Homework II Seismological Topics

1. The relationship between energy released, E, and earthquake magnitude, M, is given by the empirical relationship:

$$\log_{10}E = 5.24 + 1.44\,M$$

where E is measured in units of joules (1kg m^2 s^{-2}).

a. Why is this equation different from the one given in class?

b. Calculate the amount by which the seismic energy released by an earthquake increases when the magnitude increases by one unit. (i.e. how many times larger is a magnitude 8 earthquake than a magnitude 7 earthquake?)

c. The daily electrical consumption of the U.S. in 2000 was about 27.6 x 10^{12} kilowatt hours. If this energy were released by an earthquake, what would its magnitude be? (1 watt = 1 joule/sec)

d. It is sometimes suggested that small earthquakes can act as a safety valve by releasing energy in small amounts and so averting a damaging large earthquake. Assuming that an area (like California) can statistically expect a magnitude 8 earthquake once every 100 years, calculate how many small earthquakes with (i) M = 6, (ii) M=5, and (iii) M=4 would be required to release the same amount of energy. If it were possible to trigger these smaller earthquakes, would it help?

2. Figure 1 is a seismogram recorded at Berkeley, California of an earthquake that occurred near Borneo at a distance of 11,000 km from Berkeley. This corresponds to an epicentral angle, Δ, of 102^{o}32'45". Several unidentified earthquake onsets (UEOs) are indicated on the seismogram, among them are the following, not necessarily in order:

SKS an S wave that traveled through the mantle, through the outer core as a P wave and through the mantle again as an S wave

PP a P wave reflected once from the underside of the earth's surface.

SS an S wave reflected once from the underside of the earth's surface.

SSS (Should be obvious from above)

PS a P wave reflected from the underside of the earth's surface as an S wave.

PPS a P wave reflected once from the underside of the earth's surface as a P wave and then reflected again as an S wave.

S a Single S wave (no reflections)

P a single P wave (no reflections)

Other arrivals are possible, but are not recorded on this seismogram.

Using the travel time curves of figures 2 or 3, identify each of the UEOs indicated on the seismogram of figure 1.

3. In the table below the azimuth, A, and angle of departure of the first motion ray, i, are recorded for several seismographic stations. In the table a + indicates that the first motion at the seismographic station was compressional, and a - indicates that the first motion was dilatational.

A	i	+/-	A	i	+/-
10	84	+	352	65	+
35	82	+	323	75	-
57	86	+	306	69	+
346	48	-	290	79	+
310	45	-	65	62	+
324	14	-	66	39	+
273	84	+	264	60	+
236	28	-	120	28	-
102	54	+	104	80	+
241	84	+	166	36	-
133	62	-	228	72	+
188	70	-			

a. Plot the data on a Schmidt equal area projection of the focal sphere (see last page). Then, determine the focal mechanism of the earthquake (i.e. was this earthquake caused by normal, reverse, or strike-slip faulting?)

b. Determine the strike and dip of each of the possible faults, and the azimuth of the slip vector for each of the possible faults.

c. If you are told that this earthquake occurred somewhere in the Pacific Ocean, what type of tectonic feature would you expect to find at the location of this earthquake, and what orientation would it have?

4. Crustal thickness in California

Following an explosion at the Nevada test site (NTS), first and second arrivals are recorded at a number of stations located approximately on a straight line from NTS to San Francisco, CA. (figure 4) Close to NTS the following arrivals are observed:

Station	Distance (km)	Time (secs)
T 24	6.1	1.8
T 12	9.4	2.7
T 23	13.8	3.3
T 20	15.2	3.4

At greater distances, two P phase arrivals separated by a few seconds are noted as follows:

Station	Distance (km)	Phase 1 (secs)	Phase 2 (secs)
LDJ	67.4	---	12.4
LDA	95.9	---	17.0
OAS	133.1	---	23.9
WMT	155.7	26.9	---
CHV	169.7	28.3	29.4
TOM	198.0	32.2	34.0
MML	231.2	36.3	38.9
WAL	264.6	39.9	42.3
HAP	278.5	41.6	46.4
YOS	281.5	42.1	46.9
ELP	297.2	44.1	49.7
OCT	311.3	46.0	51.1
COU	334.1	48.7	55.2
JAS	358.9	52.2	---
PDM	385.5	56.2	63.9
RVM	406.8	58.9	65.4
EUM	426.2	61.8	71.1
YDM	445.2	64.0	73.4
GRU	467.1	65.8	77.4
MDC	486.8	68.2	78.6
BKS	514.5	71.6	---
BRK	516.7	71.8	81.2
SFR	527.2	73.2	83.5
SAC	528.5	73.0	81.9
KEN	543.2	75.2	86.1
OLC	565.1	77.9	91.1

Note all arrival times have been corrected for delay caused by differences in elevation from NTS.

From this data you are to determine the average crustal thickness between NTS and San Francisco. To do this you must

a) Plot all travel time data given above and determine the crustal and mantle velocities.

b) Using the arrivals of phase 1 and phase 2 determine the crustal thickness (h) by **two** methods as explained in lecture. Note that the results of the two methods do not agree very well.

c) To trace the source of this discrepancy, look carefully at the travel time for phase 2. Does it go through the origin? Should it? If it does not go through the origin, look more closely at the arrival times at stations very close to NTS. Do they fall on the travel time curve for phase 2? If not, suggest an explanation, and a method for improving the determination of h.

d) Note that arrivals of phase 1 at stations PDM, RVM, EUM, and YDM tend to be a little late with respect to average travel time for phase 1. Looking at the map, and from your knowledge of the geology of California, can you suggest an explanation for the delay?

e) Our calculations assume that the crust is uniform in composition and thickness. Is this likely to be true? Explain.

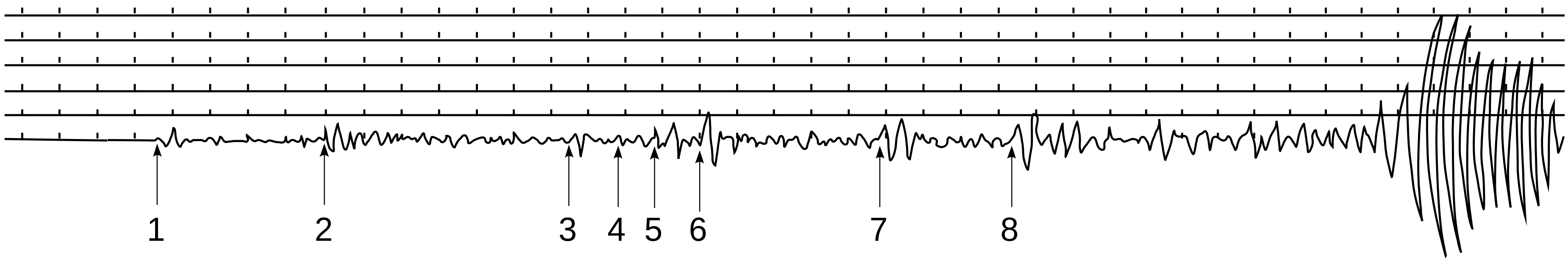


Figure 1

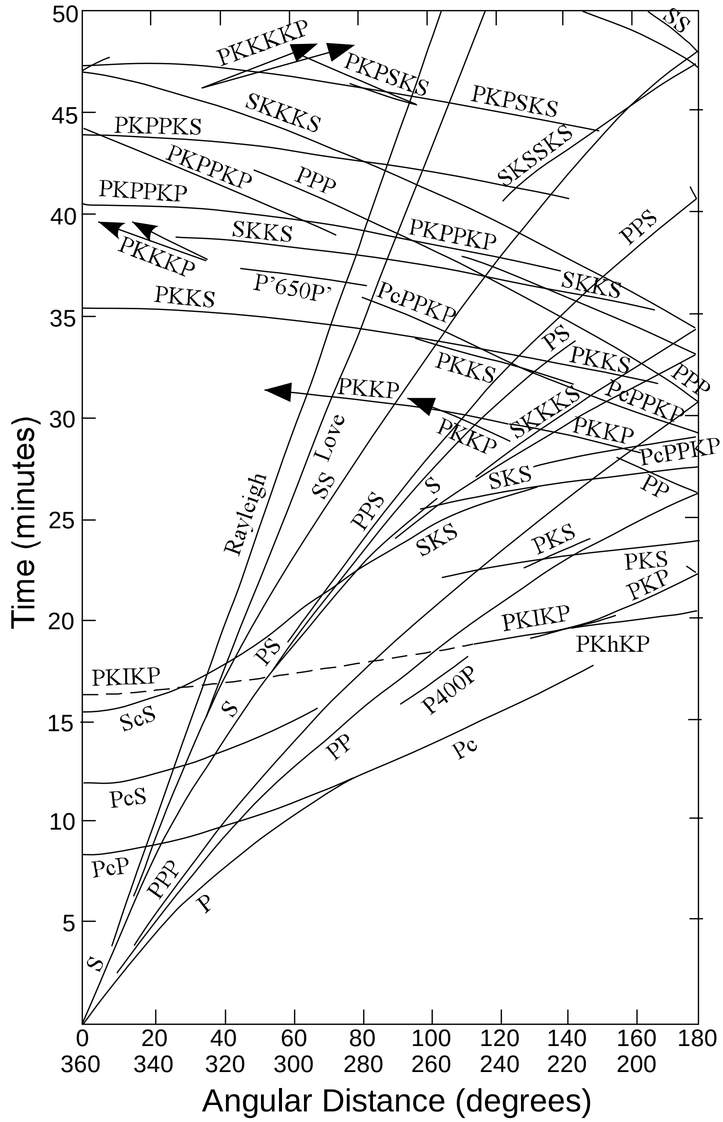
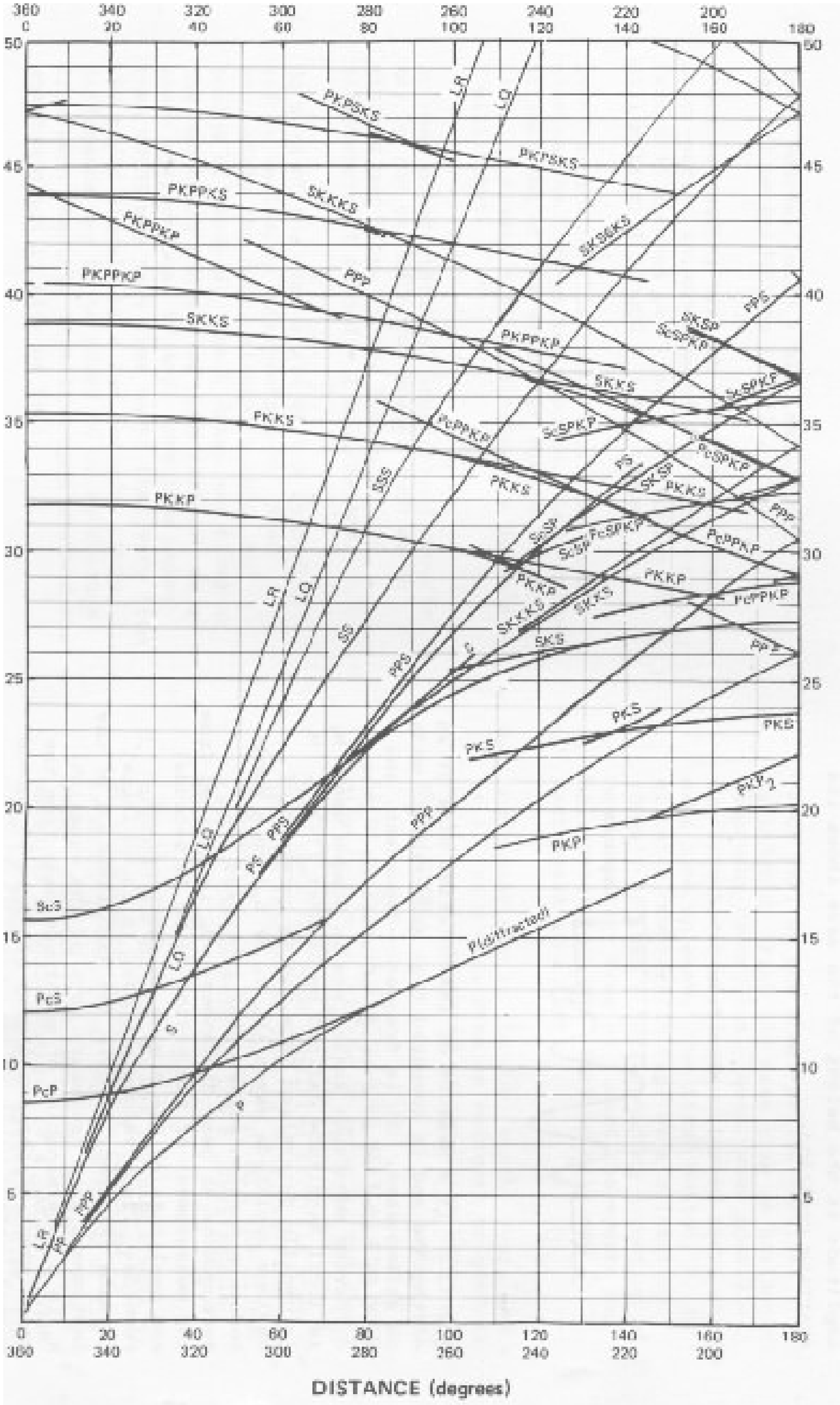

Time (minutes)
Angular Distance (degrees)
50
45
40
35
30
25
20
15
10
5
0
20
40
60
80
100
120
140
160
180
360
340
320
300
280
260
240
220
200
PKKKKP
PKPSKS
PKPSKS
SS
SKKKS
PKPPKS
SKSSKS
PKPPKP
PPP
PKPPKP
SKKS
PKPPKP
PPS
PKKKP
P'650P'
SKKS
PcPPKP
PKKS
PS
PKKS
PKKS
PPP
PKKP
SKKKS
PcPPKP
PKKP
PKKP
PcPPKP
Rayleigh
SS Love
S
SKS
PP
PPS
SKS
PKS
PKS
PKP
PKIKP
PKIKP
PKhKP
ScS
PS
S
P400P
PP
Pc
PcS
PcP
PPP
P
S

Figure 2



PKPSKS
PKPPKS
SKKS
PKPPKP
PKPPKP
PPP
SKSSKS
SKKS
PKPPKP
SKSP
ScSPKP
PPS
PKKS
PcPPKP
ScSPKP
PKKS
PKKP
PKKP
SS
SSS
LR
LQ
PKS
PKP
P(diffracted)
ScS
PcS
PcP
DISTANCE (degrees)

Figure 3

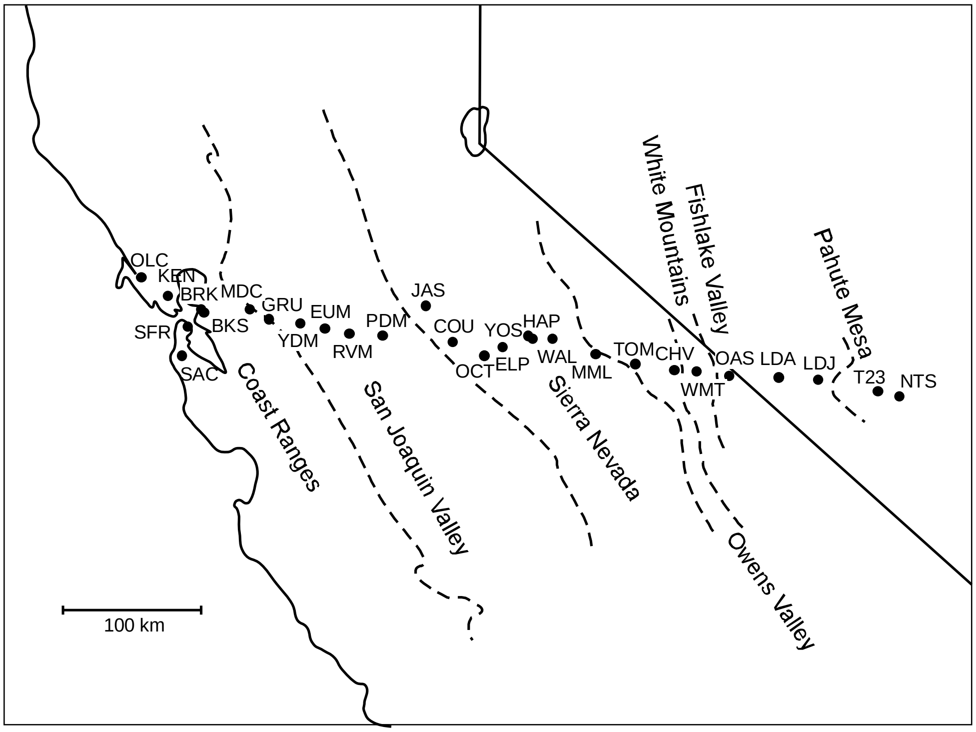

OLC
KEN
BRK
MDC
GRU
EUM
PDM
JAS
COU
YOS
HAP
SFR
BKS
YDM
RVM
OCT
ELP
WAL
MML
TOM
CHV
WMT
OAS
LDA
LDJ
T23
NTS
SAC
White Mountains
Fishlake Valley
Pahute Mesa
Coast Ranges
San Joaquin Valley
Sierra Nevada
Owens Valley
100 km

Figure 4