b) $[0°, 90°, 60°]$, and c) $[30°, 30°, 60°]$.

Figure 2: Focal mechanisms. (http://earthquake.usgs.gov/earthquakes)