"How to locate the epicenter of an earthquake"

The lesson plan was developed according to the Italian national curriculum

School level: high school

Grade, age of students: from 8th to 13th grade, 13-18 years old

Approx. time needed: 90 minutes

Domain: Natural sciences

Sub-domain: Geology and geophysics

Classroom organization: teams of 2- 3

Concept competences:

- Explain how geophysicists individuate the location of the epicenter of an earthquake

(Indicative) Skill competences:

- Interpret data gathered from the analysis of a seismogram;
- Carry out a true scientific experiment using real data by mean of ICTs

Means and materials:

For each student:

- work sheets suitable to collect data

For each team:

- computer
- software:
  - Seisgram2K
    - Files of seismic recordings
  - Google Earth Pro:

You can download Google Earth Pro from:

https://www.google.it/earth/download/gep/agree.html

You can download Seisgram2K from:

http://www.edusismo.org/liste_meds.php or http://www.sismoscholar.it/sofware-per-analisi-dati

You can get seismic recordings from:

http://www.orfeus-eu.org/ and in particular from

http://www.orfeus-eu.org/eida/eida.html

Activities description:

Orientation phase

This educational activity concerns the analysis of seismograms and in particular the localization of the epicentre of an earthquake starting from the analysis of the recordings gathered by seismic stations seated all around the world.

The lesson can be started by showing to students some pictures of seismograms related to earthquakes of different magnitudes and triggered at different depth, as well as recorded by seismographs seated at different distances from the epicentres. The interest will be focused on some shapes characterizing the recordings and allowing us to grasp some features of an event like the hypocentre depth and the distance between the epicentre and the seismic station.

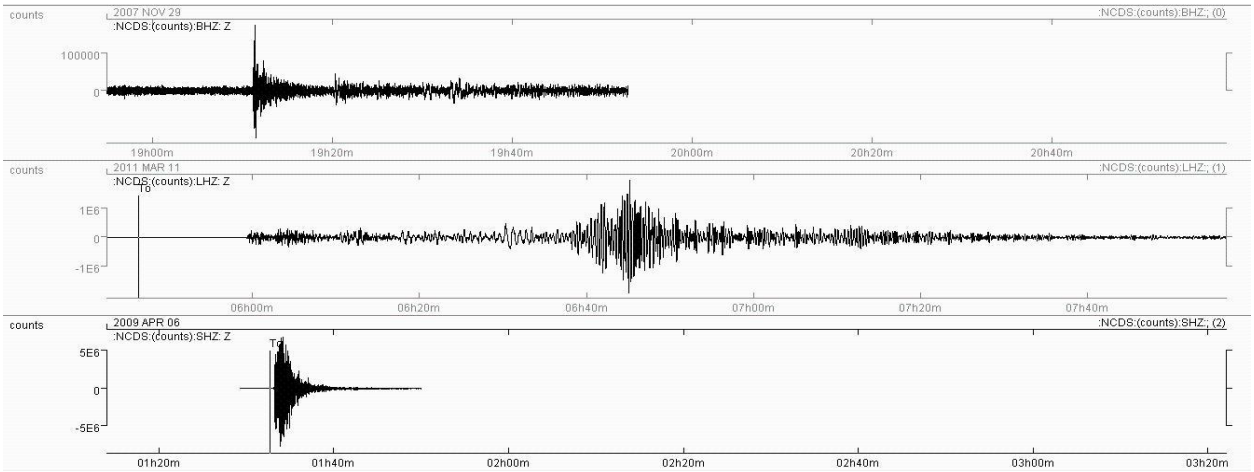


Fig1.The waveforms of three different earthquakes recorded by the same seismic station (PDM broadband seismometer seated in Città della Scienza, Naples, Italy). Above: waveform of an earthquake occurred in Winward, Martinica, on November 29th 2007, M 7,3, depth 173 km. Centre: the earthquakes occurred in Honshu, Japan, on March 11th 2011, M 8,8, depth around 20 km. Below: earthquake occurred in L'Aquila, central Italy, on April 6th 2009, M 5,9, depth around 10 km.

Conceptualization phase

The localization of the epicentre of an earthquake is carried out by means of the so called three circles method (triangulation). Once the distances between at least three seismic stations and the epicentre have been calculated, starting from the differences in time of the first arrivals of the P and S waves to the station, three circles, whose diameter is proportional to the related epicentral distances, are traced on a topographic map. The epicentre is located in the point where all three circles intersect.

Once the students have grasped the idea that the distance between the epicentre of an earthquake and a seismic station can be calculated starting from the related seismograph, the teacher will train them by the use of Google Earth Pro. This application offers the function "circle" on the menu "ruler" from the toolbar. The function "circle" allows drawing on a world map circles whose radiuses are variable. So, the students can be invited first to set three mark points on the earth's surface and then three circles having the mark points as centres. Therefore, the students will verify that the three circles can reciprocally touch each other in just one point, depending on the chosen radiuses.

Investigation phase

To locate the epicentre of an earthquake, usually researchers apply this method recurring to recordings gathered by seismic stations seated close to the epicentre to get a more accurate localization. Moreover, in these contexts the localization doesn't feature just the calculation of the difference in time between the arrivals of P and S waves and the solving of an equation, but it also implies complicated corrections depending on the depth where the events has been triggered, the local geology and therefore the mechanical features of the rocks passed through by the waves. These factors should be well known by the researchers studying an earthquake.

Instead our activity entails the use of recordings gathered by seismic stations seated very far (thousands of kilometres) from the epicentre. In this way, the effect of local geology as well as the occurring errors in distance is negligible if compared with the distances between the epicentre and the seismic stations. The use of such kind of software application like Google Earth Pro allows us to mark circles having as radiuses directly the great circle route due to the round shape of the Earth.

Students will be divided into groups of two or three people. Each group will be equipped with a PC.

The teacher will have previously installed on each PC the software and files necessary to localise the epicentre of an earthquake:

- Seisgram2K to analyze the seismograms;
- Google Earth Pro to localize the epicentre.

On the desktop of each PC each group will find a directory containing the seismogram of a significant earthquake recorded by a seismic station chosen by the teacher and gathered by the EIDA database of the Orfeus web site (145.23.252.222/eida/webdc3/), and a file giving some information about the seismic station such as geographical coordinates and altitude. Each directory can be named with the acronyms officially identifying the seismic station.

For example, in this script it has been chosen an earthquake occurred on October 26th 2015 in the north-eastern Afghanistan. This earthquake has been chosen because of its high Magnitude (7.5) and therefore seismographs all around the world recorded it and because it has been triggered very deep (over 200 km) and therefore the first arrivals of P and S waves are clearly visible on the waveforms.

Three seismic stations have been chosen (table 1) seated respectively in southern Italy[1], Japan and in Maldives' islands. Students compare the data they collected during the previous phase with their concept map (initial ideas). They can add/delete/adjust (with a different color) what they have learnt and present it to the classroom (they can also do the same thing after they listen to all the teams or you can have a classroom concept map and teams can add to that). The stations have been chosen because of their position and their distance which is relative to the epicentre of the earthquake. For such kind of earthquakes an effective distance could be in a range between 2000 and 6000 km.

Seismic station	Network	Location	Latitude	Longitude	Altitude (m s.l.m.)
KAAM	G (Deutsches GeoForschungsZentrum)	Madaveli, Maldives'	0,4926 N	72,9949 E	0
INU	GE (Geoscope – IPGP)	Inuyama,	35,35 N	137,029 E	132

[1] The EIDA database of Orfeus web site makes available seismographs recorded in every country of the world so teachers and educators can choose for a seismograph recorded in their own countries.

		Japan			
LIO3	IX (AMRA)	Lioni (AV), Italy	40.8969002 N	15.1803999 E	737

Table 1. Acronyms, geographical coordinates and other information about the seismic stations.

Then, the teacher will ask the student to open the file of the seismographs they got by using Seisgram2k. On each of the three recordings the students should easily recognise the first arrivals of P and S waves considering the pictures of seismograms showed by the teacher at the very beginning of the lesson. So, the teacher will ask the students to determinate the difference of time between the first arrival of P and S waves by using the available function "pick". Once they will have gathered this difference in time they will be invited to determinate the distance between their "own" station and the epicentre first by using the printed table of Jeffrey & Bullen (see figure 3) and a ruler. Then they will do the same exploiting the function "Hodrochrone-Tele" of Seisgram2K [2].
In both cases the distance they will get will be expressed in degrees (°). The value of a degree on Earth surface is around 111 km, so the students must multiply the gathered value in degree by 111 km to get the distance in kilometres.

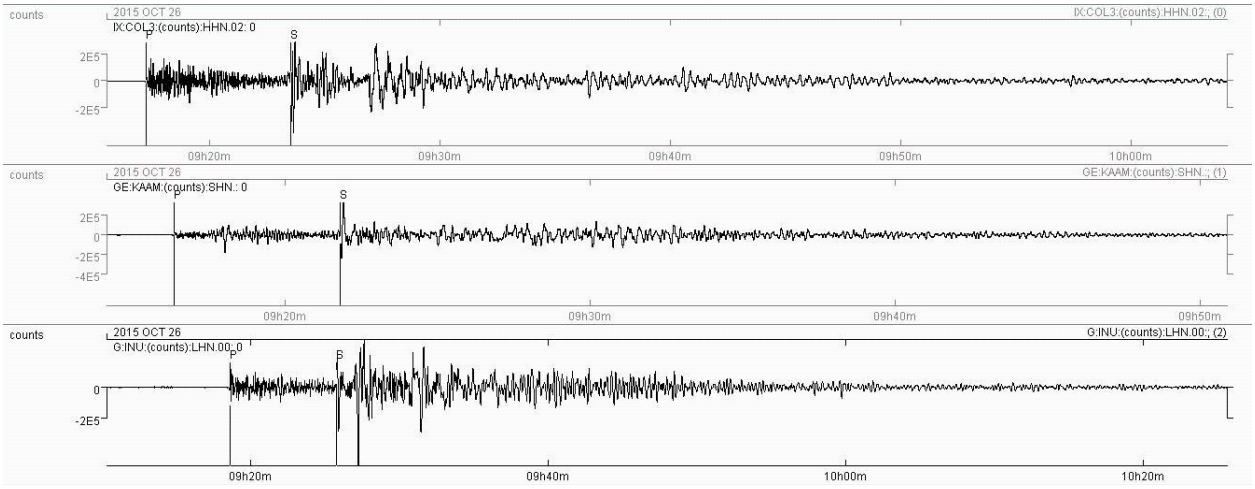
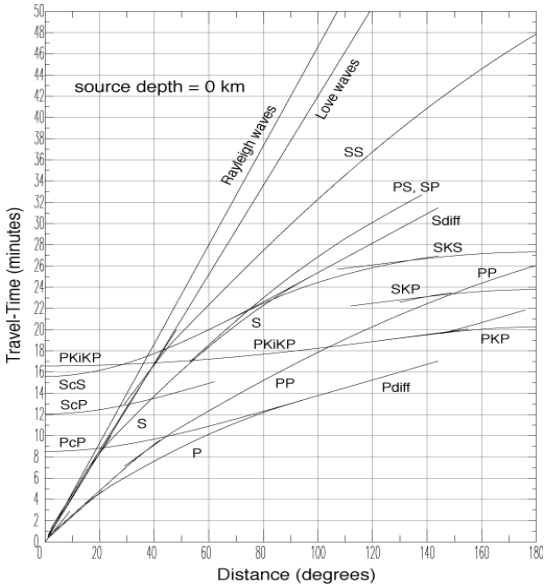


Fig.2. the seismograms of the event recorded by the N-S components respectively of the seismic station LIO3 (top), KAAM (centre) and INU (below). The vertical lines highlight the first arrivals of P and S waves on each recording.

[2] The hodochrone changes the shape of its trend in relationship with the hypocentral depth. The students couldn't previously know the depth but the teacher could remind them the pictures showed at the beginning of the lesson and suggest setting up a depth of 150 - 200 km.



Travel-time curves for a source depth of 0 km. Not all possible phases are shown.

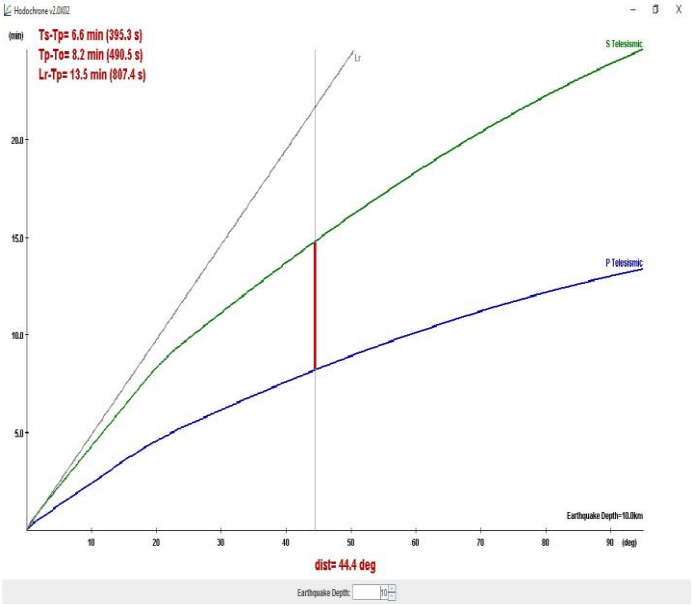


Fig.3. the table of Jeffrey & Bullen (left) reports on y-axis the arrival times of different kinds of seismic waves depending on the distance from the epicentre (x-axis) expressed in degrees (°). Notice the trend of the two curves on the window Hodochrone-Tele of Seisgram2K (right) is the same of the ones for P and S waves on the table of Jeffrey & Bullen.

Conclusion phase

Once each group has calculated the distance between their own station and the epicentre, they will share this information with the geographical coordinates of their own stations. To make the activity more interactive, the groups will be named by the teacher with the names of the seismic station they are representing. So during the sharing of information the groups will interact as real international groups of researchers.

Seismic station	T_S - T_P (s)	Distance (°)	Distance (km)
INU	433,6	52,9°	5872
KAAM	325,7	36,2°	4018
LIO3	379,9	44,4°	4928

Table2. epicentral distances of the three seismic stations determined by means of the window "Hodochrone-Tele" of Seisgram2K knowing the difference in time of the first arrivals of P and S waves ($T_S - T_P$). Considering the shape of the seismograms, in the window it was set up a depth of 200 km.

The location of the epicentre will be determined in a graphical way using Google Earth Pro. First, each group will place on the 3D World map some "placemarks" corresponding to the seismic stations whose geographical coordinates will be already known by the students.

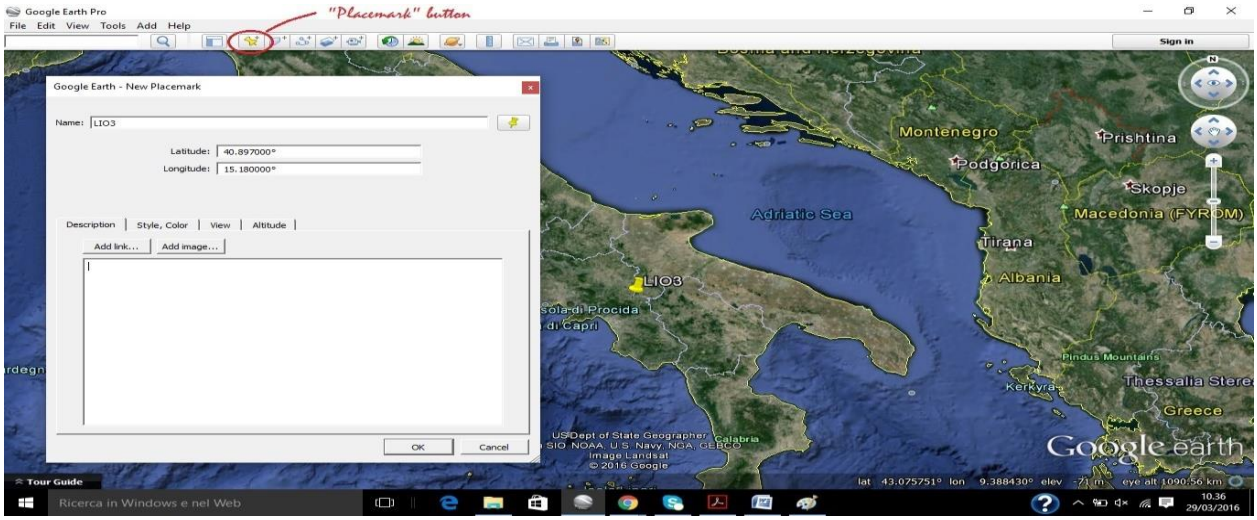
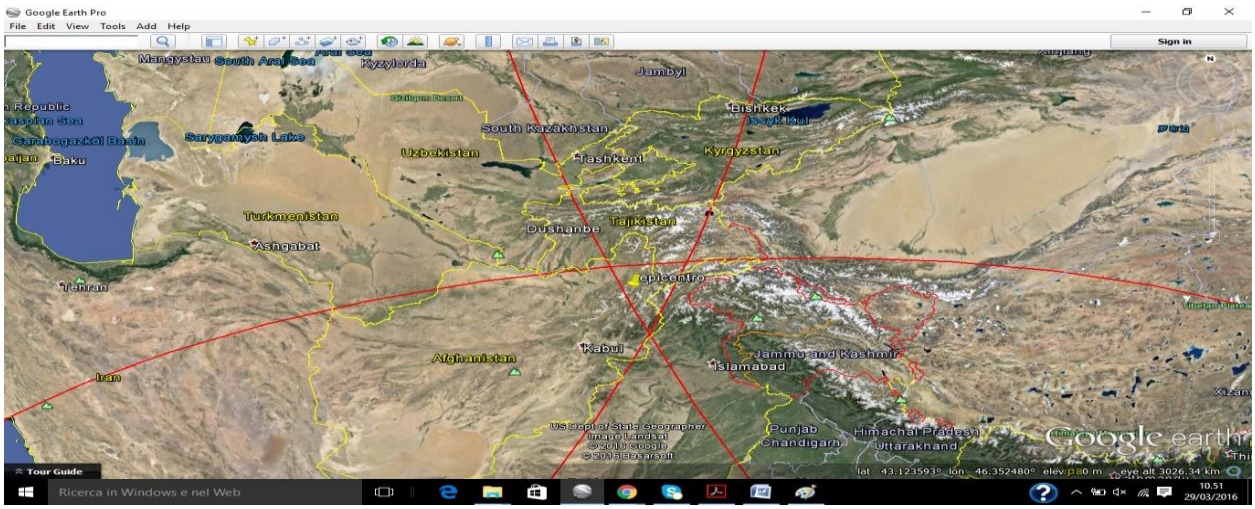


Fig.4. the "Placemark" button, its dialogue window and the placemark of LIO3 seismic station

Once the placemarks are placed, by using the function "circle" of the menu "ruler" of the toolbar, they will draw three circles having the centres corresponding to the seismic stations placemarks and radiuses scaled to the epicentral distances. The epicentre is located in the point where all three circles intersect. As already said, the radiuses of the circles traced on Google Earth Pro are not conceived as straight lines but as circle routes on round surfaces, so the method can work also for distances thousands of kilometres long.

As a feedback to evaluate if the procedure was performed right, the teacher will show to the students the web page related to the earthquake in question on the Significant Earthquakes Archive of USGS (http://earthquake.usgs.gov/earthquakes/browse/significant.php) where there is a researches report of the geographical coordinates of the event. So, the students will put on the Wold map a new placemark having these coordinates to verify if they are situated into the area



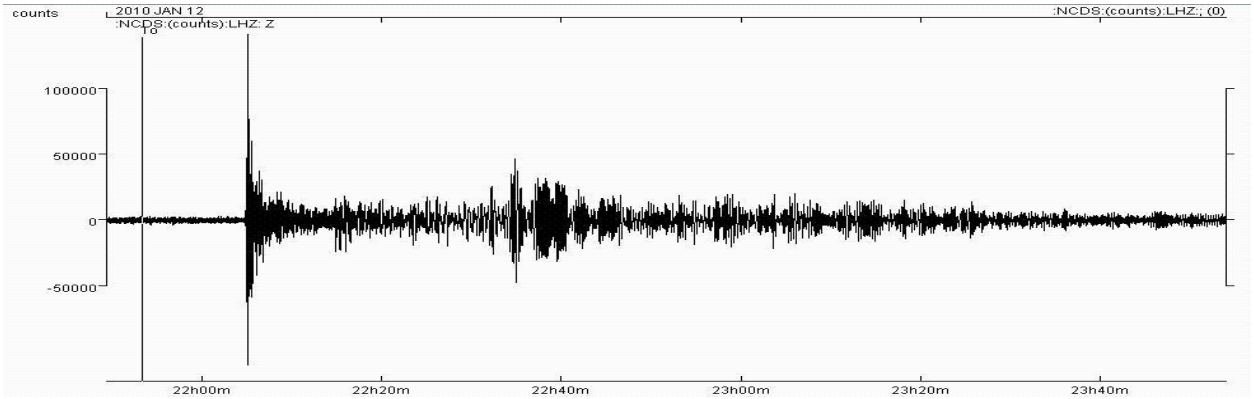
described by the intersected circles.

Fig. 5: the placemark showing the epicentre of the earthquake seated inside the spherical triangle made by the intersection of the three circles. The geographical coordinates the have been provided by USGS bulletin.

APPENDIX

All the activities proposed can be carried out by the students by using just their PCs. Work sheets reporting some questions and exercises like the ones below can be provided to each student to allow better training and more confidence with the topics proposed during the activity.

Look the seismogram below. Remember the ones the teacher has showed you at the beginning of the lesson and try to grasp the features of the earthquake that produced it.



First consider its duration. Where do you think it has been recorded?

☐ Near its epicentre ☐ Far from its epicentre

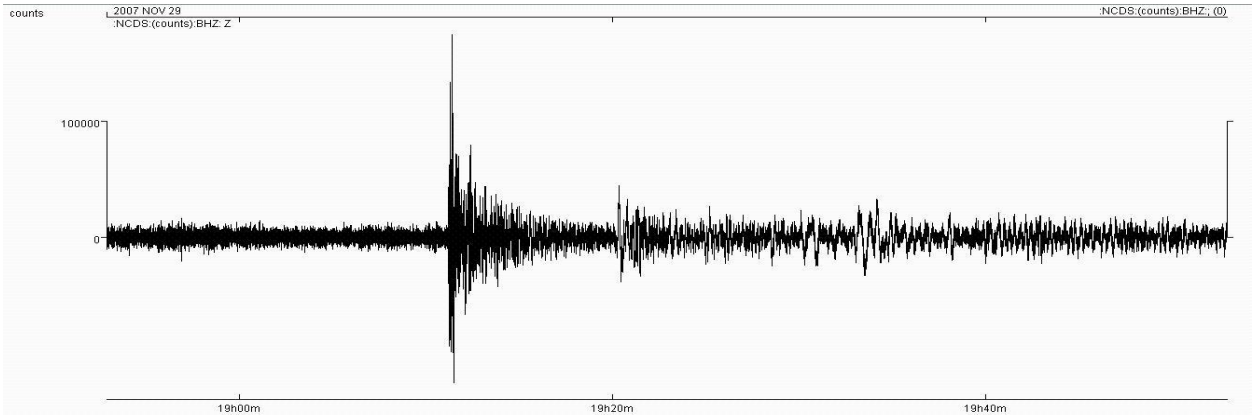
Do you think its magnitude is:

☐ Low ☐ High

Now try to individuate the first arrivals of P and S waves and indicate them with a pencil. Then individuate the surface waves and draw a circle around them.
Starting from these features of the recording, do you think the hypocentre of this earthquake is:

☐ Deep ☐ Surface ☐ I don't know

Now look this second seismogram below try to grasp the features of the earthquake that produced it.



First consider its duration. Where do you think it has been recorded?

☐ Near its epicentre ☐ Far from its epicentre

Do you think its Magnitude is:

☐ Low ☐ High

Now try to individuate the first arrivals of P and S waves and indicate them with a pencil. Then individuate the surface waves and draw a circle around them.
Starting from these features of the recording, do you think the hypocentre of this earthquake is:

☐ Deep ☐ Surface ☐ I don’t know

Work table

Consider the information you can find in the directory on the desktop of your pc. Fill the table below reporting the name and the geographical coordinates of your seismic station. Then ask the members of the other research teams and report also the names and the coordinates of their own stations.

Seismic station (Acronym)	Location	Latitude	Longitude	Distance (°)	Distance (km)

Once you will have determined the distance between your station and the epicentre of the earthquake (see next page), put it into the table and then do the same for the stations of the other teams.

Now try to situate on the World map below all the seismic stations in their right places:

World Mercator Projection

Now open the seismograms from the directory and try to individuate the first arrivals of P and S waves. Once you will have done it, using a ruler report the values of their difference ($T_S - T_P$) into the hodochrones' graph in the right scale with the y-axes. The distance should find its right place between the two curves describing respectively the trend of the arrival of P and S waves depending on the distance (expressed in degree °). Once you will have gathered the distance in degree multiply it by 111 km to get the distance in km and report it in the table above.