MUST Workshop (09/08/2018) - Seismology Practical

Earthquake locations and the seismic source

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The aim of this exercise is to determine the location and the focal mechanism of an earthquake that occurred in Ethiopia in 2003. This will be done by identifying the P- and S-wave arrivals recorded by seismometers in the region and then looking at the polarity of P-wave first motions.

The attached map (Figure 1) shows the location of the seismic stations and Figure 2 shows the seismograms that were located at each station.

(1) The seismograms in Figure 2 show both the P- and S-wave arrivals times. Generally – but not always - the P-wave is a much clearer arrival than the S-wave. The distance (r) between the earthquake and seismic station can be approximated as:

$$r = 8 \text{ x } tt_{S-P},$$

where tt_{S-P} is the travel-time difference between the S- and P-wave arrivals. This assumes that the P-wave velocity is 5.85 km/s and that $Vp/Vs = \sqrt{3}$.

(a) Determine the P- and S-wave arrival times, S-P travel time differences and source-receiver distance (r). This may not be possible for every station.

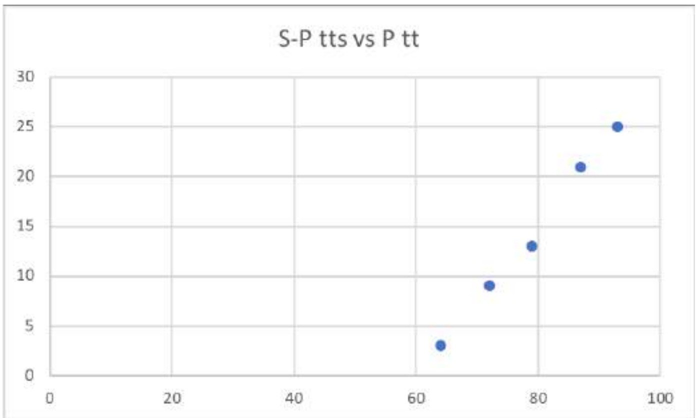
Station	P-wave tt (secs)	S-wave tt (secs)	S-P tt (secs)	Distance - r (km)
1219	62	?	?	?
BORE	64	67	3	24
E82	72	81	9	72
CHAE	79	92	13	104
MIEE	87	108	21	168
1001	93	118	25	200

(b) Using a pencil and compass, locate the event by drawing circles with a radius ‘r’ around the stations. The circles will intersect at the earthquake location. If you have access to a computer and the internet you can use http://www.freemaptools.com/radius-around-point.htm to do this. See Figure 1.

(c) How could you constrain the depth of the earthquake? A seismic station directly above the event would help a lot. Also, the use of depths phases (e.g., pP) can help with this. The time difference between a direct phase arrival and the following depth phase (e.g., pP or sP or sS or pS) helps to constrain the depth.

(d) Using the graph paper, construct a Wadati diagram to determine the origin time of the earthquake. Roughly 60 seconds – note that you need to know absolute time (usually stored in the seismic data header).

(e) Determine the Vp/Vs ratio from the Wadati diagram. Does this agree with the initial assumption of √3? I get slightly higher, which is not surprising given the abundance of melt in the region.



(f) BONUS question: derive the relation r = 8 x $tt_{S\text{-}P}$.

$tt_s = r/v_s$ and $tt_p = r/v_p$. Therefore, $tt_s - tt_p$, or $tt_{s\text{-}p} = r\,(1/\,v_s - 1/\,v_p)$.
Multiplying through by v_p and rearranging for *r* gives:
$t_{s\text{-}p}\,.\,v_p\,/(\mathrm{sqrt}(3) - 1) = r$, which can be approximated as $r = 8 \times t_{s\text{-}p}$.

(2) Source focal mechanisms. The second step is to then use the direction of P-wave first motions (up or down) to determine the focal mechanism of the earthquake (e.g., is it a normal fault mechanism, strike-slip, etc.). Figure 3 shows zoomed-in images of the P-wave arrivals (compare the time scale on Figure 2 with that on Figure 3). Each station is labelled 'a' through to 'x' and the station is shown on a lower hemisphere projection (centre of Figure 3) indicating the take-off angle and azimuthal direction at the source. Note that Figure 3 shows more seismograms than Figure 2.

(a) Which stations are farthest from the earthquakes? Those at the centre of the hemisphere – 's' and 'p'. Which stations lie to the north of the earthquake? 's', 'w', and 'x' are the most northly.

(b) Using Figure 3 determine the sense of first motion (up or down). Then indicate the sense of first motion on the lower-hemisphere projection. Use a '+' to indicate an upwards (positive) first motion and use an open circle 'o' to indicate a downwards (negative) first motion.

(c) Draw the nodal planes on the projection. Remember that the nodal planes must be perpendicular to each other. Comment on their strike and dip. An open circle means a dilatational first motion, whilst a '+' indicates a compressive first motion. BONUS: you can be more accurate using a stereonet projection to draw the nodal planes. Shade in the regions of compressional motion to reveal your 'beachball'. See Figure 3 below.

(d) Identify the type of fault motion associated with this earthquake. It is primarily a strike-slip event.

(e) Based on the outline map, determine which nodal plane is most likely to be the fault plane. Explain how you came to your conclusions. How could you further constrain this? The plane that strikes with an azimuth of 45 degrees is parallel to the border faults and therefore most likely the fault plane. However, there may be a cross-rift-cutting structure that could favour the 135 degree oriented plane. Locating more seismicity in the region could help to better delineate the fault plane.

Figure 1

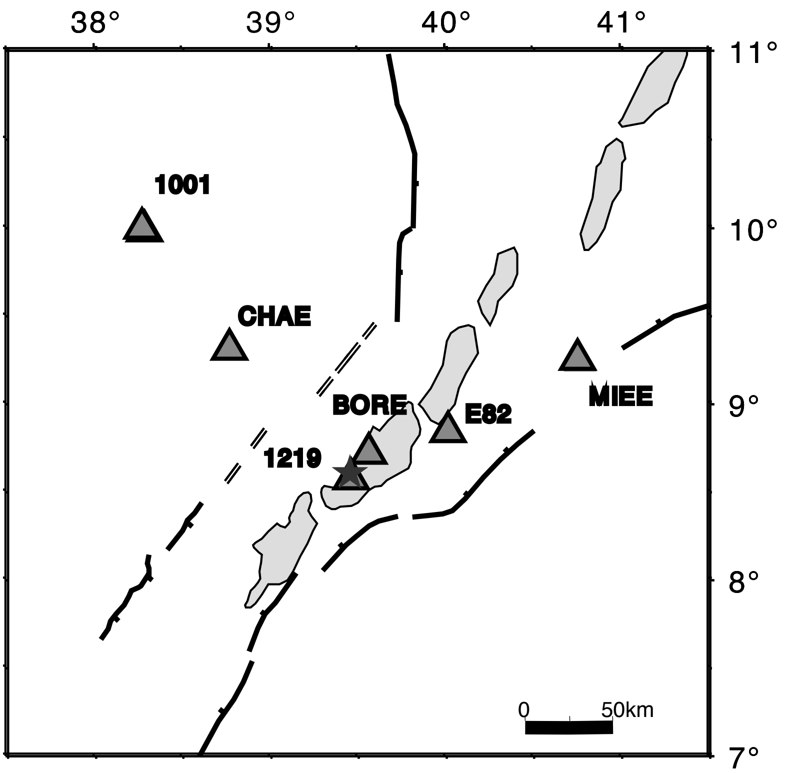


Figure 2

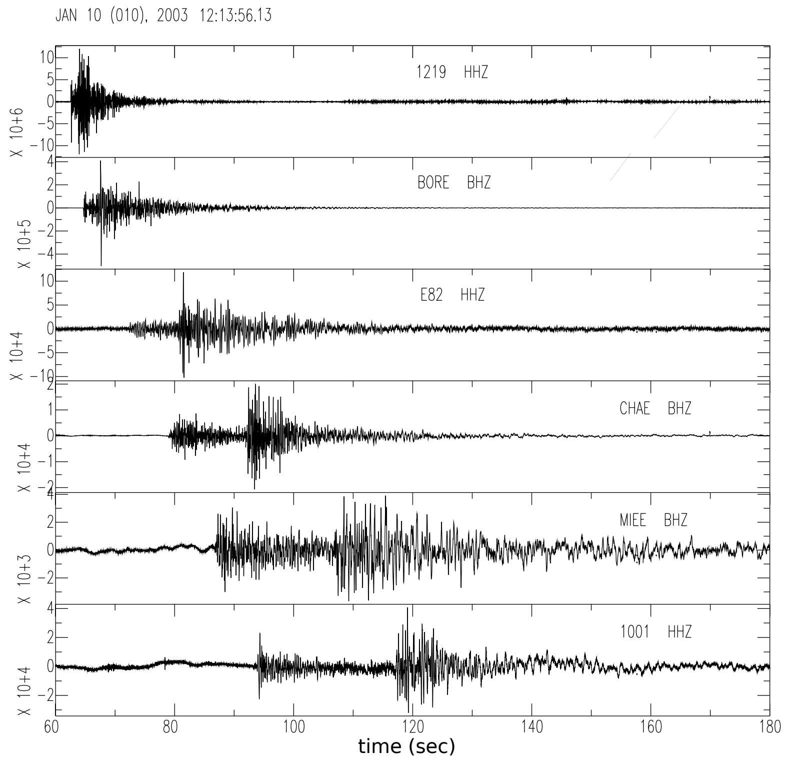


Figure 3