Study of Earthquakes

General description:

School-project plan, resources and classroom activities for high-school students (ages 15-18) in accordance with the Greek Science Curriculum

Orientation phase

In this phase the objective is to provoke students' interest and curiosity about the earthquake phenomenon. If a significant earthquake occurred recently at local, national or international level, the teacher can ask students to recall and mention their experiences (of what they felt, what they or others did and reacted, what is/was the understanding of what happened etc.). A related video or news broadcast about an earthquake event may be shown as well. After that some main general questions can follow, for example: "What is an earthquake?", "How and why earthquakes happen?", "Are they frequent in Greece?", "Are they frequent in other countries? Which countries?", "How can we study earthquakes?", "What parameters can we study?", ''What kind of equipment and tools do scientist use to measure earthquakes?''. Students may be requested to form teams to discuss their ideas about earthquakes and present some of them to the rest of students.

Conceptualization phase

In this phase, more specific questions, hypotheses and information can be formulated and gathered about earthquakes and tectonic plates, earthquake parameters, focus, epicenter, magnitude, intensity, faults, generation mechanism, seismic waves and seismographs. Students ask questions and make hypotheses based on their observations or preliminary knowledge and understanding which will then investigate.

Investigation phase

Students work in teams to do their studies and work like seismologists. They use online resources of earthquake data and seismograms or they may be given worksheets or printed seismographic data in paper. Students follow the investigation plan which can be adjusted according to their needs, their inquiry skills and knowledge. Through this phase students learn to identify and describe types of seismic waves from seismograms of real earthquakes, they gather and interpret data like real scientist do and finally measure and determine the epicenter and magnitude of real earthquakes and compare their results and findings.

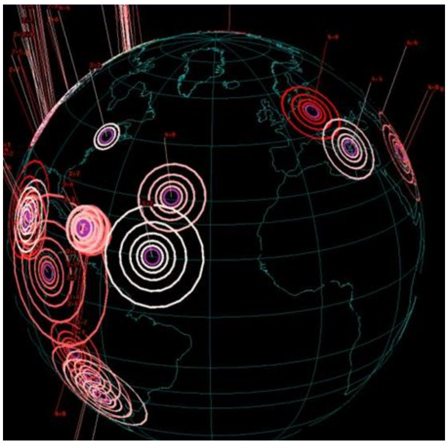
During the investigation phase, teachers' main role is to guide and assist their students in their tasks. Depending on students' skills and competences the guidance may be more focused to avoid students misdirect their focus of work or misinterpret their findings.

Conclusion phase

During this phase students compare their results, conclude on what they found and discuss the overall procedure they followed. Within the context of a school –project they may get together all the pieces of their work, what they have learnt and how and present it to the whole classroom or to the school community. As a closing activity students discuss and present through videos or poster guides precaution and safety measures that they should follow in the event of an earthquake.

Introduction and orientation
(Provoke curiosity)

Observe carefully the following images:



Have you ever wondered what an earthquake is?

Have you ever experienced an earthquake?

Watch the following video of earthquakes happening all over the world:

http://video.nationalgeographic.com/video/earthquake-montage

Watch the following video on the Earthquake of San-Francisco in 1989:

http://www.history.com/topics/san-francisco/videos/mega-disasters-san-francisco-earthquake

Discuss your ideas concerning earthquakes.

How do you believe they are generated?

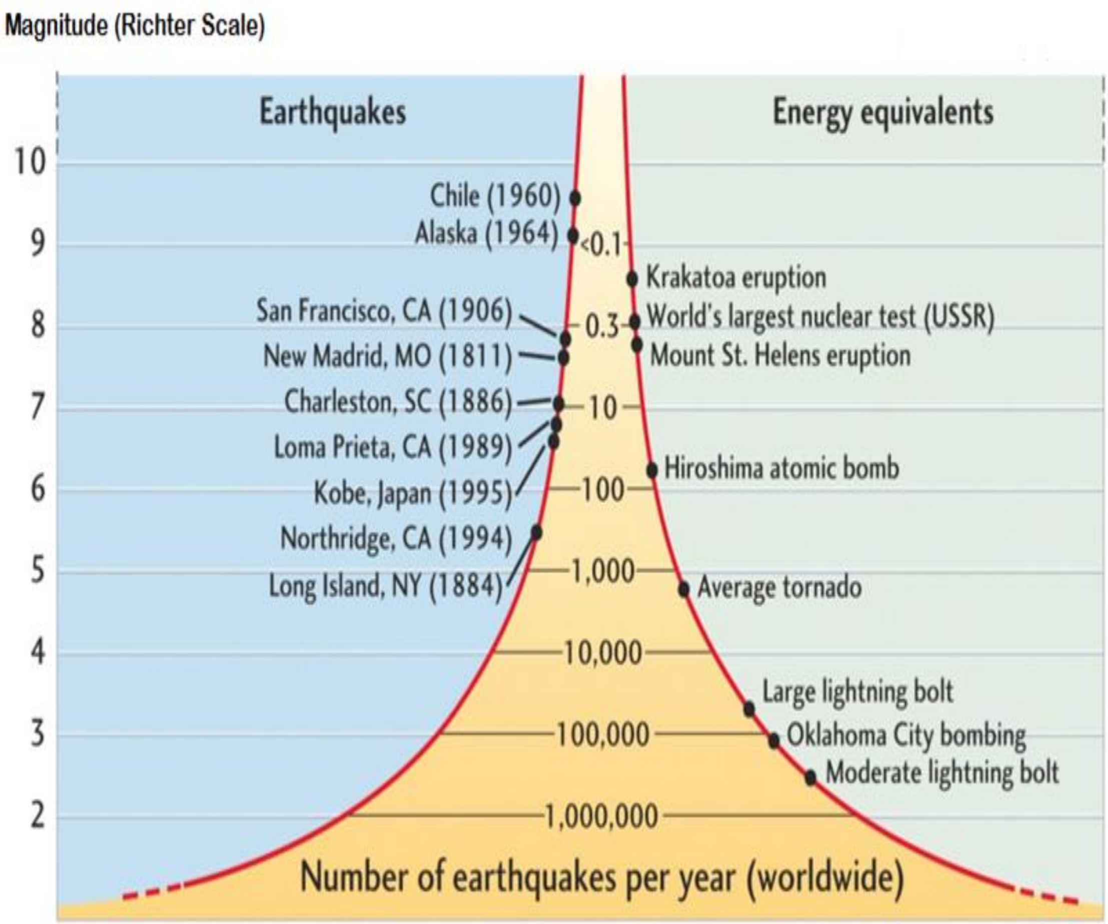
Define goals and/or questions from current knowledge

Definition:
An Earthquake is the shaking and vibration at the surface of the earth resulting from underground movement along a fault plane or from volcanic activity.

Earthquake Scales:
As we have seen, earthquakes can cause major destructions. In order to describe the severity of these destructions, scientists have invented the Richter and Mercalli scales.

The **Richter magnitude scale** is a measure of the energy released by an earthquake. The earthquake magnitude M ranges from 1 to 10, with 1 being equal to the vibration of the earth when a train passes by. When earthquake A has one unit more magnitude than earthquake B, this means that A is 10 times stronger than B, or A releases 31.6 times more energy than B!! The Richter scale is a logarithmic scale.

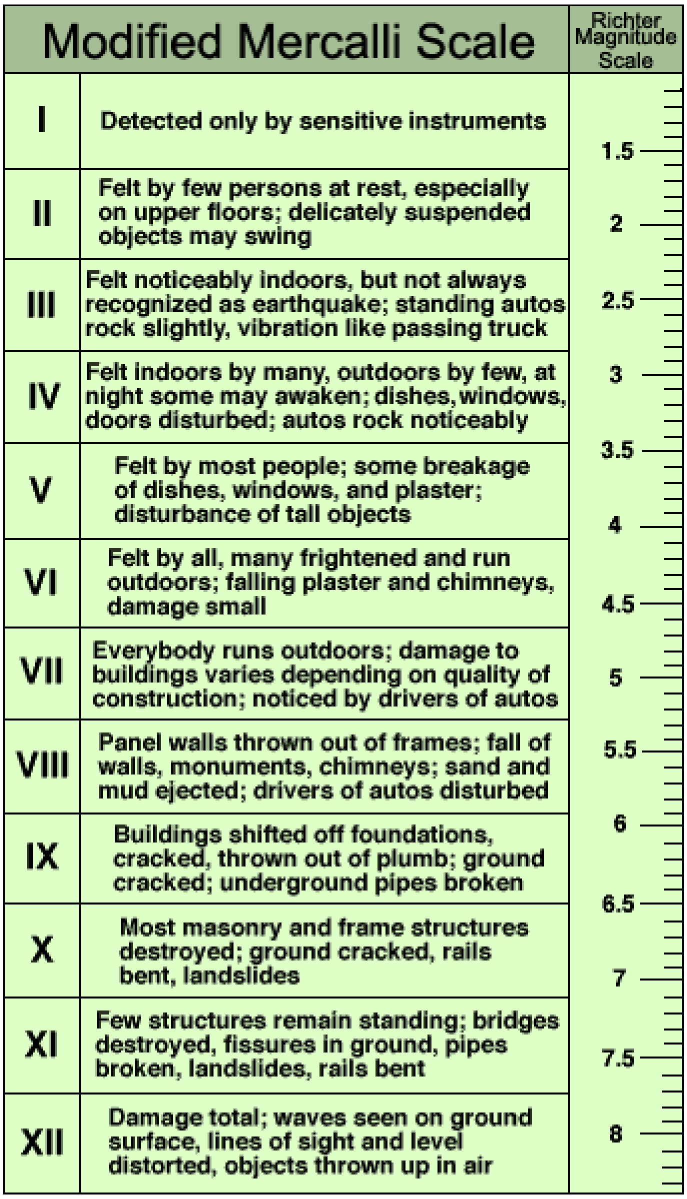
Below you can see the Richter scale and the comparison of the energy release:



Discuss your findings: how does an earthquake of magnitude 8 compare with the Hiroshima atomic bomb?

The **Mercalli intensity scale** is a measure of the observed effects of an earthquake to both natural and human environment.
The value of the Mercalli scale depends on the distance from the epicentre of the earthquake (aka its source) and on the structure of the ground.

Look at the picture below and discuss the relations between the Mercalli and the Richter scales. In the picture, the term: Scale refers to Mercalli and Magnitude to the Richter scale.



Modified Mercalli Scale	
I	Detected only by sensitive instruments
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibration like passing truck
IV	Felt indoors by many, outdoors by few, at night some may awaken; dishes, windows, doors disturbed; autos rock noticeably
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up in air

Activity!

If you have experienced an earthquake try to find out what affects you observe on the Mercalli scale.
Then go to the previous picture and make an estimate of the Earthquake's magnitude in the Richter scale.
Compare your finding with the original reports from the news on the magnitude of the

earthquake.
Was this method successful?

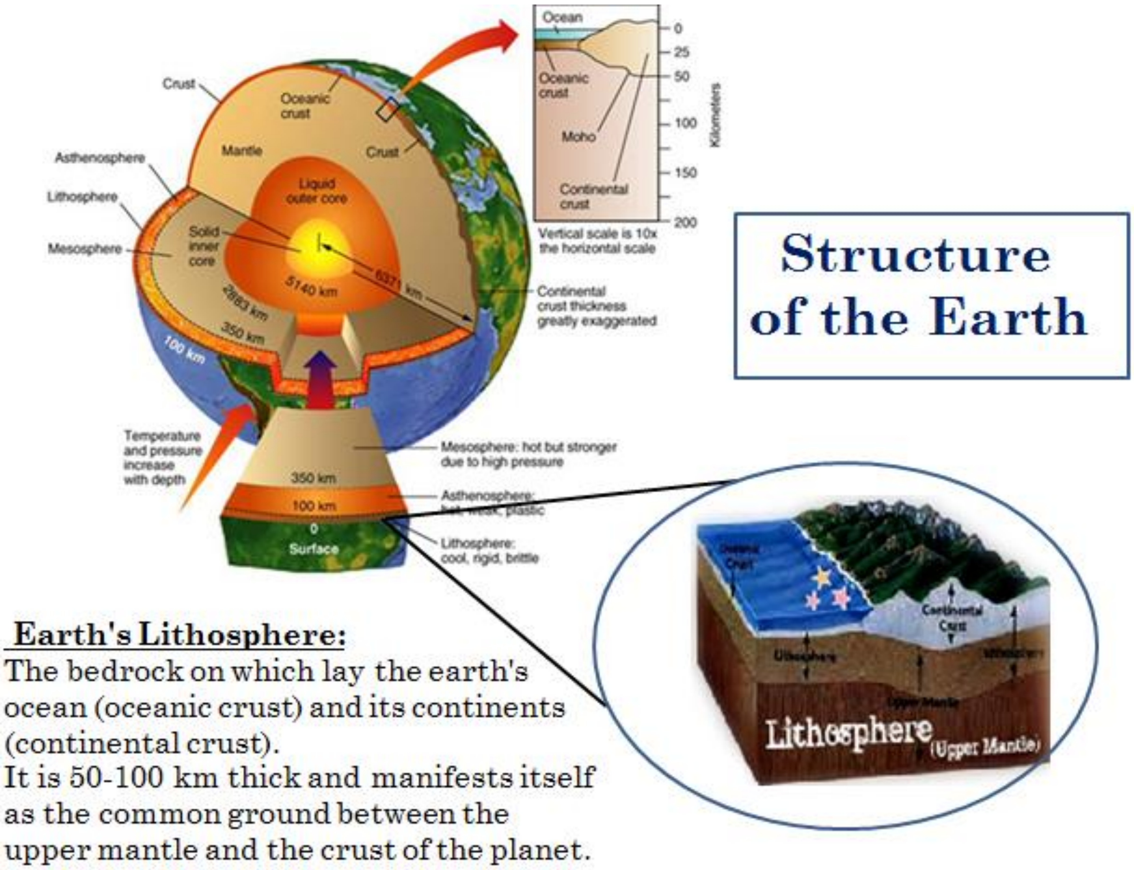
Define goals and/or questions from current knowledge

Why do earthquakes occur?
Suppose that you live in the middle of Siberia while a friend of yours lives in Turkey. Which of the two is more likely to experience an earthquake?

Back in the 60's, people knew that earthquakes and volcanoes tended to appear in certain parts of the world. They knew for example the so called "ring of fire": a belt of going around the edge of the Pacific Ocean in which exist active volcanoes and there is strong seismic activity. The belt goes through New Zealand, Indonesia, Japan, Alaska and the North America. On the contrary, places like Britain have neither active volcanoes nor strong seismic activity.

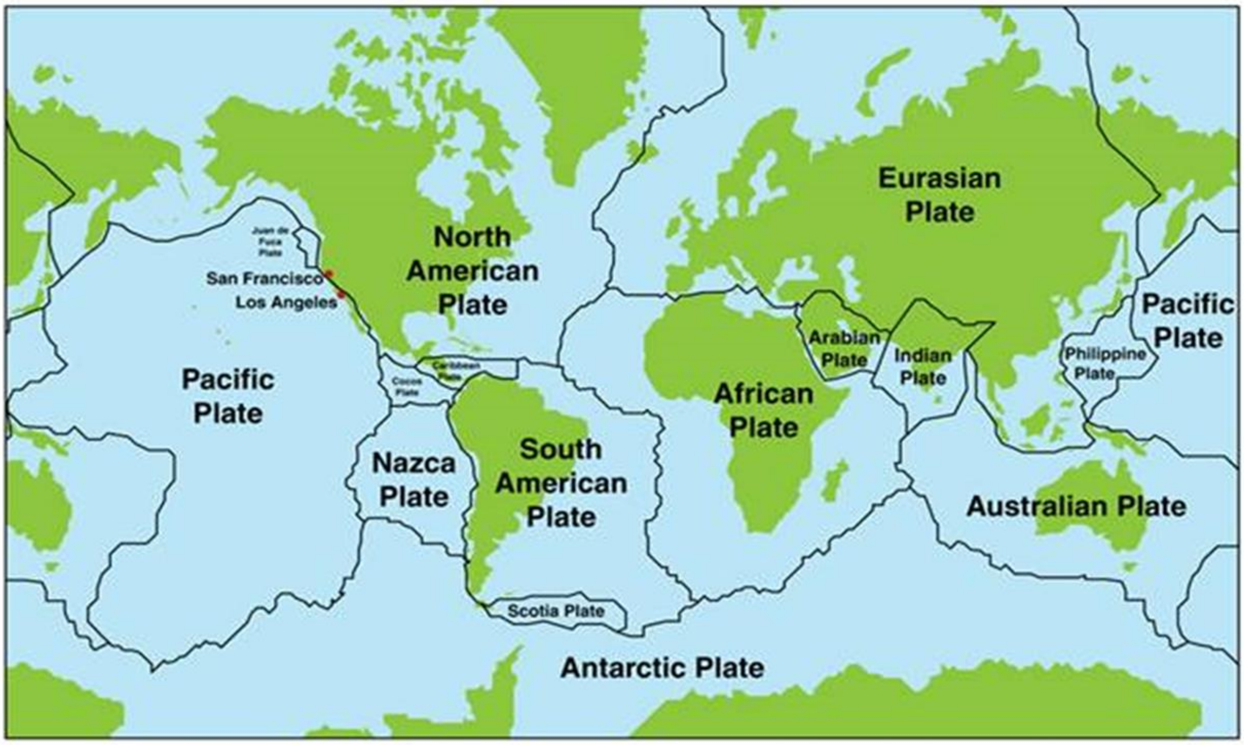
People assumed that the Earth's crust was ripped open along these "lines of weakness" for some reason allowing the molten rock from under the surface to pour out in volcanoes. The reasons for these cracks of the Earth were unknown. Maybe it was just chance. With this course of thought, a crack might appear anywhere in the world at any time creating volcanoes and producing seismic activity!

Below you can see an image of the structure of the earth. Special attention needs to be paid



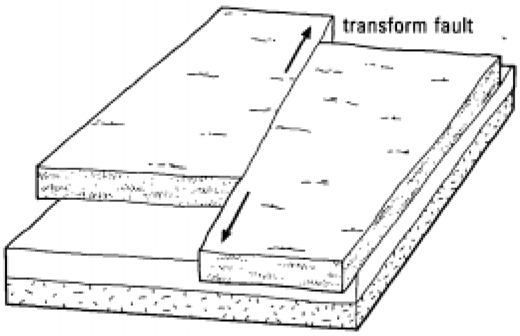
on the Lithosphere:

According to the theory of tectonic plates, first developed by Wegener, the earth's lithosphere is not uniform. On the contrary it consists of the lithospheric plates which slide on top of the upper mantle.

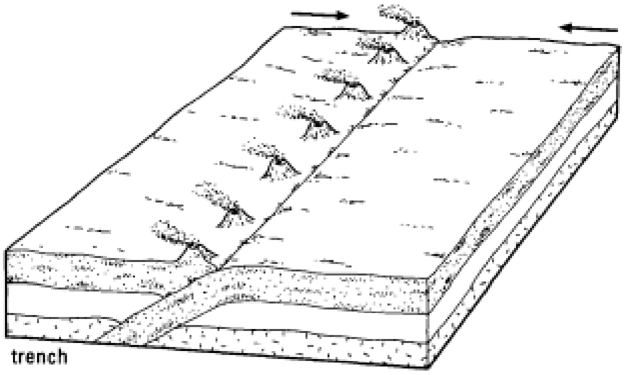


The plates are constantly moving with respect to each other and colliding.

In cases such as the San Andreas Fault in California, the tectonic theory supports that the plates push past each other as we can see below:



There are also cases such as the one illustrated below, that a plate is pushed below the surrounding plates and melts when it goes deep inside. This leads to extreme volcanic and earthquake activity and the creation of mountains as happens in Japan for example.

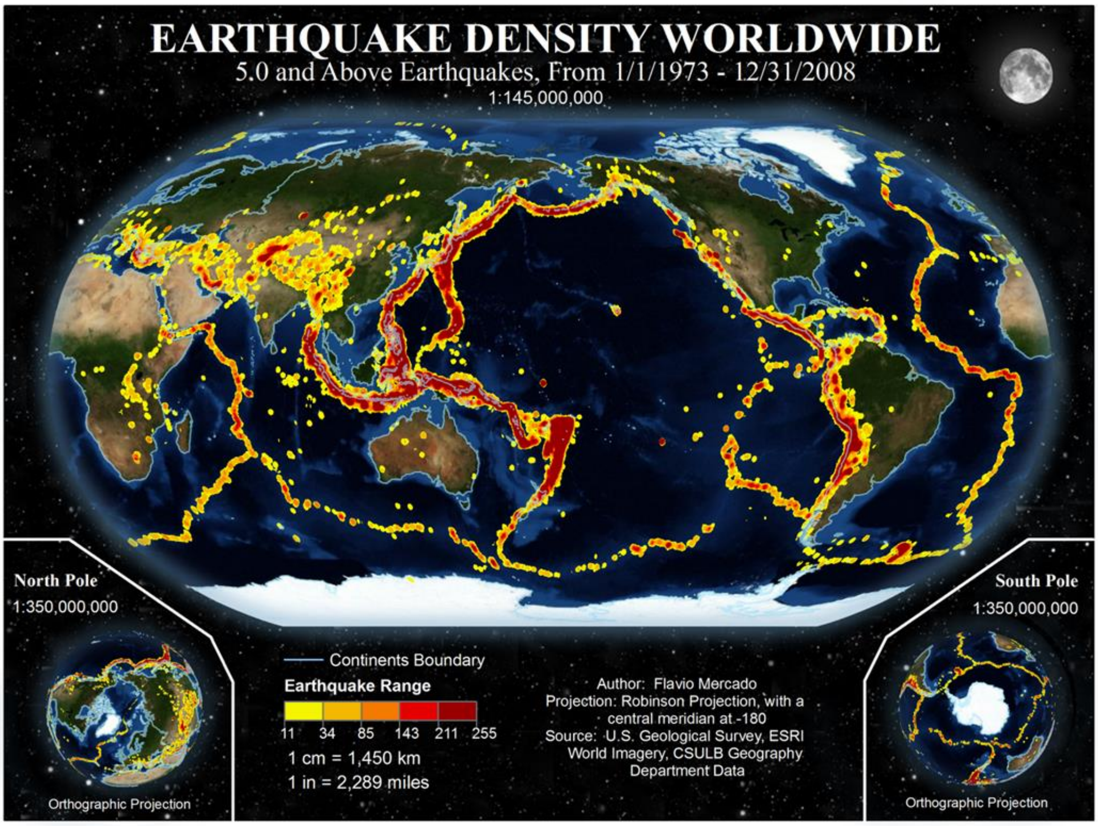


Earthquake Generation Mechanism:

Very high tensions are developed around the borders between plates.

Energy is released in the form of seismic waves which travel very long distances and can be detected on the earth.

Observe the following map and discuss:



Is there any correlation between the tectonic plates boundaries and the seismic activity distribution on the earth?

Fundamental Characteristics of Earthquakes

Observe the picture below: You can observe the seismic waves expanding from a source inside the earth. This "source" of the seismic waves is the Focus (or hypocenter).

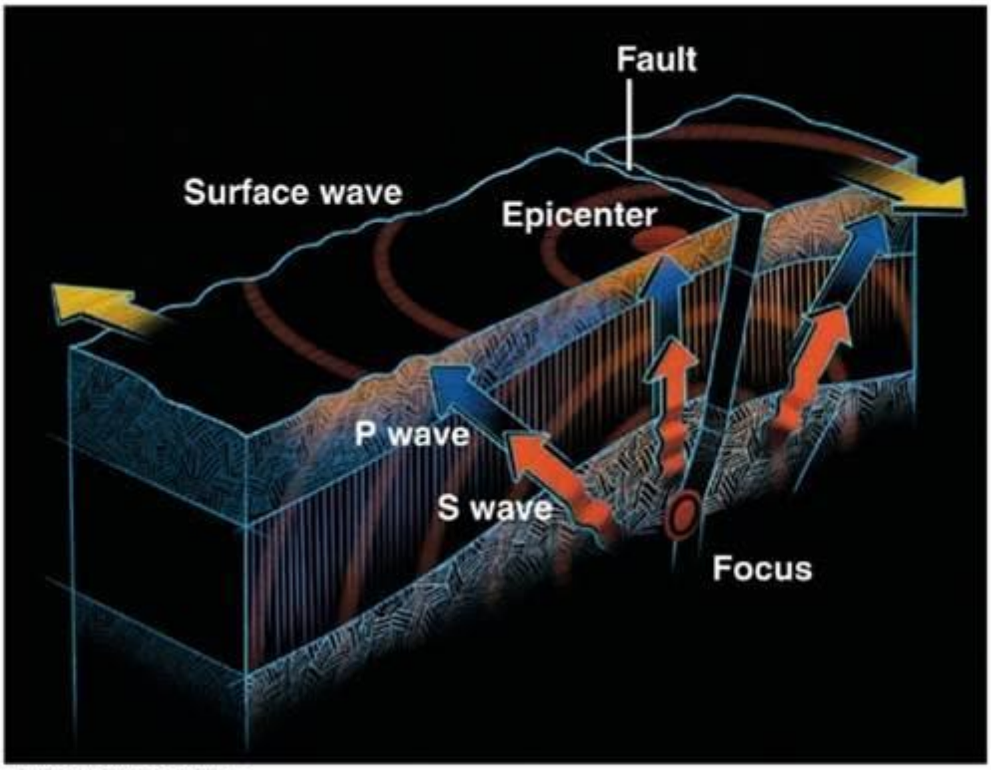


Figure 5-10c Visualizing Geology, 1/e

Now, let's draw a vertical line that starts from the focus and ends at the surface of the earth. The point on the surface of the earth exactly above the focus is called the "epicenter". The length of the line is called the "depth" of the earthquake. Shallow earthquakes are between 0 and 70 km deep; intermediate earthquakes, 70 - 300 km deep; and deep earthquakes, 300 -

700 km deep. In general, the term "deep-focus earthquakes" is applied to earthquakes deeper than 70 km. All earthquakes deeper than 70 km are localized within great slabs of shallow lithosphere that are sinking into the Earth's mantle.

A fault is a fracture along which the blocks of crust on either side have moved relative to one another parallel to the fracture.

Now that we have a good idea on why earthquakes occur and what their main characteristics are, we are ready to become young seismologists and learn the techniques that help us find the epicenter and the magnitude of an earthquake!!

Generation of Hypotheses or preliminary explanations

Now that we have comprehended the main characteristics of earthquakes, let's discuss the fundamentals of earthquake detection:
During an earthquake, a fraction of the collision energy on its focus is radiated in the form of seismic waves.

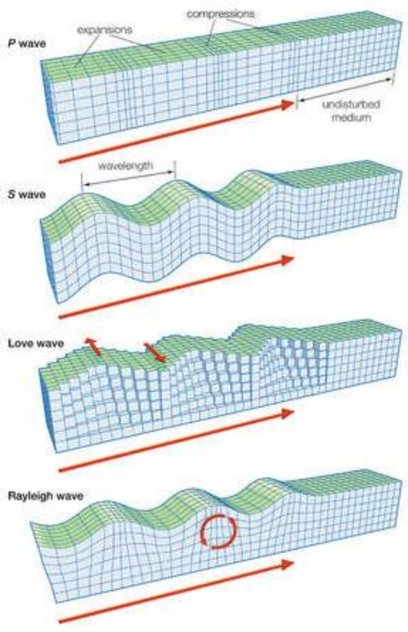
Seismic Waves

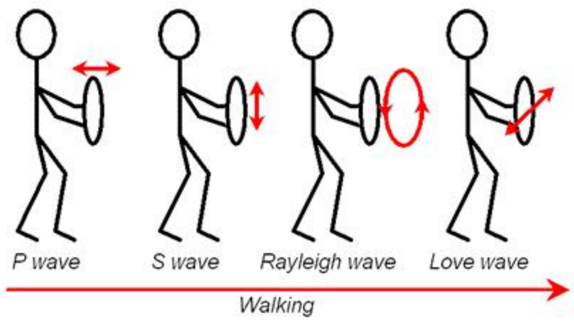
There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are **body waves** and **surface waves**. Earthquakes radiate seismic energy as both body and surface waves.

Body waves have high frequency and can travel through the earth's inner layers. They are divided in two categories: The P- Waves (P: Primary), which arrive first, and the S- Waves (S: Secondary) which arrive after the P- Waves. This time difference between P- and S- waves is one of the most prominent characteristics which is taken into account when we detect earthquakes.

Surface Waves have lower frequency than the body waves and arrive after them during the earthquake. They can only move along the surface of the planet like ripples on water. Surface waves divide in Love waves and Rayleigh waves and are responsible for the majority of destruction taking place during an earthquake.

Look at the pictures below:





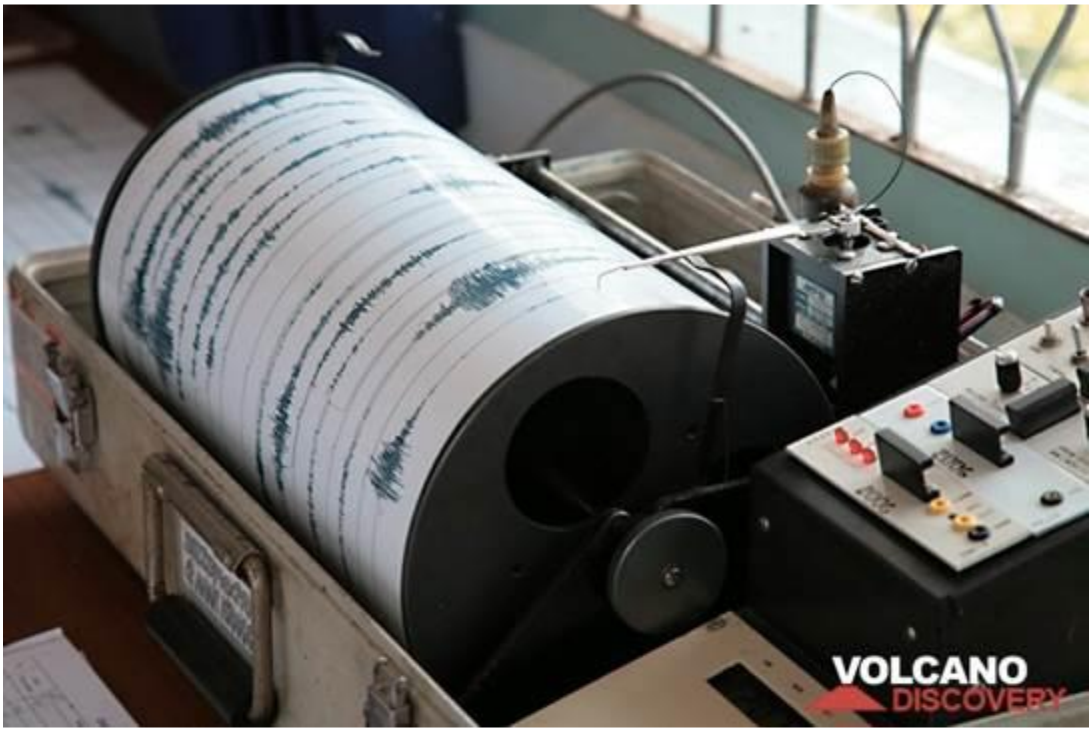
Can you describe the different kinds of motion that earth is being put into due to the different kinds of seismic waves? Can you replicate the waves using your body?

Detecting Earthquakes

What do you think: can we determine the epicentre and the magnitude of an earthquake ourselves?

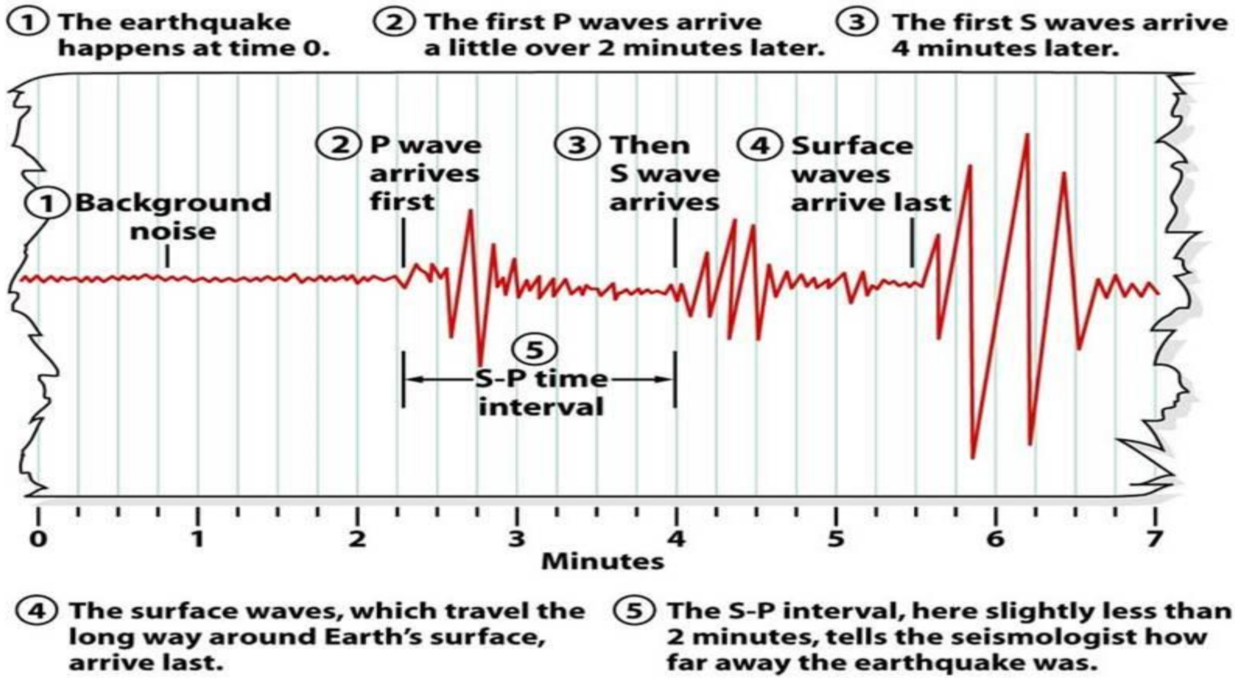
Discuss: What methods would you propose in order to locate the epicentre and the strength of an earthquake?

In order to detect earthquakes scientists use seismographs or seismometers.



From them, one gets the seismogram:
Below you can see a seismogram and the relevant details that can be extracted from it.

Take some time to comprehend the characteristics of a seismogram. In the horizontal axis we measure time (minutes or seconds) and in the vertical axis we measure amplitude (mm).



Using a seismogram, we can extract two kinds of information:

Timing and amplitude

The timing refers mainly to the time difference between the two components of body waves, the S- and P- waves which can be employed to find the location of the epicentre of the earthquake.

The amplitude refers to the oscillation amplitude of the ground during an earthquake. This amplitude is directly related to the energy radiated in the form of waves during an earthquake and can be measured to determine the magnitude of the earthquake in the Richter scale.
In the following activity, we will employ the method of trilateration in order to find the epicentre of an earthquake using real data, and then measure the earthquake's magnitude using a Richter nomogram.

Let's solve a simple exercise using simple physics and maths:

Suppose that we have two waves A,B traveling in a straight line and originating from the same point x=0 simultaneously.

Wave A travels with uA = 2m/s and wave B travels with uB = 1m/s.
Three observers : Nick, Mary and Jessy are standing at distances 2m, 10m and 100m from the wave source.

a) Calculate the arrival time of wave A (tA) and of wave B (tB) for each of the observers.
b) Subtract tA from tB for each of the observers.
c) Plot tB-tA with respect to the distance of each observer from the source at your notebook. Does the time difference scale with distance?

d) Using the above plot, predict what will be the time difference at a distance of 300m.

Discuss: Do you think that the method described above has anything to do with the determination of the epicentre of the earthquake?

Plan investigation

PART A - The Earthquake's Epicentre

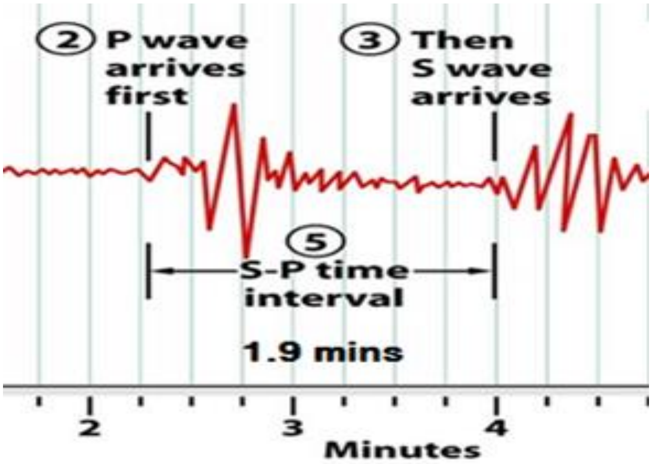
The problem of finding an earthquake's epicentre is similar to the problem of finding our unknown position using a GPS. In order to achieve it we employ the trilateration technique. Trilateration is defined as the method employed in order to find your unknown location when you know its distance from at least three reference points.

Let's assume that an earthquake happens at an unknown location. The earthquake is detected by at least **three seismic stations** which are flagged in the following map.

* (The flags are randomly placed for the sake of demonstration)

Each station is equipped with seismometers which will produce seismograms

The P- wave is the first to arrive and after it the S- wave arrives. After the S- wave the surface waves of the earthquake arrive too.
Using the seismogram, we measure the time interval between the S- and the P- wave as we can see in the picture below. This information will be used in order to find the distance between the epicentre and our station.



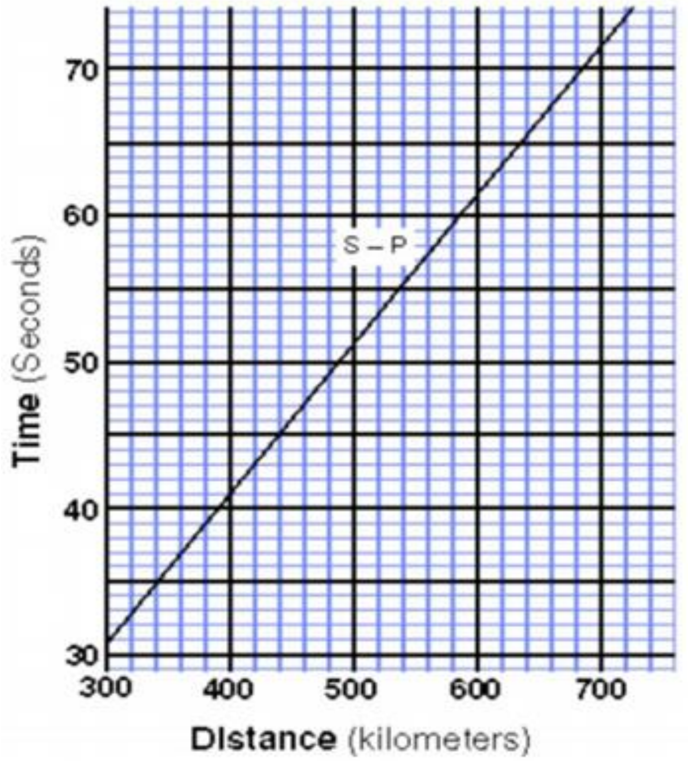
Graph.1: S-P time interval calculation

However, seismograms tend to be rather complex. Usually you see wiggles of higher and lower amplitude.

So which wiggles represent the earthquake? The P wave will be the first wiggle that is bigger than the rest of the little ones (the microseisms). Because P waves are the fastest seismic waves, they will usually be the first ones that your seismograph records.

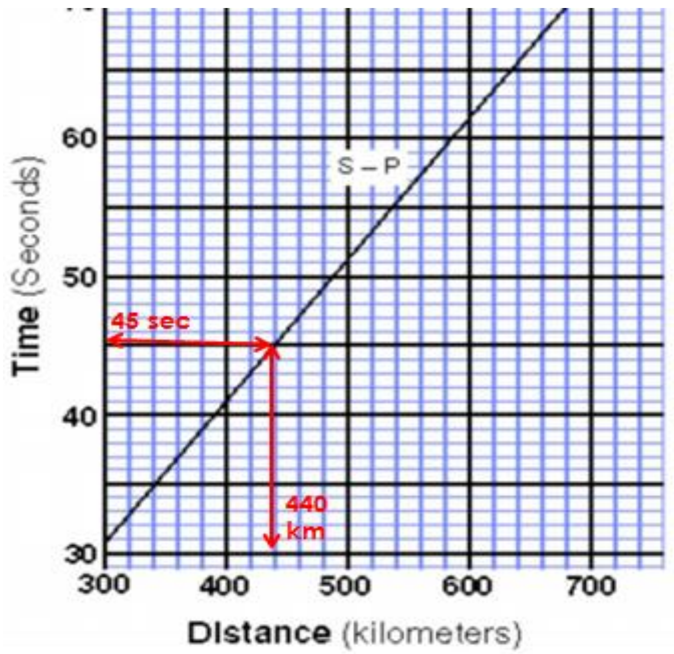
The next set of seismic waves on your seismogram will be the S waves. These are usually bigger than the P waves. The surface waves come later than the S- waves and have lower frequency which means that they are more spread out.

After we measure the time interval between a P- and an S- wave, we need to use these data in order to find the distance of our detector
from the epicentre. This is done using the following graph which represents the time vs epicentre distance for S- and P- waves:



Graph.2: Time vs epicentral distance

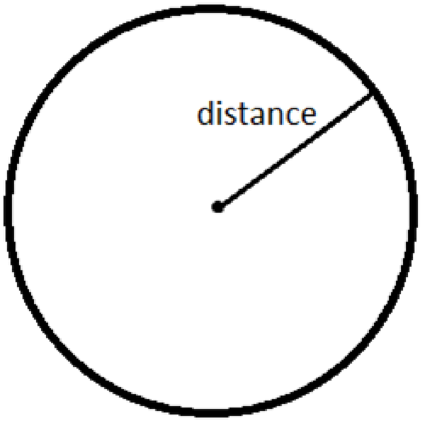
For each station we note the time difference between the S- and the P- waves on the graph. Then we locate the relevant epicentral distance as demonstrated below:



Graph.3: A time difference of 45 sec is shown to correspond to 440 km epicentral distance

This procedure is repeated for every station that measures the earthquake.
Why don't we just use data from one station?

Because we know the epicenter’s distance but we don’t know its direction! The epicenter can be anywhere in a radius equal to the epicenter distance.



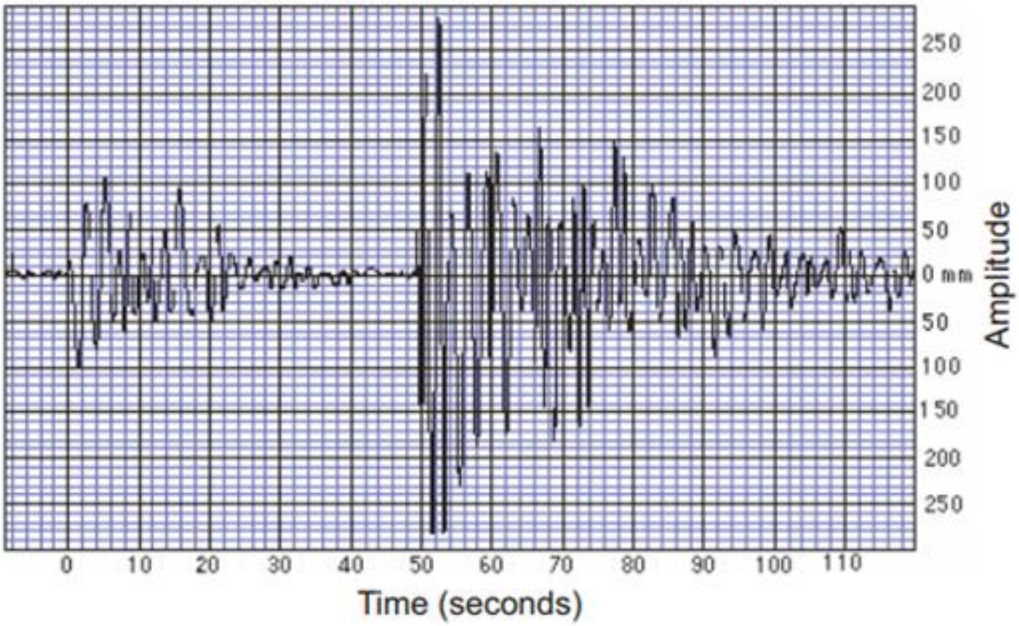
We need at least two more detectors in order to locate the epicentre!
This is done the following way:
After we obtain the epicenter distance for each station, we draw a circle with its center being on the station and its radius being equal to the epicentre distance. We find the place where the three circles intersect: This is the earthquake's epicentre!

Graph.4: The trilateration technique

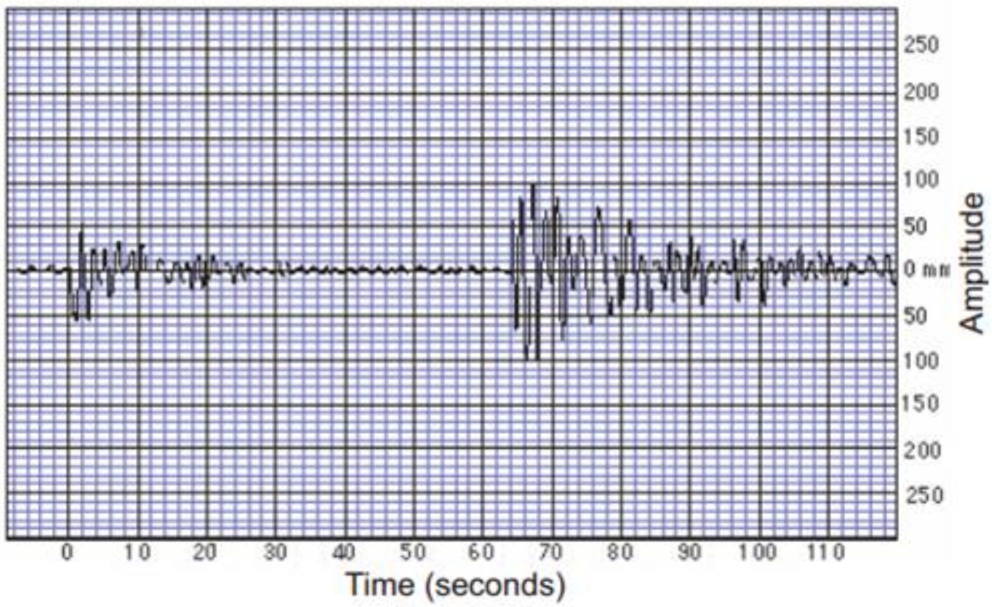
IMPLEMENTATION

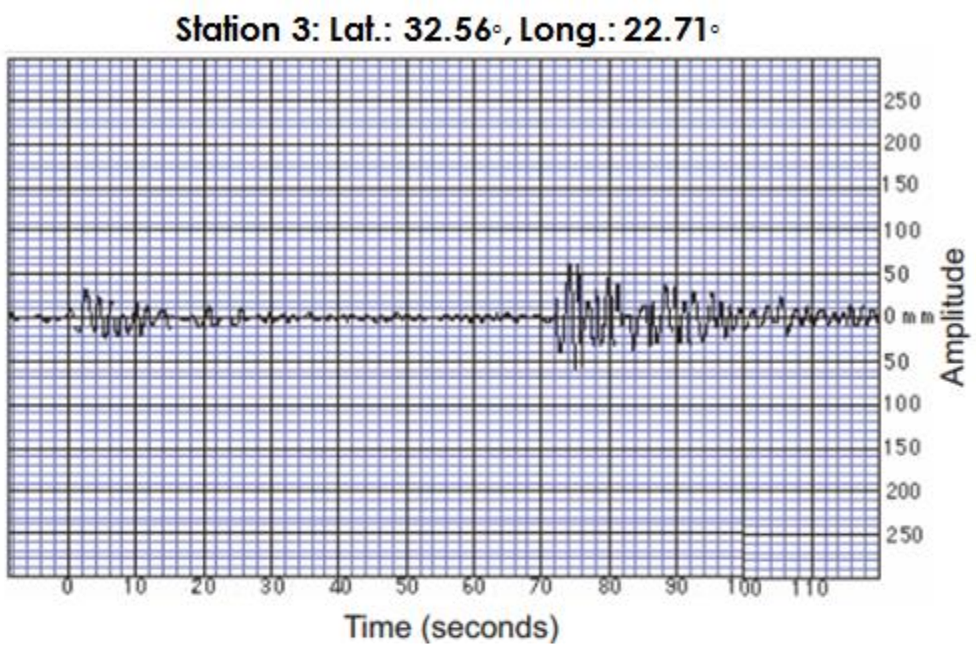
Divide in groups and observe the following three seismograms:
Note the units in the horizontal and the vertical axes.

Station 1: Lat:41.59◦, Long: 24.86◦



Station 2: Lat.: 41.46◦, Long.: 34.30◦





For each seismogram:

- Determine the arrival time of the S- waves (Ts) and the arrival time of the P- waves (Tp). Subtract them to find the time difference:
ΔT = Ts - Tp

- Write the Ts, Tp, ΔT for each seismogram at a spreadsheet.

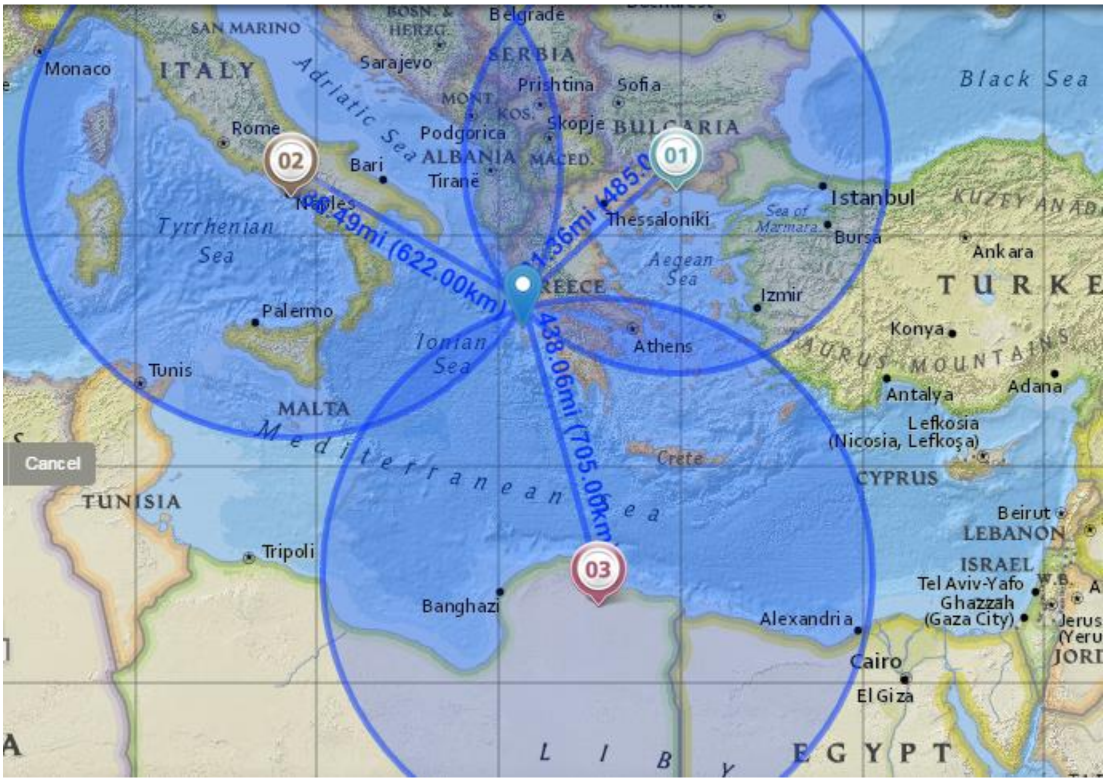
- Using graph 2 and the method presented on graph 3, find the epicentral distance (Δ) for each station. Note Δ at the spreadsheet too for each station.

- Now that you have found the epicentral distances for each seismogram, you can apply the trilateration technique to find the epicenter.
The technique will be applied using the Interactive Mapmaker at http://mapmaker.education.nationalgeographic.com/

- Use the guidelines (http://tools.inspiringscience.eu/author/resource/uuid/4624f4e6) on how to calculate the epicenter using the interactive mapmaker.
- Note the coordinates of your epicenter at your notebook.

The epicenter location is at: Lat: 38,67◦, Long: 20,60◦

A correct implementation of the activity will result in the students' obtaining an image like the following for the epicenter location determination:



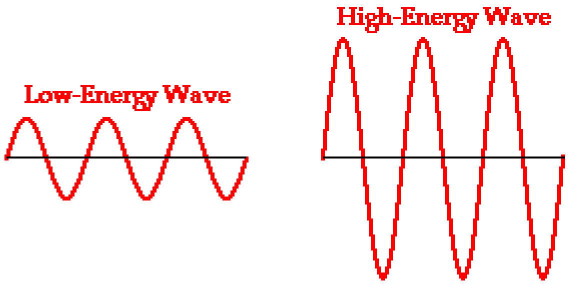
The correct inputs for the spreadsheet are the following:

Station	Latitude (°)	Longitude (°)	Ts (sec)	Tp (sec)	ΔT (sec)	Δ (km)	A(mm)
A	41,59	24,86	50	0	50	485	285
B	41,46	34,3	64	0	64	622	100
C	32,56	22,71	72	0	72	705	60

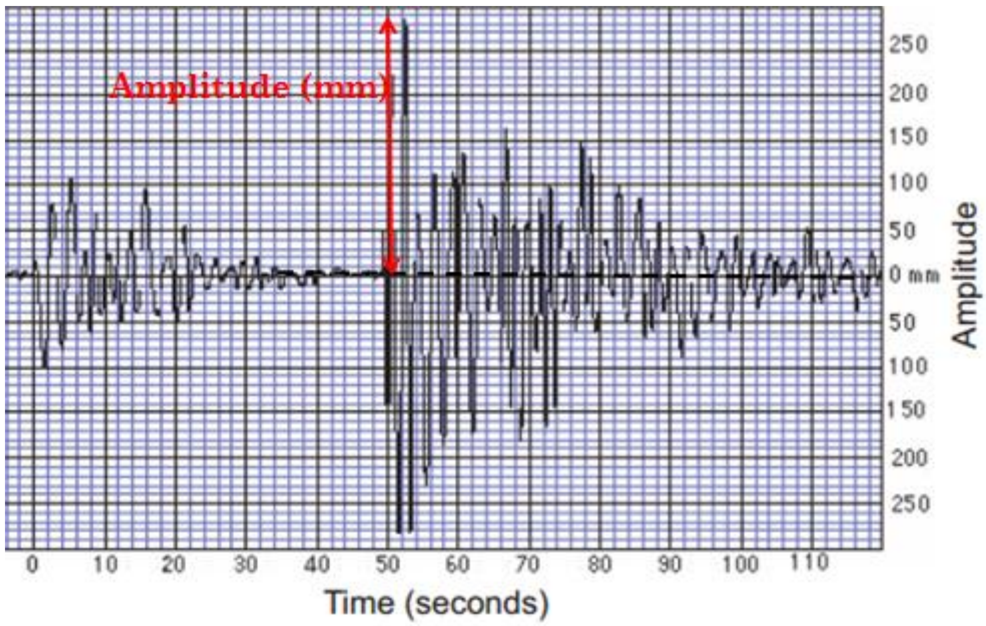
The last column of this table will be filled by the students in the following part of the activity. The next part of the activity: "The Earthquake's Magnitude" is optional. However, it is suggested that it is implemented for the sake of completeness.

PART B - The Earthquake's Magnitude

After having completed the determination of the location of an earthquake's epicenter, the next step is to determine the strength of the earthquake.
This is done by mesuring the magnitude of the earthquake using the Richter magnitude scale which has been defined previously (Orienting and Asking questions phase). The magnitude of an earthquake is an indicator of the total energy released in form of seismic waves from the rupture in the earth.
The energy and thus the magnitude depend on the amplitude of the seismic waves: As the energy of the seismic waves increases, the amplitude of the ground's oscillation increases too.

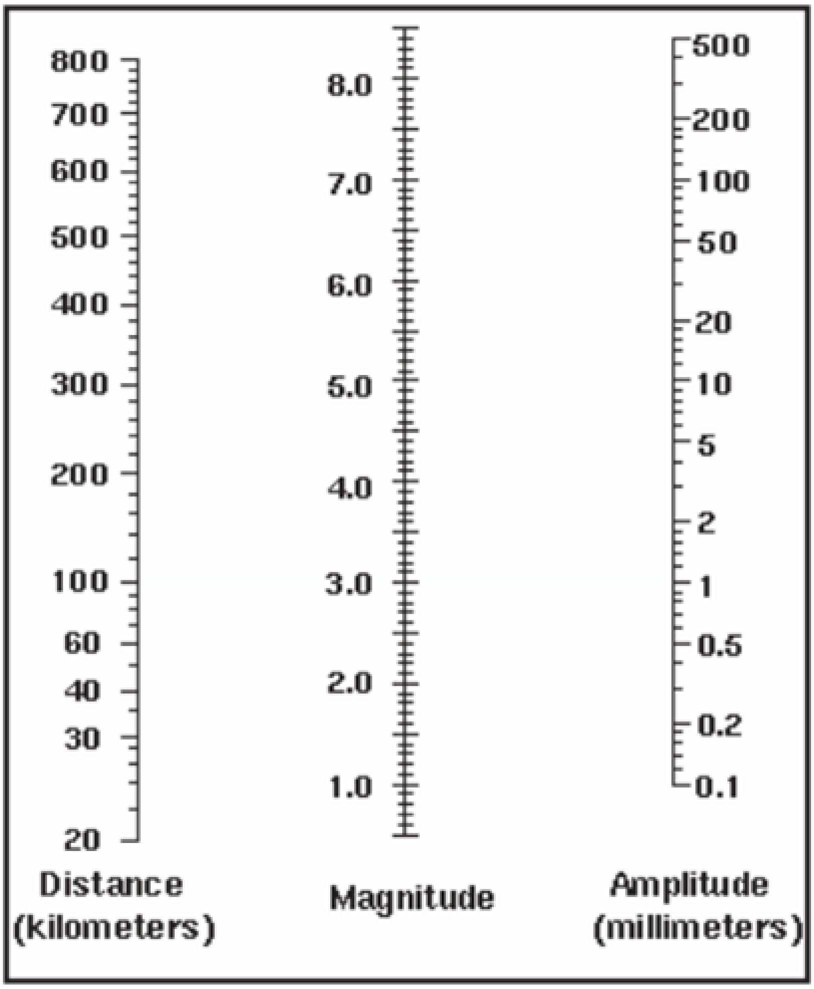


This amplitude can be measured using a seismogram the following way:
We find the line of zero amplitude and measure the height of the highest S-wave. The amplitude is measured in mm.



Another variable on which the energy and magnitude depend is the epicentric distance of the waves.
If we assume that we observe two earthquakes of the same amplitude, the one originating 100 km further than the other, then we can conclude that the further one carries more energy. This happens because the energy lost by the earthquake during its travel towards the station increases with distance. Therefore, if the amplitude is the same, the initial energy released by the rupture will be greater for the furthest earthquake.

In order to estimate the magnitude of the earthquake, we use the Richter Nomogram:



An earthquake detected by three or more stations will provide us data about:
a) The epicentric distance for each station (Previous activity)
b) The amplitude measured in each station.

Different combinations of distance and amplitude result in different earthquake magnitudes. In this part of your investigation, you will use the three seismograms presented to you at the previous part of your investigation, in order to determine the magnitude of the earthquake.

IMPLEMENTATION

- Measure the amplitude of the three seismograms provided to you at the previous part of the activity. As you can see, each tick on the seismograms corresponds to 50mm.

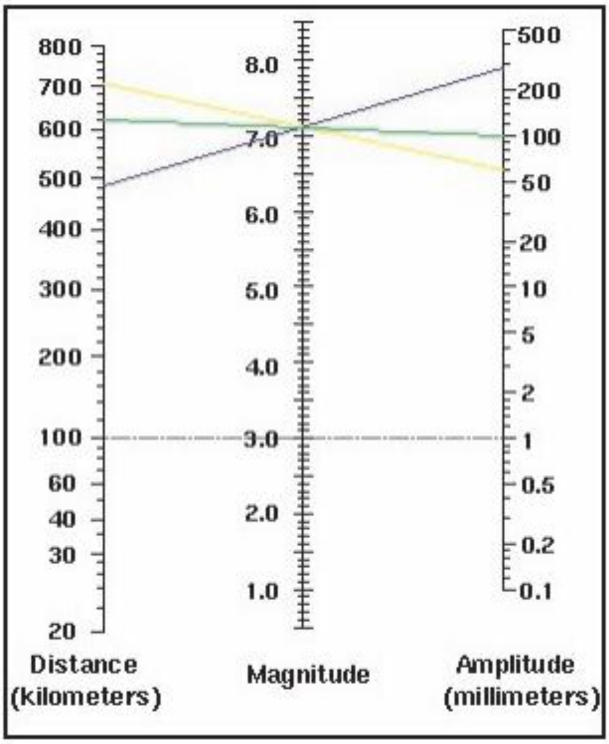
- Note the amplitude of each seismogram at the last column of your spreadsheet.
- Use the Richter nomogram (it would be optimal if you could print the nomogram from here):

i) For each seismogram, note the epicentral distance and the amplitude on the respective columns (left and right) of the nomogram.
ii) Connect the two points with a straight line. The line will intersect the middle column (earthquake magnitude).
iii) Repeat for the other two seismograms.

Now you will have three lines connecting the left and the right column. If your results are correct, then the three lines will meet at a specific point in the middle (magnitude) column. This is the Richter magnitude of your earthquake!

Note the magnitude of the earthquake at your notebook.

The magnitude of the earthquake described above can be found to be 7.1 according to the nomogram reading.



Analysis and Interpretation: Gather results from data

PART A - The Earthquake's Epicentre

Each group will present their epicentre location.
Compare your results and discuss with your classmates and your teacher any possible discrepancies.

What are the experimental uncertainties in your investigation?
Try to estimate the error in the epicentre's location.

Parameters that can affect the accuracy in determining the epicentre are:

a) The precision in finding the S-P time interval.
b) The precision in pinpointing every station on the map.
c) The precision in drawing the circles with the correct radius between the epicenter and each station.

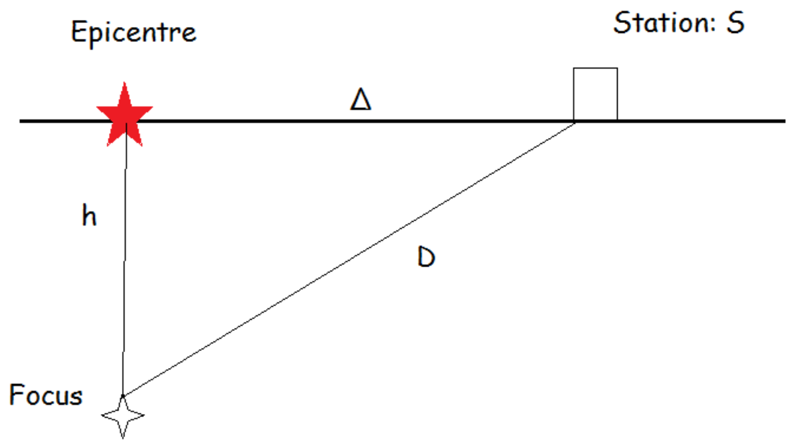
The last two factors can be improved by optimizing the zoom options of the interactive map. When you draw the circles in order to find their intersection point, if you zoom in you will observe that the three circles don't coincide in one point, but instead a triangle is formed. If you draw a circle which will enclose the triangle within it, then we can assume that the circle's radius equals to the epicentre uncertainty, and its center is defined as the epicentre location.
The following discussion concerning the investigation of the parameter of depth can be omitted. However it is most relevant to the curriculum and requires the use of basic math and physics skills from the students.

During the hypothesis generation and design phase you solved a short exercise considering two waves of different speeds propagating at a straight line. Different observers were set at different distances from the wave source and recorded the time interval of each wave.
We found that the time interval between the two waves scales with the distance between the observer and the source.
Exactly the same method is applied for the determination of the earthquake's epicenter.
Discuss with your classmates and your teacher to evaluate the above statement.

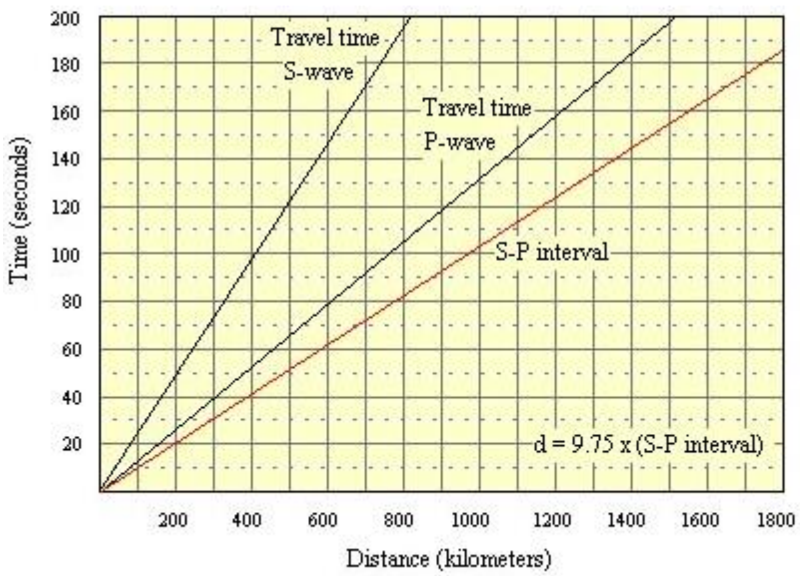
Investigation of the parameter of depth

Until now we have considered that the earthquakes are generated at zero or negligible depth compared to the epicentral distance.
Let's investigate the dependency of the arrival times on the depth of the earthquake.

We are assuming that the earth is uniform and thus that the S- and P- waves propagate in straight lines. Furthermore, the speeds of the S- and the P- waves are constant with respect to depth.
Assume that a station S is located at an epicentral distance Δ from the epicentre . The focus of the earthquake is found at a vertical distance h below the epicentre.
The focus and the station are separated by a distance equal to D.

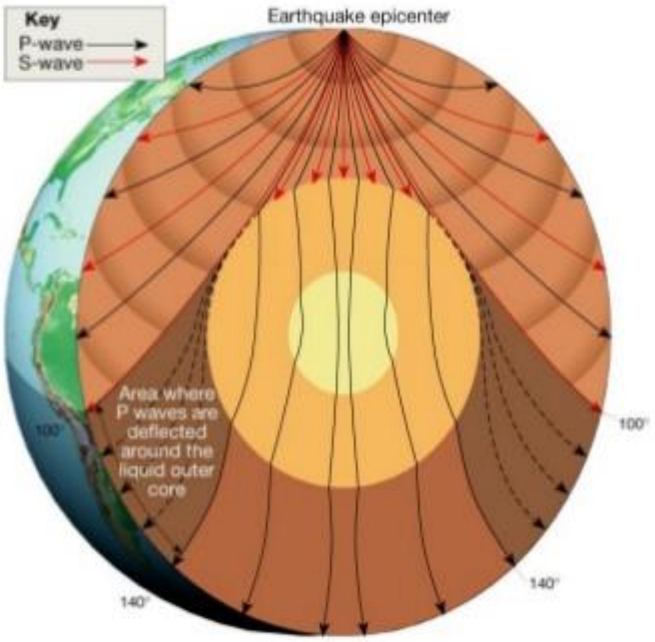


Assume that the S- and the P- waves originate from the focus and travel a straight distance equal to D until they reach the station.
The S- waves travel with Us = 3.5 km/s and the P- waves with Up = 7km/s. The S- waves reach the station at a time equal to Ts and the P- waves at a time equal to Tp.
a) Find a formula which will relate the distance D to the time difference : Ts-Tp.
b) Using the picture abve, find the relationship between D,Δ and h. (Hint: is the triangle orthogonal?)
c) Taking into account the two solutions above, find an expression for Ts-Tp with respect to h and Δ.
d) Assume an epicentral distance of Δ = 100 km and two depths : h1 = 10km and h2 = 30 km. What is the time difference Ts-Tp for each depth?
e) Check the following graph of the S-P time interval time difference vs epicentral distance and compare the time difference you calculated for the two depths to the time difference it provides for Δ=100km.
What do you observe?



The results seem inconsistent, but this happens because we compare a time-epicentral distance plot with time differences occuring when the depth of the earthquake is not negligible.
When seismologists deal with earthquakes of varying depth, they employ different methods in order to calculate the epicentric distances.
One of them is the Brunner method. For each depth there is a specific Time difference - epicentre distance curve which can be used to better interpret our data.

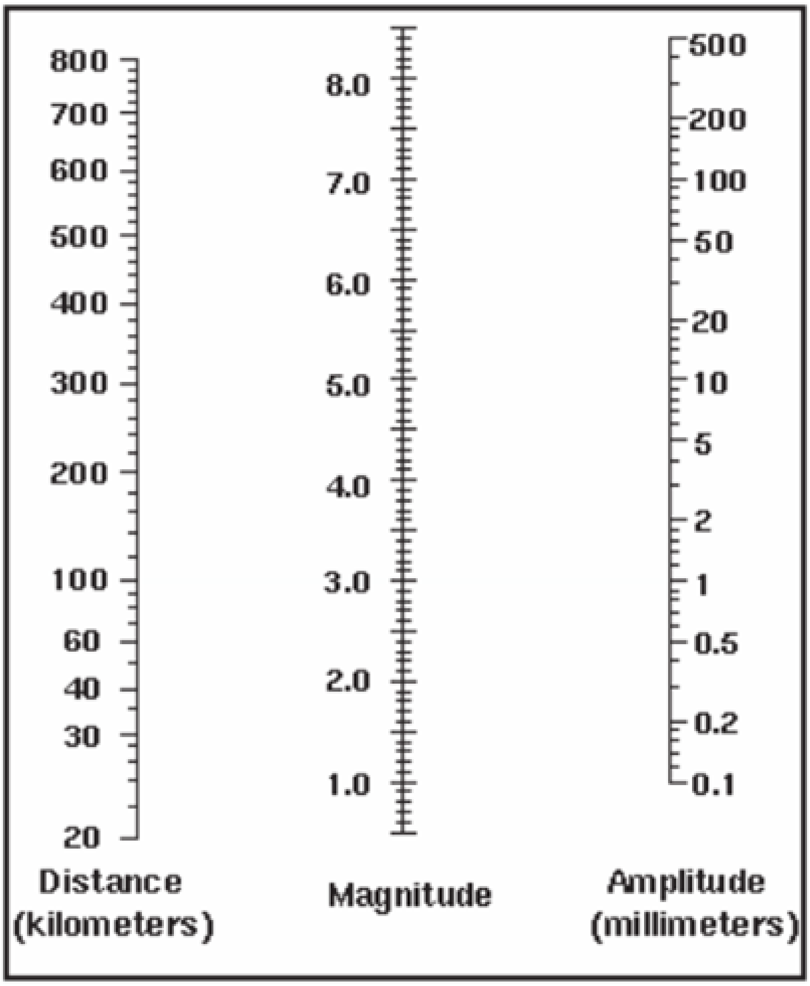
Considering the model of the depth we discuss here:
This is generally not the case because earth is not uniform and thus the speeds of the S- and P- waves differ with depth. As the depth Since the speeds differ, the seismic waves are diffracted and their paths are not generally linear. Furthermore, the S- waves are transverse and thus cannot penetrate the liquid core of the earth and are reflected. The model we discuss can be considered valid for shallow earthquakes, with short epicentral distances.
See the following picture for further insight:



The next part of the analysis describes the investigation of the Richter nomogram and can be omitted if the time schedule is tight.

Part B - The Earthquake's Magnitude

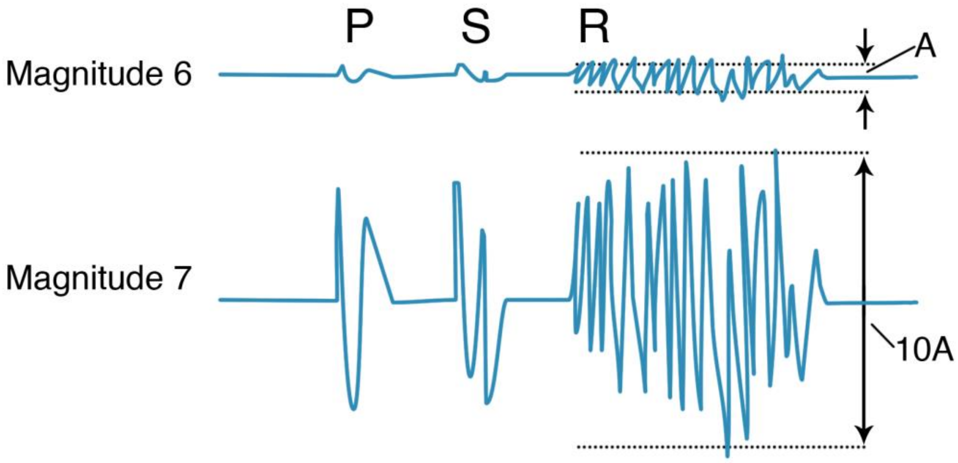
The magnitude of the earthquake was estimated using a Richter nomogram with the amplitude and the epicentral distance as inputs.
Use the nomogram of the previous phase of your activity.



Magnitude vs Amplitude

Assume that the epicentric distance is equal to 100km.
Find the magnitudes M1,M2,M3 of an earthquake with amplitude equal to 1, 10 and 100 mm.
Discuss your findings.
How does the magnitude scale with amplitude?
How much higher amplitude does an earthquake of magnitude 6 have compared to a magnitude 4 earthquake?

Observe the following plot.
Does it agree with what you found?



Magnitude vs Distance
Now we will perform the same investigation now keeping amplitude a constant.
Keep amplitude equal to A=100mm and draw a horizontal line passing from magnitude M = 7. This will lead to epicentral distance equal to 600km.
Now do the same thing for A=100mm, and for various M, from 6 till 3.
What do you observe?
How does the magnitude change with distance if the amplitude is kept constant?

Students will observe that for the first part,
the magnitude is increased by one unit when the amplitude is increased tenfold. This is the definition of a logarithmic scale.

The earthquake's magnitude can be calculated from the formula:

$$\mathrm{M} = log_{10}\left(\frac{A}{Ao}\right)$$

assuming that the distance between seismograph and epicentre equals to 100km, and Ao = 0.001mm.

For two different earthquakes of amplitudes A1, A2 the logarithmic properties imply that:

$$M1 - M2 = log_{10}\left(\frac{A1}{Ao}\right) - log_{10}\left(\frac{A2}{Ao}\right) \rightarrow$$

$$M1 - M2 = log_{10}\left(\frac{\frac{A1}{Ao}}{\frac{A2}{Ao}}\right) \rightarrow$$

$$M1 - M2 = log_{10}\left(\frac{A1}{A2}\right)$$

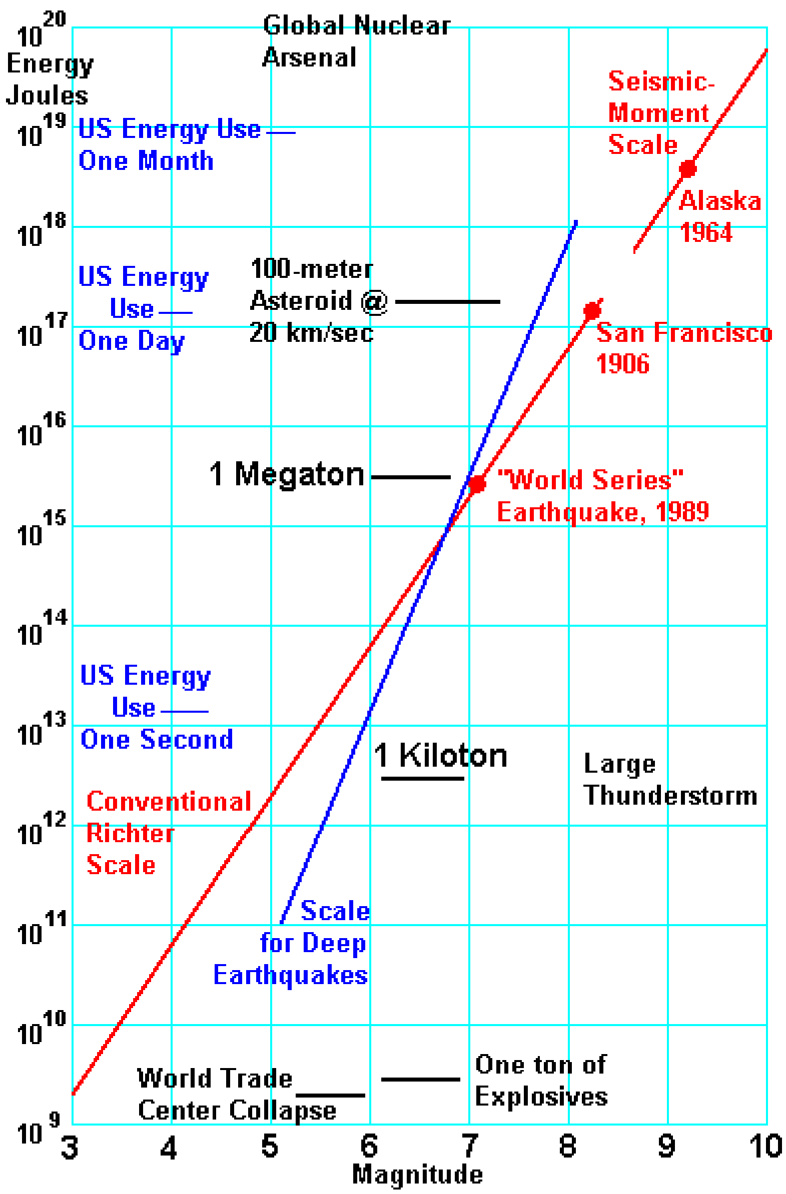
Therefore if the 1st earthquake has 10 times the earthquake of the 2nd earthquake, its size will be one unit higher.

This part can be used in order to introduce (or refresh) the students' knowledge of logarithms.

For the second part,
the magnitude increases by 1 unit when the distance is doubled in order to keep the same amplitude.
This means that the energy of the earthquake is higher since the surplus of energy compensates the energy loss of the waves during their travelling a greater distance.

Magnitude vs Energy
As we have discussed, the magnitude relates directly to the energy carried by the seismic waves.
Every wave carries energy which depends on the amplitude and the frequency of the waves,the density of the earth, the propagation speed and the time it takes for the wave to travel from the focus to the station.

Observe the following plot:



The horizontal axis displays the earthquake magnitude whereas the vertical axis the energy of the earthquake measured in Joules.

- Use the value of the magnitude you measured in the investigation phase in order to find the energy of the earthquake you studied. Use the red line to map the magnitude into energy.

- If 1 g of TNT releases 4184 J of energy during its explosion, find the energy of the earthquake you studied in equivalent kilotones of explosive.

- Find the energy of an energy of magnitude equal to 5 and compare the values. How many times more energy does the earthquake you observed release in form of seismic waves? How would you interpret this result?

- What is the error in the energy calculation if I overestimate (or underestimate) the magnitude by 1 unit?

- Can you determine what will be the observable effects of an earthquake of the magnitude you observed?

The energy of an earthquake compared to its magnitude can be approximately given by the following formula:

$$log_{10}E = 1,5.M + 11,8$$

The resulting value of energy is measured in erg . In order to convert it in Joules you have to multiply by 10-7.
Our earthquake has M = 7.1, therefore E = 1015,46 J
Using the logarithmic identities again, we can find that if the magnitude of an earthquake increases by one unit, the energy increases 31,6 times. This implies that an earthquake of magnitude equal to 7 has approximately 1000 more energy than an earthquake of magnitude 5.
In other words, 1000 earthquakes with M=5 compare to an earthquake with M=7.

Conclude and communicate result/explanation

Observe the following video to review the technique of measuring the epicentre of an earthquake:

http://highered.mheducation.com/sites/dl/free/0073135151/90798/16_08.swf

Discuss possible differences between the technique proposed from the animation above and your method.

Do you consider the use of three stations as adequate in order to locate precisely the epicenter of the earthquake with the interactive map?

Evaluation/reflection

Each team will present their epicentre results and compare them with the real epicentre as it will be provided by the teacher.
Discuss the trilateration technique that you used in order to locate the epicentre.

If you have carried out the earthquake magnitude part of the activity present your magnitude-energy results too.

Discuss your overall results.
Do you believe that the job of a seismologist is easy? Is it interesting?

Topics for further discussion:

Safety during an earthquake

Once we know how catastrophic an earthquake can be for the environment, let’s see what we should do in case an earthquake happens:

http://www.earthquakecountry.info/dropcoverholdon/

Check this video out and see how one should deal with earthquakes while they happen: https://youtu.be/G57gCZGEPK0

Antiseismic buildings

To protect us from earthquakes, engineers have worked extensively in order to develop solutions for buildings resistant to the catastrophic forces of earthquakes. Look at the following videos and discuss:

https://youtu.be/sxpi9A7_syE

https://youtu.be/-N_Q6Q-3o7M