

Name _____

Lab 5b: Seismicity and Earthquakes Part II

Due: Friday November 1st

This laboratory exercise introduces you to some of the basic procedures used to estimate earthquake time and source locations. You will need to draw on your knowledge of seismicity and plate tectonics to interpret the plate tectonic setting and reason for the seismicity.

There are four parts to this exercise. In the first part, you will study focal mechanisms from two recent earthquakes in the Indian Ocean and interpret them in terms of regional tectonic processes. In part two, you will plot the differences in travel times between P- and S- waves vs. the P-wave travel times for several stations and two different earthquakes to estimate the time of occurrence of an earthquake. Part three uses triangulation methods to graphically locate the epicenter of an earthquake using the arrival time of an earthquake at four different stations. In the last part, you will use your knowledge of seismicity and plate tectonics to answer some tectonic questions about the regional data sets presented in this lab.

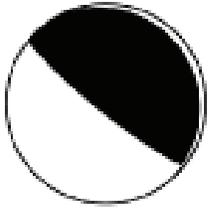
PART I. Inferring the source mechanism of two large earthquakes.

1) April 11th 2012, the largest strike-slip earthquake ever recorded occurred off the coast of Northern Sumatra (Southeast Asia). It was originally assigned a moment magnitude (M_w) of 8.9, but was later revised to an 8.6. Assuming the estimates of rigidity and rupture area did not change, approximately how much less slip would this imply? Remember that moment magnitude is defined as $M_w = \frac{2}{3} \log_{10} M_o - 10.73$, where M_o is seismic moment (which has units of work).

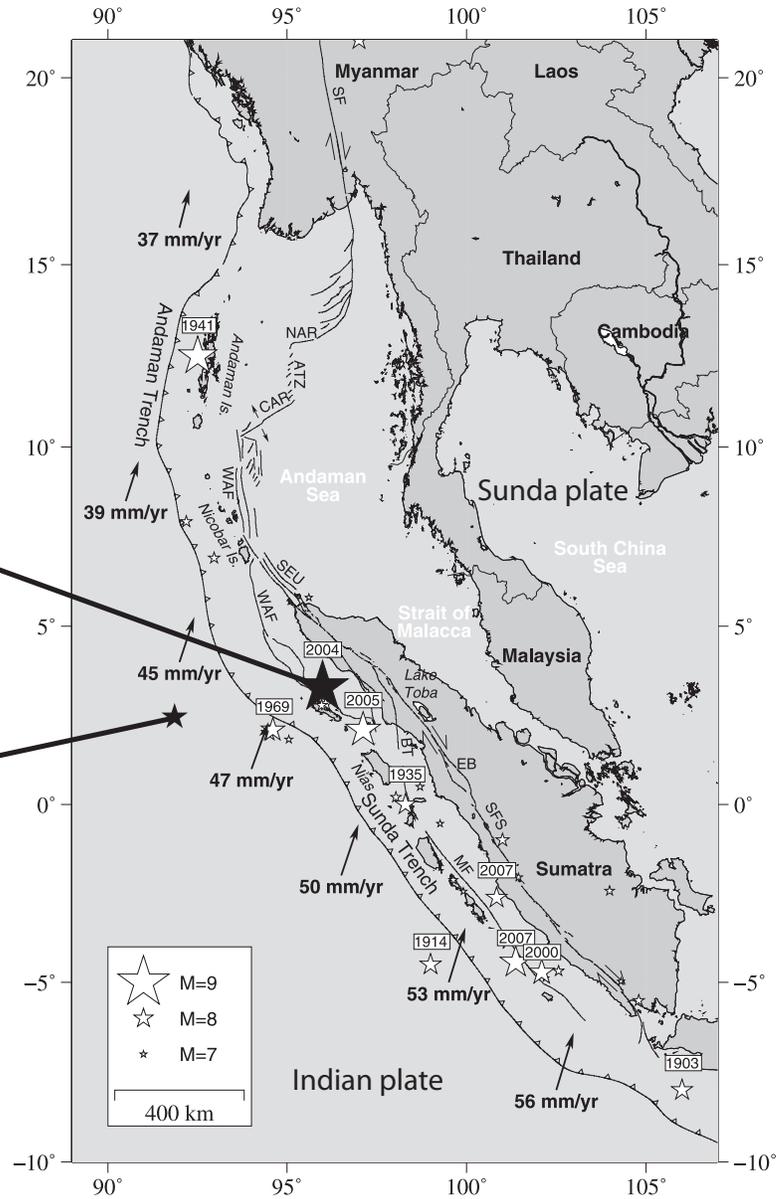
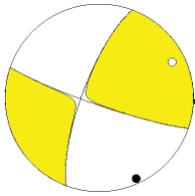
2) This area is famous for the devastating $M_w = 9.1$ earthquake and tsunami of December 26th, 2004. The focal mechanism of this event is shown on the map below, along with that of the 2012 event. For **each** event, list the two possible fault geometries, including the approximate direction of strike, the direction and approximate steepness of dip (vertical, steep, intermediate, shallow, or horizontal), and the sense of slip.

3) This area is marked by subduction of the Indian plate under the Sunda plate. The map above gives you the velocity of the Indian plate relative to the Sunda plate as determined by GPS. Explain why the 2004 event is clearly related to the subduction (mega)thrust fault. In question 2), you identified two possible fault geometries for the 2004 event. Based on this new information, which one is more likely to represent the 2004 rupture? Explain.

December 26, 2004
 Magnitude 9.1, depth 30 km



April 11, 2012
 Magnitude 8.6, depth 23 km



Modified after Cattin et al. 2009 focal mechanisms from USGS.

4). Why can't the 2012 event possibly be associated with the subduction (mega)thrust?
 (Hint: look at the location of the epicenter). Why did it **not** trigger a major tsunami
 (unlike the 2004 event)?
 Which fault geometry do you think was active in 2012 (explain)?

PART II. Determining the time of occurrence of an earthquake.

We know that P-waves travel faster than S-waves, and can assume that this travel will be along about the same path. This means that the P-wave will always be the first arriving wave, and the S-wave will usually arrive afterwards (depending on the location of the earthquake and the station). If it is true that both waves move through the same real estate, then we would expect that, as we get further from the earthquake, the S-wave would lag further and further behind the P-wave, since the S-wave travels slower. Of course, if we are recording the earthquake at the epicenter, then both P-waves and S-waves will arrive at the same time, since they are created at the same time. We also know that the arrival time of the waves will be later, if the recording station is further from the earthquake. Even if we don't know where an earthquake occurred, we can get a good estimate of when it occurred by the following procedure:

Step 1: Collect data of the arrival times of P-waves and S-waves at several stations and tabulate these data.

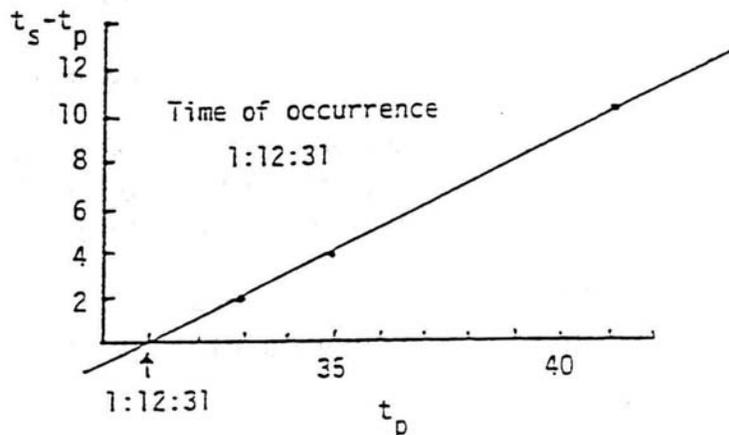
Step 2: Calculate the difference in travel times between the P-waves and S-waves, $t_s - t_p$ and add these to the table.

Example:

t_p	t_s	$t_s - t_p$
1:12:33	1:12:35	02 sec
1:12:35	1:12:38	03 sec
1:12:41	1:12:51	10 sec

Step 3: Plot $t_s - t_p$ vs. t_p , as shown in the example below. The time at which $t_s - t_p$ goes to zero provides an estimate of the time when the earthquake occurred.

Example:



1) Using a spreadsheet program such as Excel, enter the data from the 2 earthquakes in Maine given below. In a third column, calculate $t_s - t_p$

2) As in the above example, plot $t_s - t_p$ vs. t_p in an x-y scatter plot, fit a line to the data, and display the equation. Use this line to calculate the time of the earthquake for each data set. Include your plots and your estimates of earthquake occurrence times with your lab.

Station		P-time	S-time	$t_s - t_p$
Livermore Falls, Maine, January 3, 2000				
WVL	Waterville, ME	21:05:57.89	21:05:65.74	
HNH	Hanover, NH	21:05:79.10	21:05:100.22	
VT1	Waterbury, VT	21:05:83.60	21:05:106.09	
BCX	Chestnut Hill, MA	21:05:84.56	21:05:116.75	
WES	Weston, MA	21:05:84.90	21:05:115.35	
PQ1	Presque Isle, Me	21:05:94.55	21:05:135.76	
BRY	Smithfield, RI	21:05:98.03	21:05:131.04	

Dixfield, Maine, January 17, 2000				
WVL	Waterville, ME	08:16:30.59	08:16:38.22	
HNH	Hanover, NH	08:16:47.73	08:16:67.86	
VT1	Waterbury, VT	08:16:49.43	08:16:70.90	
WES	Weston, MA	08:16:57.44	08:16:83.50	
BCX	Chestnut Hill, MA	08:16:59.25	08:16:86.43	
BRY	Smithfield, RI	08:16:64.20	08:16:104.17	

PART III. Locating the epicenter.

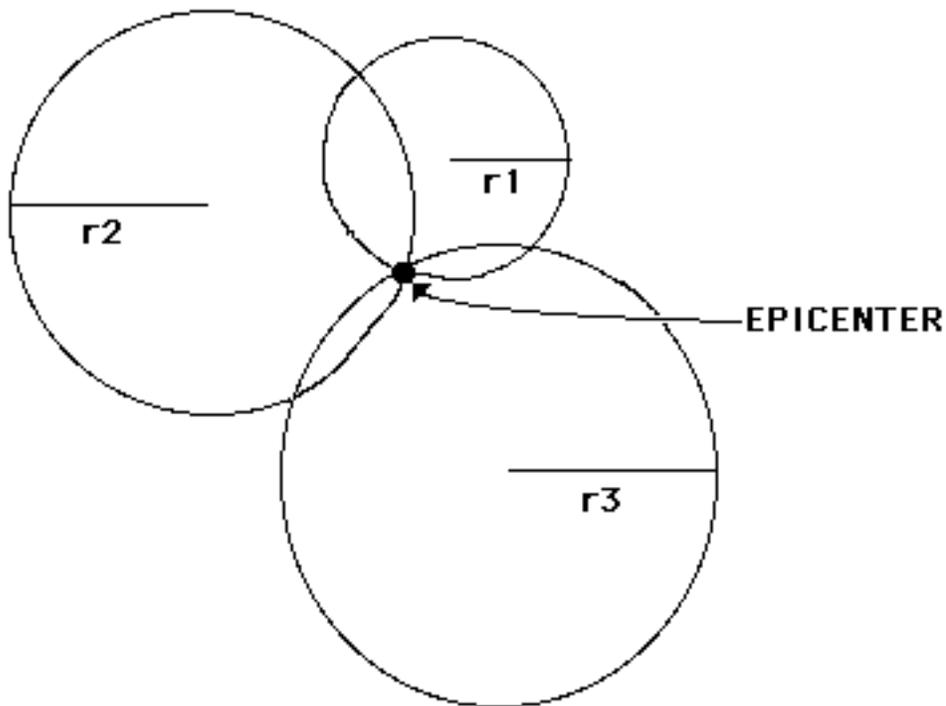
Once time of occurrence has been determined, the epicenter can be estimated by assuming that the P-waves travel at a constant velocity of about 6 km/sec. If we subtract the time of occurrence from the time that the P-wave arrived at a station, we determine the time it took for the wave to get from the earthquake to the station. If we multiply this time by the velocity of travel, we know the distance to the source. Using data from many stations (four in these cases) we can use a map and a compass to locate the earthquake approximately. Once the distance from the station to the earthquake has been determined, as described above, draw a circle of that radius about the station. Do the same for each station. The circles will intersect, or come close to intersecting, at the epicenter.

Example:

time of occurrence = 1:01:05 AM

Station P-wave arrival Distance traveled

Station	P-wave arrival	Distance traveled
1	1:01:10	5 sec X 6 km/sec = 30 km.
2	1:01:13	8 sec X 6 km/sec = 48 km.
3	1:01:17	12 sec X 6 km/sec = 72 km.



Find the approximate locations of the epicenters for the two data sets given below. *Note that these are different data from those given in Part II*, even though they're both in Maine!

Use an average P-wave velocity of 6 km/sec for these problems.

Data Set 1

Time of Occurrence 12:18:35.2

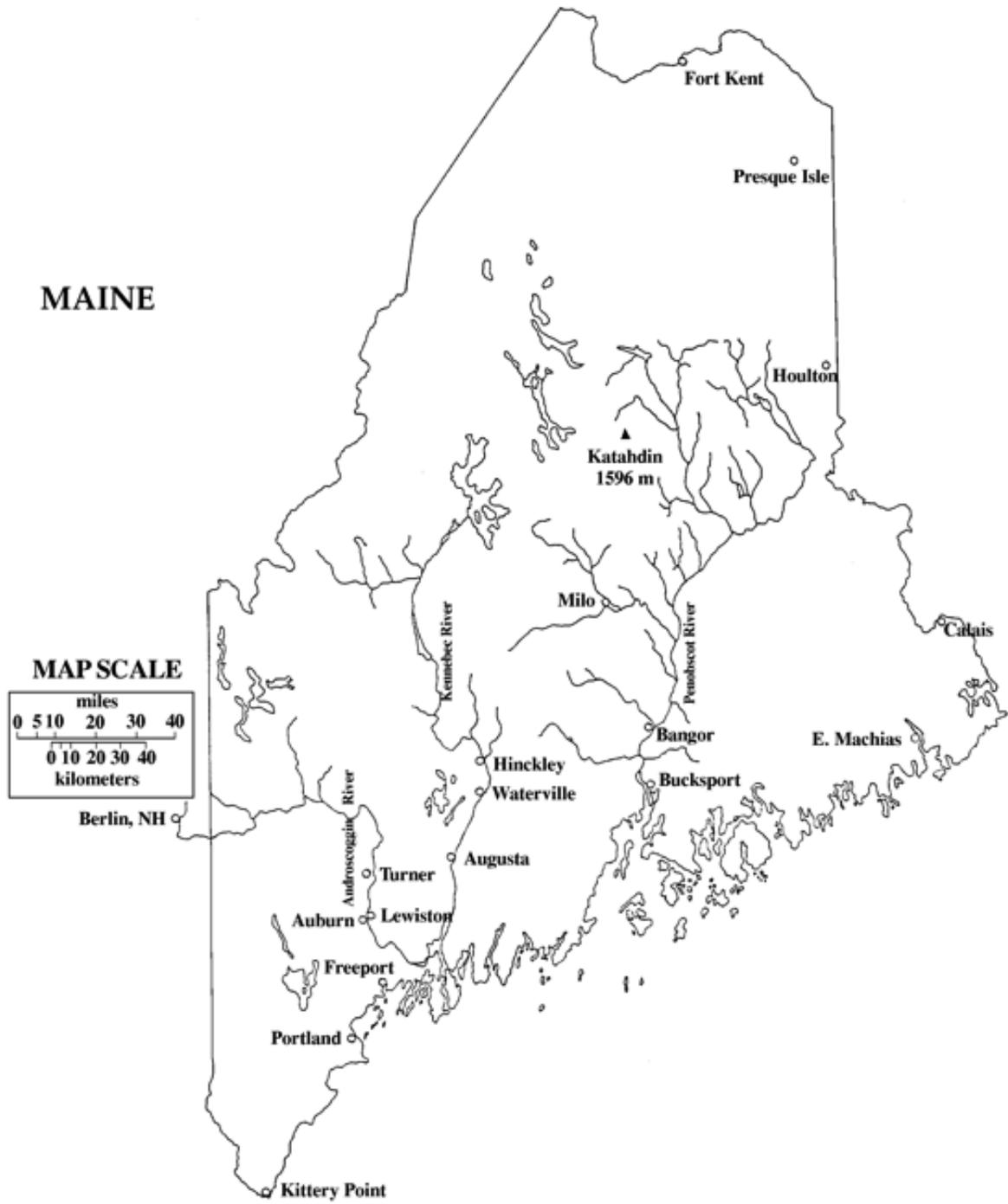
Station	P-wave arrival time	Distance (km)
Turner, ME	12:18:62.00	
Milo, ME	12:18:58.6	
Hinckley, ME	12:18:57.0	
E. Machias, ME	12:18:49.6	

Data Set 2

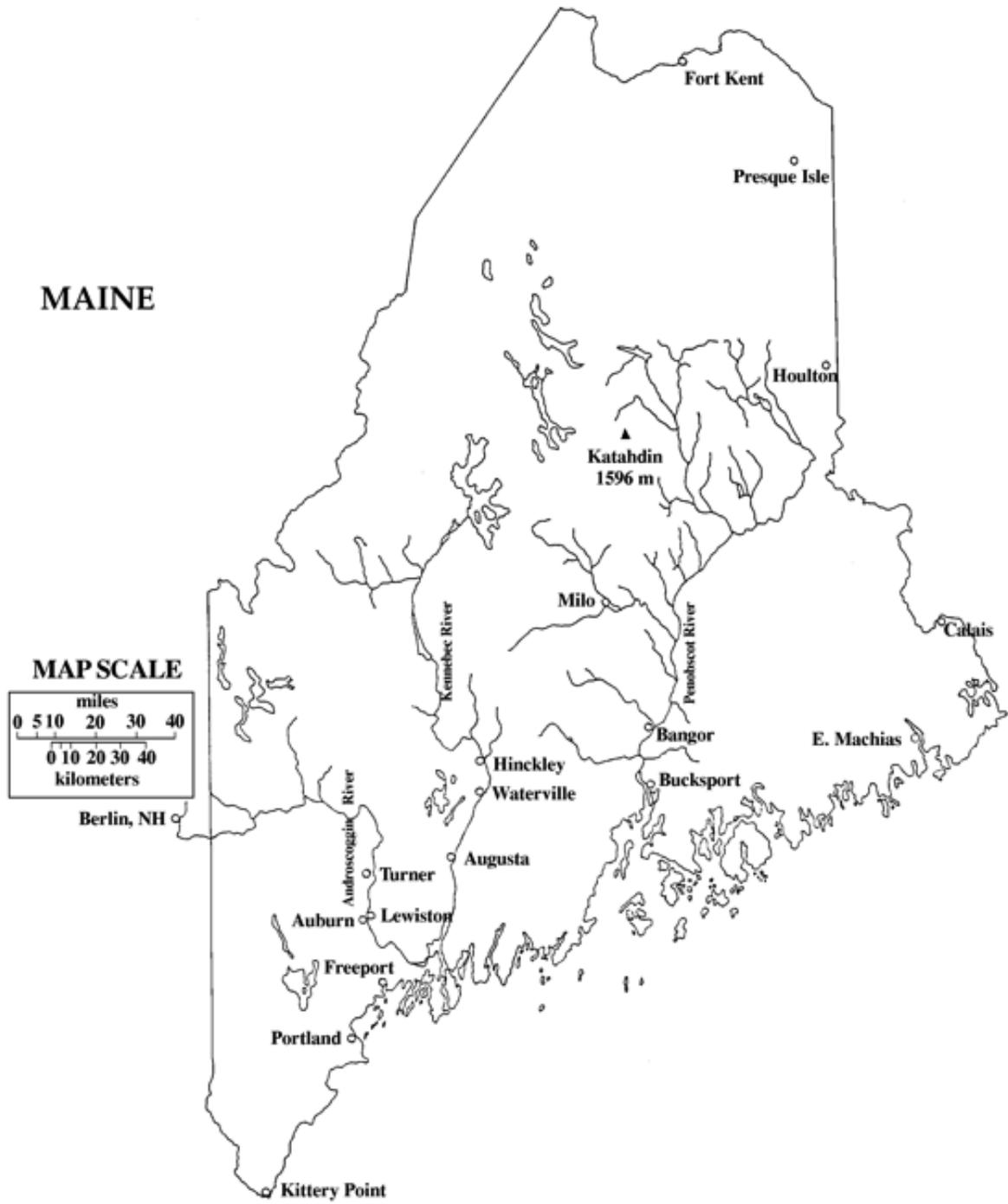
Time of Occurrence 06:28:37.9

Station	P-wave arrival time	Distance (km)
Hinckley, ME	06:28:41.8	
Bucksport, ME	06:28:53.0	
Milo, ME	06:28:54.0	
Berlin, NH	06:28:55.5	

Map for Data Set 1



Map for Data Set 2



PART IV. Linking seismicity and tectonic context.

- 1) In your previous labs and lectures you've learned about both the source of earthquakes (i.e. brittle rock failure) and the relationships between seismicity and plate boundaries. Use this knowledge to discuss the reason for the measured seismicity in this area of Maine. Include in your answer: 1) the location of the nearest plate boundary, 2) whether or not this earthquake occurred along an 'active' fault, and 3) the relationship between the seismicity and Maine's geologic past. A geologic map of Maine and a global stress map have been posted on the Stellar site to help you think about this question.

- 2) In this lab we calculated the geographic location of epicenters assuming the Earth is flat. Seismologists today determine not only the location but also the depth of the earthquake. Explain in general terms how this is done. Include a diagram of the Earth showing the earthquake focus and the paths of the seismic waves emitted by the earthquake.

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12.001 Introduction to Geology
Fall 2013

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