Topic III

Internal geology of Mars versus Earth

Atmospheric parameters and impact on seismic records

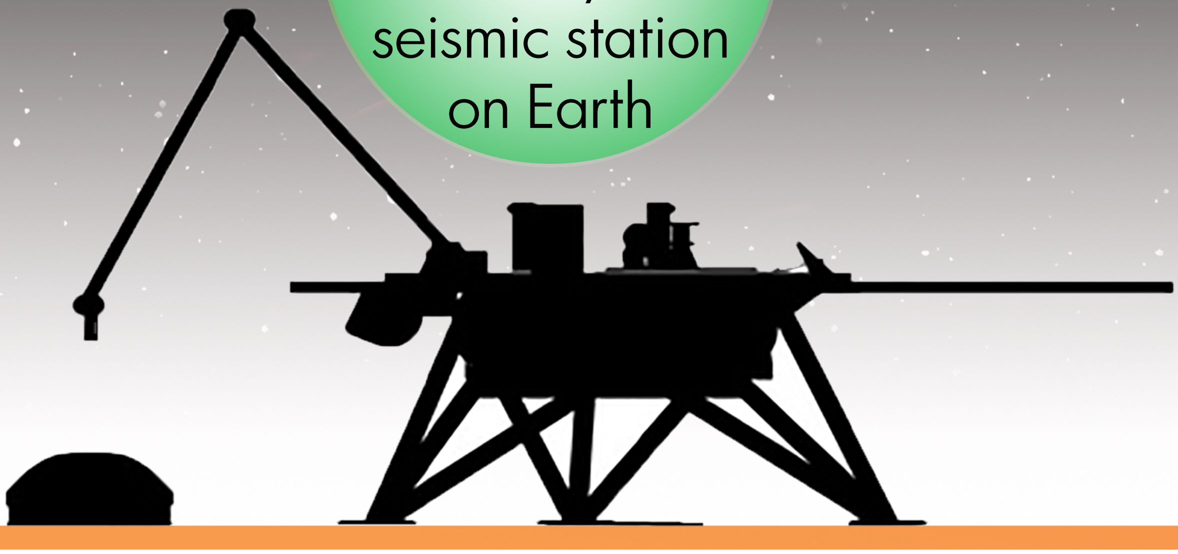
Plasticine balls: how can we explore inside Mars?

Plasticine balls: comparing planets

Determine the location of a Martianquake from a single seismometer

The seismogram : a complex signal

How to estimate the epicenter location with only one seismic station on Earth



Atmospheric parameters and impact on seismic records

1. Introduction & Pb

A seismic station is designed to detect infinitesimal ground motions. Its electronic devices can be impacted by ground motions, and also by atmospheric parameters. We proposed here seismograms where the continuous signal is not flat: day after day big daily arks are observed.

2. Age of students 15 – 17 years

3. Objective

Filter seismic noise by detecting atmospheric variations in the signal

4. Primary subjects

Earth science - Physics

5. Additional subjects

Informatics: SeisGram2K80_ECOLE©

6. Time required 2hrs

7. Key terms

Seismograms – Frequency - Waves

8. Materials

Supports used:

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

Data:

- Continuous seismic signal from February 3 to February 7, 2019, recorded at the station MYLF (Forcalquier, Alpes de Haute Provence, Observatoire de la Côte d’Azur).

9. Background

Using the SeisGram2K80_ECOLE© software

10. Procedures

Step one: Analysis of the continuous signal.

Students have to describe continuous signals from the picture in Figure 1.

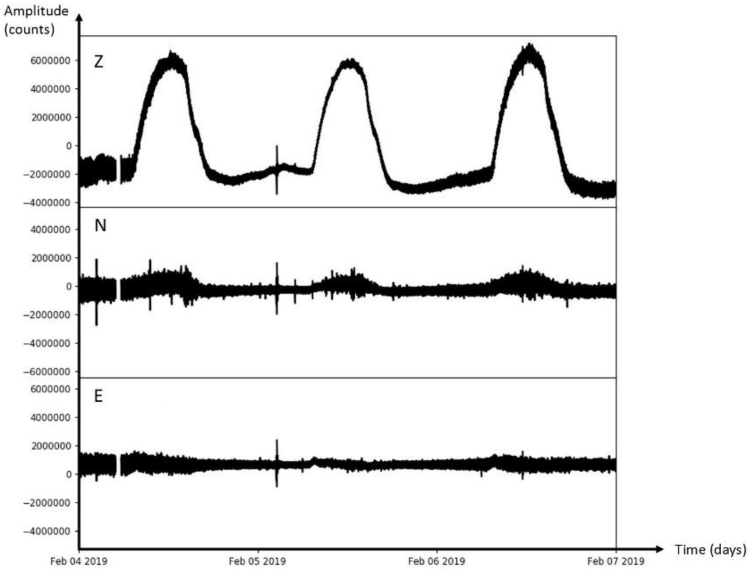


Figure 1. Records from the station MLYF (from February 4 to February 7, 2019). E: East component. N: North component. Z: vertical component.

In this case, students must highlight that the signal from the Z component is clearly daily disturbed: each day, the signal form an ark which increase till midday, and decrease after. This phenomenon is also observed in signal from the north component. The East component seems less impacted.

Step two: Find a physical parameter which can induce this drift of the continuous signal.

The seismogram from the vertical component can be used to ease analyse the continuous signal.

Step three: Find remarkable event except the daily arks.

In this case, an earthquake is recorded on 02h29m06s.

But in this continuous signal four others earthquakes are recorded (Fig. 2).

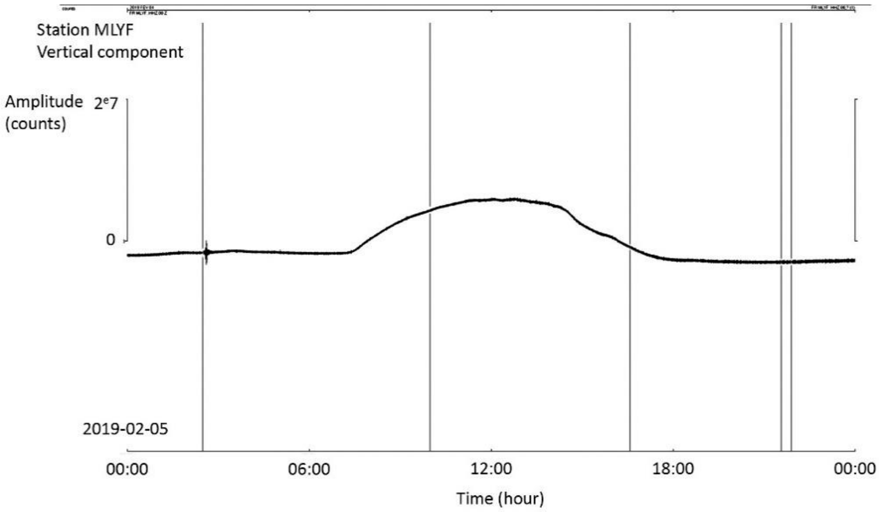


Figure 2. Continuous signal from the station MLYF (February 5, 2019). Vertical black lines: pick of earthquakes recorded this day.

Step four: Observation of these earthquakes

With SeisGram2K and the zoom and scroll tools, try to identify seismic waves recorded at each pick marker on Figure 2, and find the corresponding earthquake in Table 1.

time	Latitude (deg)	Longitude (deg)	Depth (km)	Magnitude
02/05/2019 02:23:20	44.623	6.999	5.22619	1.10
02/05/2019 02:59:21	44.620	6.996	5.90243	0.98
02/05/2019 03:14:54	44.627	6.995	3.97904	1.05
02/05/2019 03:24:12	44.632	6.994	4.50887	0.67
02/05/2019 03:30:24	44.622	7.002	5.23938	0.78
02/05/2019 03:46:13	44.631	7.004	5.74260	0.99
02/05/2019 06:40:26	44.321	7.203	2.69562	0.89
02/05/2019 11:08:10	43.431	6.337	3.15283	1.66
02/05/2019 16:33:52	43.600	5.367	0.00	2.20
05/02/2019 02:19:15	44.510	10.100	22.00	2.3
05/02/2019 06:54:58	43.420	12.470	9.00	2.1
05/02/2019 08:30:59	45.860	7.050	2.00	3.1
05/02/2019 08:31:00	45.850	7.080	10.00	3.1
05/02/2019 09:02:50	45.840	7.030	5.00	2.4
05/02/2019 09:52:45	45.970	6.970	8.00	3.0
05/02/2019 09:55:54	45.880	7.040	8.00	1.5
05/02/2019 11:47:51	44.440	12.190	32.00	2.2
05/02/2019 21:32:59	46.030	5.600	5.00	3.4
05/02/2019 21:52:57	45.980	5.580	10.00	3.2

Table 1. Catalog of seismicity on February 5, 2019 (From the catalog of European Mediterranean Seismology Center and the catalog of the laboratory Géoazur). The covered area is centered on the Region PACA, and North Italy.

11. Discussion of the results and conclusions

Meteorological parameters can have an influence if the sensors is not well isolated from its close environment. On Mars, the seismometer SEIS is protected by a dome against atmospheric activity as daily variation of the temperature and the wind. This dome could withstand squalls of 216 km/h and should even be able to survive winds of 360 km/h (https://www.seis-insight.eu/en/public-2/seis-instrument/wts).

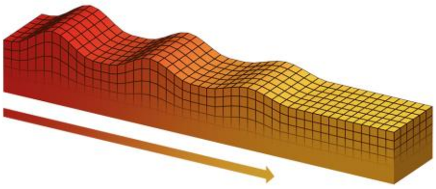
Determine the location of a Martian earthquake from a single seismometer

1. Introduction & Pb

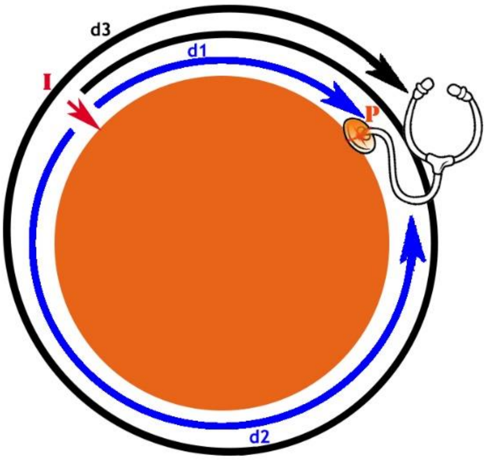
Let's try to understand how with a single seismometer it will be possible to locate the origin of seismic waves created by a meteorite impact or an earthquake.

Theoretically, Mars having a small perimeter, scientists hope to record several wave trains, shifted in time corresponding to the same earthquake or impact.

The waves that can circle the planet several times are the Rayleigh surface waves.



Principe de déplacement d'une onde de surface
(© IPGP/David Ducros).



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I: point of impact, origin of the seismic wave.

P: seismometer

T1: the time taken by seismic waves to travel the distance **d1**

T2: the time taken by seismic waves to travel the distance **d2**

T3: the time taken by seismic waves to travel the distance **d2+2d1** or **d3**

2. Age of students 15 – 17 years

3. Objectives

The Insight mission aims to locate an earthquake on Mars using a single seismometer. The distance between the epicentre, the point on the surface plumbing the area of origin of the earthquake (called the focus), and the receiving station can easily be calculated by measuring the difference between the arrival time of the P waves (which arrive first at the seismometer) and the arrival time of the S waves (which arrive second). The error here is only about 10%.
To locate the epicenter, in addition to the distance to the station, it is also necessary to determine its direction, i.e. its azimuth. The direction in which seismic waves arrive can be determined by the fact that the SEIS seismometer measures seismic signals in all three directions of space.
By studying the horizontal plane data provided by the seismometer axes, the direction can be known with an uncertainty of about 10°. In our experiment we will use an accelerometer to simulate the work of the SEIS instrument.

4. Primary subjects

Physics – Earth Science – Mathematics

5. Additional subjects

Arduino

6. Time required: 2h

7. Key terms.

Epicenter, surface waves, frequency, seismogram

8. Materials

- A pilates balloon, perimeter 250 cm
- Audacity 1.2.6
- 1 piezo cell
- 2 polystyrene bars
- 1 tape measure
- 1 ball of 11,5g and 1,4cm suspended from a 1m wire fixed to a protractor

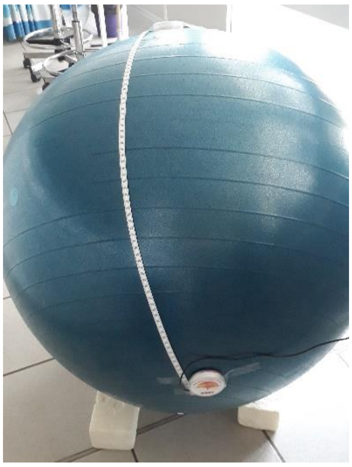
9. Background

The notions of seismic wave propagation, the origins of an earthquake.

10. Procedures

Place the balloon on the polystyrene bars to avoid any contact with the ground
Tape a piezo cell onto the balloon
Determine a striking zone 115cm from the piezo cell
Hang the protractor so that the ball is level with the hitting area.

Let's experiment with a model to better understand the theory
Detail of the experimental device



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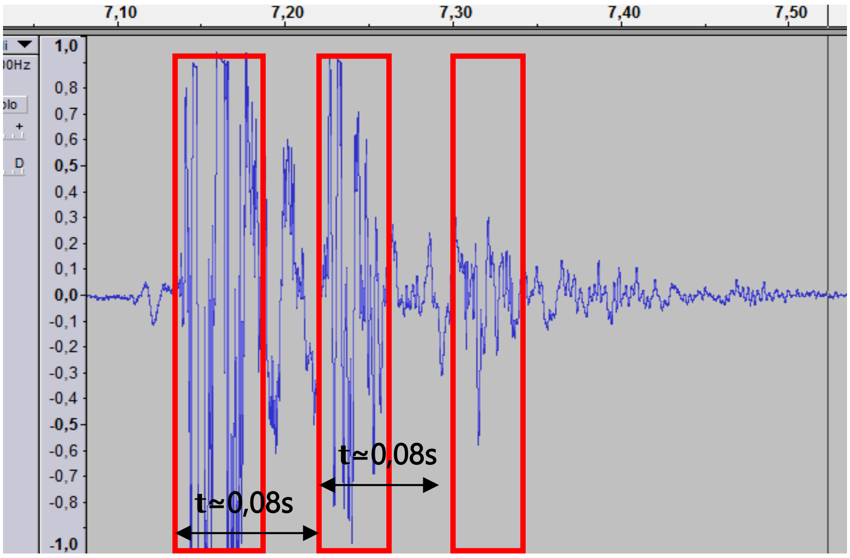
Make several successive recordings with impacts of constant intensity. To do this, move the ball so that the wire faces an angle of 60° with the vertical.

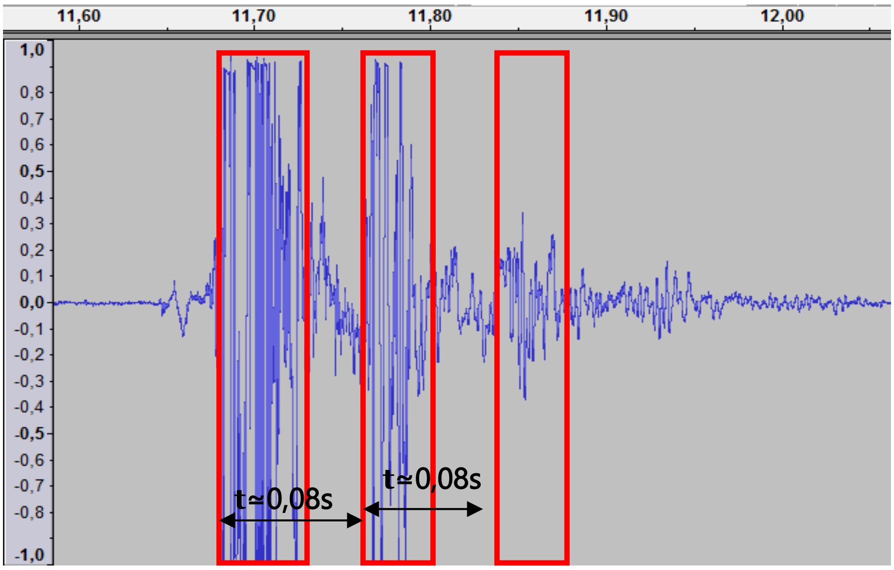
<u>Let's analyze the results obtained:</u>

Several wave trains are observed as predicted by the scientists' simulations. Let's determine the time elapsed between the different wave trains.

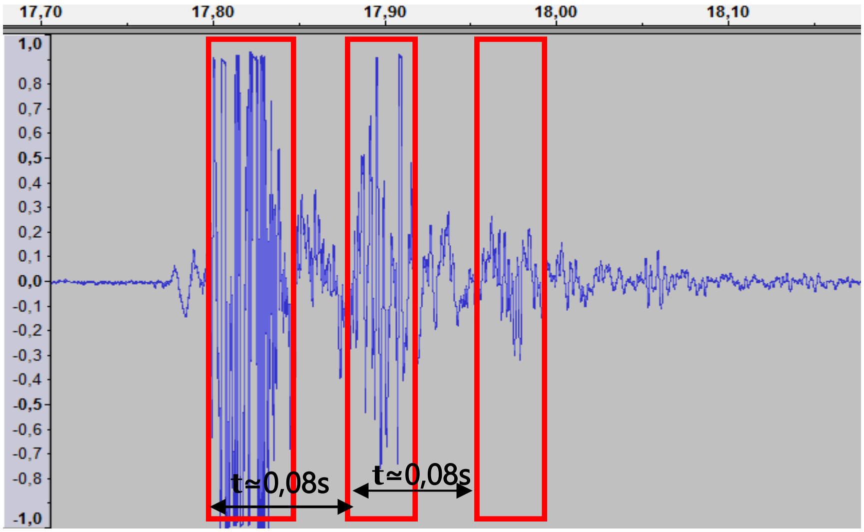
Record 1



Record 2



Record 3



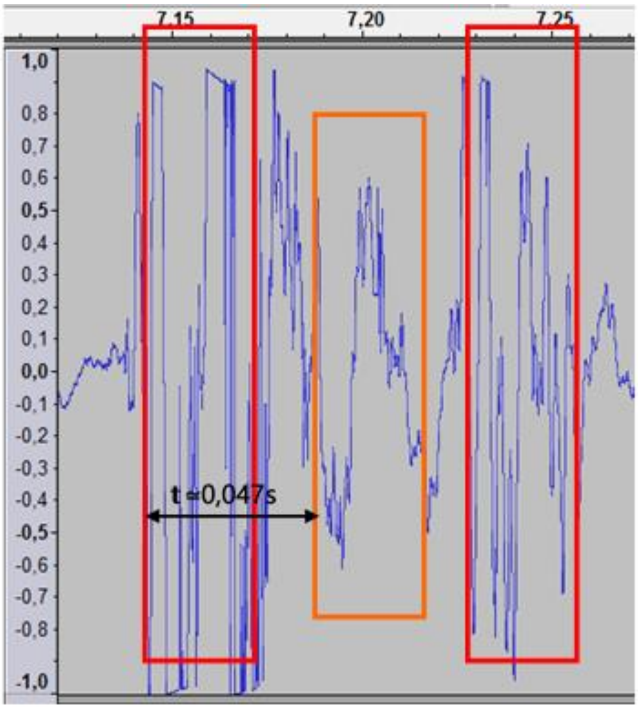
From the obtained results, let us assume that the time elapsed between each wave train corresponds to the time taken by the latter to complete a complete balloon revolution **d2+d1**

We can therefore determine an approximation for the speed of wave propagation on the surface of the balloon.

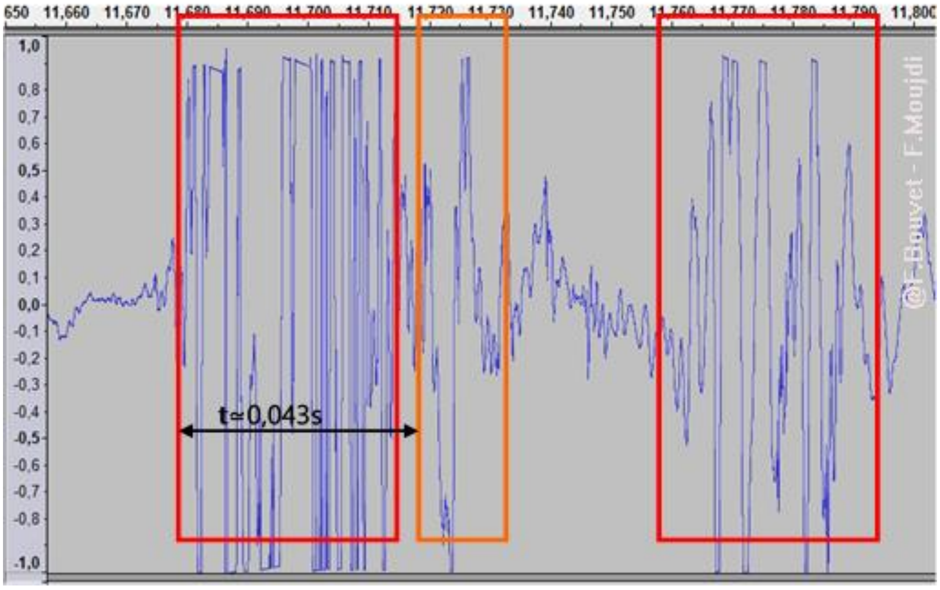
V=d /t =(d1+d2) /t
= 250 /0,08 = **3125 cm.s^{-1}**

Let's take a closer look at the signals between the first two waves trains. We are trying to find out if the waves that travelled the distance d2 were detected by the piezo.

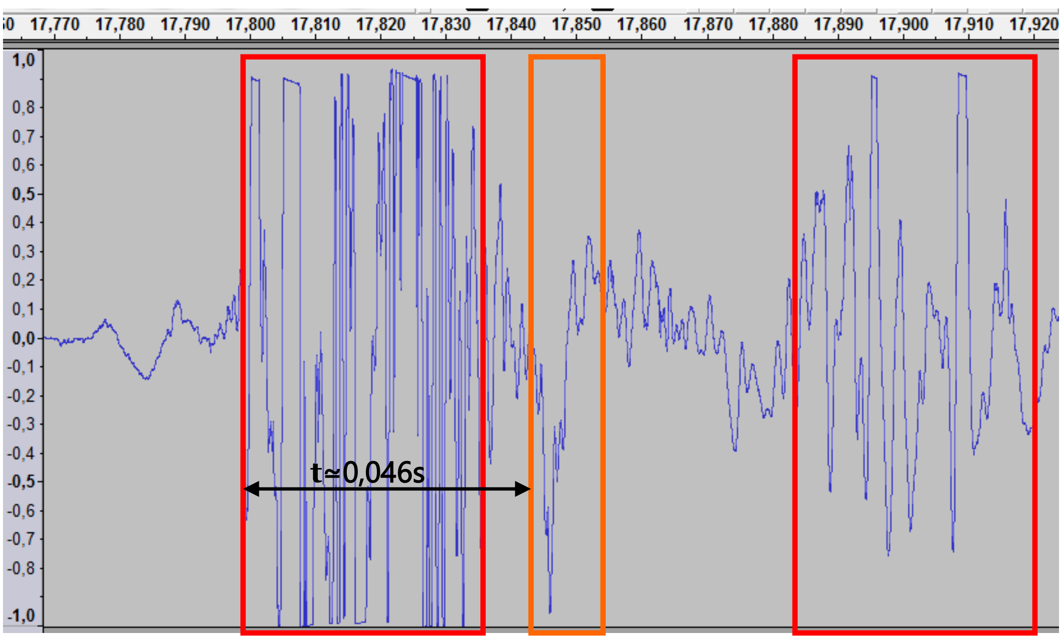
Record 1



Record 2



Record 3



Let us suppose that this signal corresponds to the waves that travelled the distance d2.

We can estimate an impact area.

d2 = **Vx** **t2**

According to the values obtained, we obtain

3125 x 0. 043 ≤ **d2**≤ 3125 x 0. 047

134 cm ≤ **d2** ≤ 146 cm

We can therefore deduce from this

250 -146 ≤ **d1** ≤ 250-134

104 cm ≤ **d1**≤ 116 cm

We obtain an estimate of **d1** corresponding to the real striking zone (115cm).

11. Discussion of the results and conclusions

The distance between the seismometer and the earthquake source, the time of the earthquake, and the average speed at which waves travel over the planet's surface can be estimated by combining the arrival times of waves R1, R2 and R3. Earthquakes of magnitude 4.5 or greater are relatively rare events on Mars, but geophysicists estimate that over the duration of the mission (one Martian year, or two terrestrial years), it should be possible to observe between about 3 and 5.

It is important to note that the effectiveness of the techniques that will be implemented for the InSight mission has been validated on Earth with data from unique stations. (cf: activity on the study of earthquakes on Earth from a single seismometer). These have led to the discovery of one of the Earth's internal structure models commonly used by geophysicists (PREM) with acceptable error bars.

However, there are unknowns, and the validity of the technique summarized above cannot be confirmed until scientists receive and analyze records from Mars.

12. Follow up activities

On the Moon geophysicists were astonished to discover that the lunar crust caused enormous diffraction of the seismic waves, preventing the existence of surface waves. Since the Martian crust, just like the lunar crust, was exposed to a massive bombardment of asteroids early on in the formation of the solar system, its pulverised nature and numerous craters, especially in the planet's southern hemisphere, could also cause seismic waves to be diffracted; seriously complicating analysis.

13. Explore More (additional resources for teachers)

- https://www.seis-insight.eu/en/public-2/martian-science/seismic-activity

- The geology of Mars, edited by Mary Chapman

How to estimate epicenter location with only one seismic station on Earth

1. Introduction & Pb

Usually, students work on epicenter location by using origin time of the earthquake and arrival time of seismic waves. With records from three seismic stations, it is possible to estimate the epicenter location.
On Mars, there is only one sensor to detect and to estimate the epicenter location. We propose here to invite students to estimate the epicenter of the Mw 9.0 Tohoku-Oki earthquake (Mars 11, 2011, Japan), with only one seismic station.

2. Age of students 15 – 17 years

3. Objectives

Use an approach similar to that used by researchers working on the mission insight to estimate the epicenter location of an earthquake with only one record from a three-components seismic station.

4. Primary subjects

Physics – Earth Science

5. Additional subjects

6. Time required: 2h

7. Key terms

Rayleigh waves, Epicentral distance, azimut

8. Materials

Supports used :

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

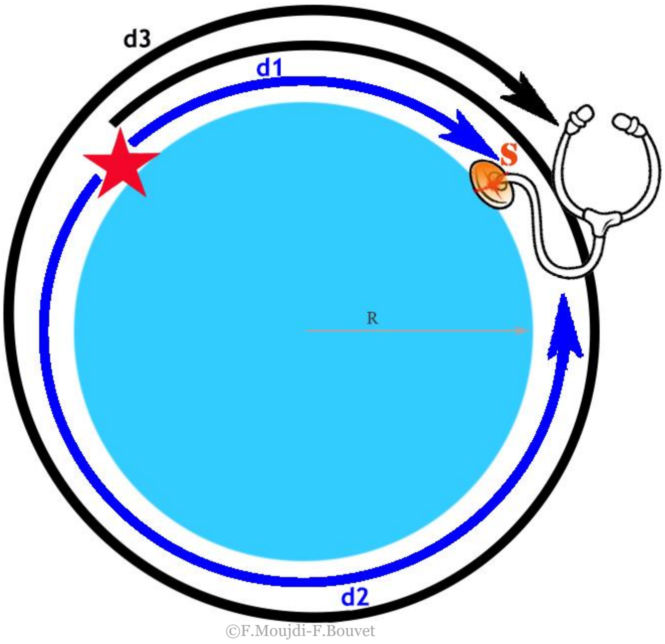
Data :

- The Mw 9.0 Mars 11, 2011 Tohoku-Oki earthquake (Japan), recorded at the station CALF (Observatoire de la Côte d’Azur, Calern, France).

9. Background

- Rayleigh waves detection:
    - They are low periods waves, the associated arks are longer than arks from body waves. They're also higher in amplitude.
    - If the earthquake has sufficient energy, the surface wave can pass several times at the station: packs of longer period signal can appear in the signal.

s (Fig. 1)



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$$distance_{(source/station)} = \frac{t3 - t2}{2} \cdot \frac{2\pi R}{t3 - t1}$$

Figure 1. Theorical approach to estimate an epicentral distance from Rayleigh waves. White start seismic source. Black inverted triangle: Seismic station. d1: shortest distance between the source and the station. d2: longest distance between the source and the station. d3: travel along the d1 distance plus a complete rotation around the planet. t1: arrival time of Raleigh waves after the propagation along d1. d2: arrival time of Raleigh waves after the propagation along d2. T3: arrival time of Raleigh waves after the propagation along d3. R: radius of the planet.

10. Procedures

Students are then invited to pick Rayleigh waves from the Tohoku-Oki earthquake, recorded at the station CALF.

- **pick of the three arrival times, and compute of the epicentral distance.**

Here, the automatic tool provided by SeisGram2k is not used. Students read arrival times and compute manually the distance to the epicenter from the formula in Figure 1.

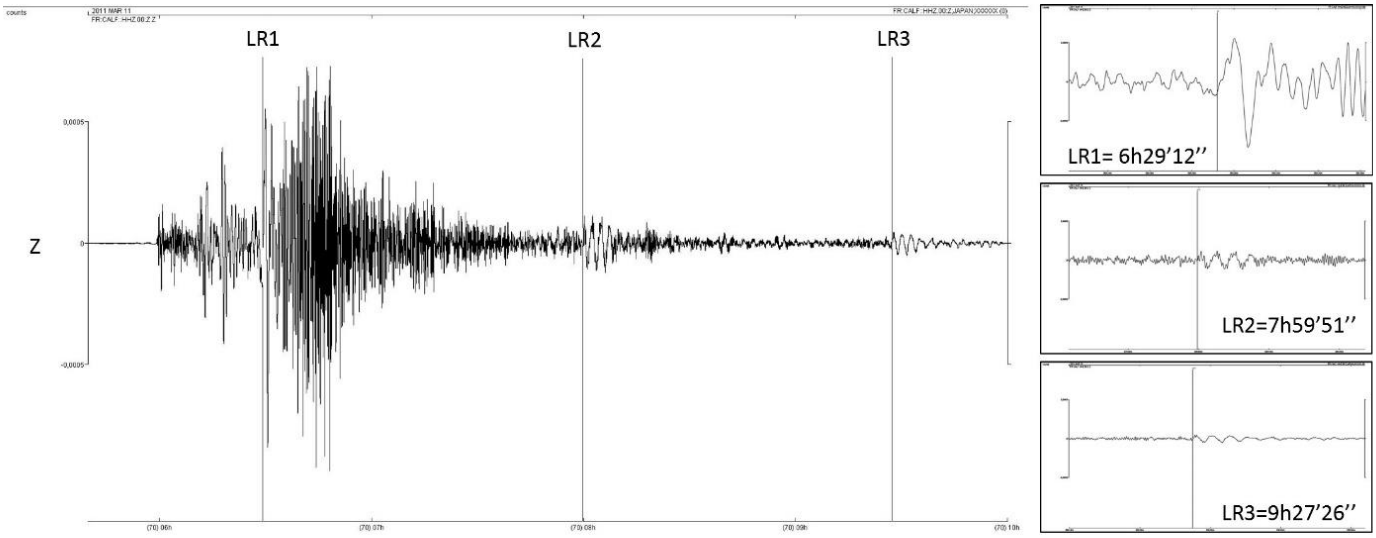


Figure 2. Pick of the three passage of Rayleigh waves (Tohoku-Oki earthquake) at the station CALF. Right column: zoom of each pick, with the observed arrival times (UTC).

10. Discussion of the results and conclusions

In this case, the epicentral distance computed is equals to 9841 km.

- **Estimate the backazimuth.**

The epicentral distance computed previously indicate that the epicenter is on a circle, which the radius is equals to 9841 km. Two parameters are required to find the correct position on this circle: the azimuth, and the backazimut. The azimuth gives the direction of the first ground motion in the horizontal plane at the station, positive clockwise. The backazimut gives the sense where the epicenter is. The polarity of the P wave from the vertical component is required: i) if the polarity is positive, the first motion is upwards, the backazimuth is equals to the azimuth plus 180°; ii) if the polarity is negative the first motion is downwards, the backazimuth is equals to the azimuth.

SeisGram2k allows to determine the azimut value, with the rotation tool. It's possible to virtually rotate the geographical frame and to compute amplitudes in the new frame. By rotating the frame, amplitude of the P wave vary between two maxima, passing by a null value, on each component. The rotation value which allows to cancel the P wave on the East component give the azimuth: the motion is only in the North direction of the new geographical frame.

a. **Detect the first P waves on each horizontal components.**

Use zoom tool of seismogram to select a time windows adapted to highlight the first P wave. The increase/decrease amplitude tool could be used.

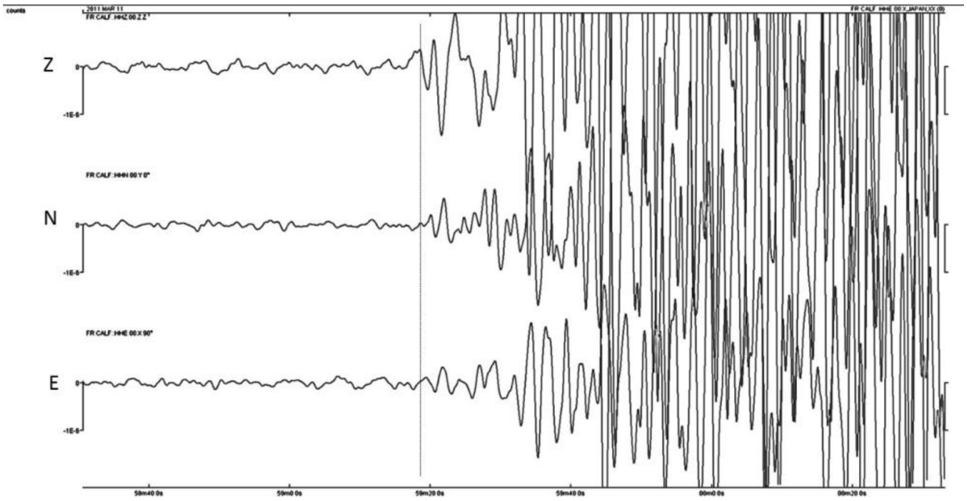


Figure 3. Records of the Tohoku-Oki earthquake. Vertical black dashed line: pick of the P wave. E: East component. N: north component. Z: vertical component.

b. **Rotate horizontal component (clockwise) to cancel the P wave on the East component**

In this case, a rotation equals to +30° allows to cancel the P wave amplitude on the East component. The first motion is in a direction equals to +30° (clockwise) from the North in the real geographic frame: it’s the value of the azimuth.

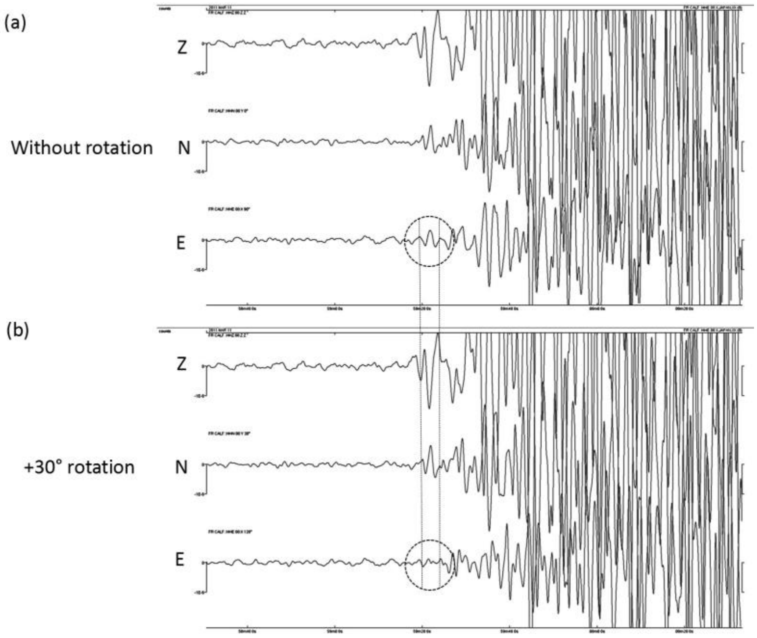


Figure 4. Records of the Tohoku-Oki earthquake. (a) Raw seismograms. Black dashed ellipse: identification of the P wave from the east component. (b) Seismograms after a rotation equals to +30°: the P wave amplitude is canceled. E: East component. N: north component. Z: vertical component.

c. Estimate the backazimut value from the P wave polarity on the vertical component

In this case, the P wave is downwards on the vertical component (Fig. 3): the backazimut is equals to the azimuth.

Information file in SeisGram2K indicate an azimuth equals to 329.5°. This azimuth is corresponding to the direction at the epicenter from the geographic North to the station: it is equals to the angle between the geographical north minus the backazimuth (counter-clockwise).

Plasticine balls: how can we explore inside Mars?

1. Introduction & Pb

During the latest centuries, many geoscientists have been working to unveil the internal structure of the Earth. Apart from observing the rocks on the Earth surface and analysing and testing them using different methods, a wide range of tools to find out how it is the structure of the Earth have been developed.

In 1970, the Kola Superdeep Borehole failed to reach the depth it had been designed for: to drill a hole 15 km deep in the Kola Peninsula (ancient USSR). This deepest hole drilled in the Earth reached a depth of 12,262 metres. So, the geoscientists don't have direct access to any rock below this depth.

Once proven that direct methods like drilling the Earth could not provide information about the internal structure of the whole Earth (its radius being of about 6,400 km), the scientists focused on improving even more the indirect methods that had already being developed since the 19th Century. Refining these techniques and making them more precise has been a major contribution to our current knowledge of the internal structure of the Earth as well as the dynamic processes that take place deep in our planet.

These methods include:

- Calculating the average density of the Earth by knowing its mass and volume.
- Studying the seismic waves that travel through its layers every time an earthquake takes place anywhere on the Earth.
- Studying and analysing the meteorites falling on the Earth surface.
- Studying the general Earth's magnetic field and what causes it.
- Studying how the Earth spins (its rotational inertia).

2. Age of students

14 to 18 years old

3. Objectives

Students can:

- propose hypothesis and discuss them with the rest of students
- suggest methods for testing these hypothesis
- suggest which of these could be useful to probe the Earth
- suggest which of these could be used to probe Mars with the available technology

4. Primary subjects

- Earth science
- Physics
- Maths

5. Additional subjects

Technology

6. Time required 30 minutes

7. Key terms

Internal structure, Earth, Mars, scientific hypothesis, testing, probing, density, seismic waves, magnetism, spheres, meteorites.

8. Materials

- plasticine™ of two colours
- small bar bearings
- several toothpicks
- a Magnaprobe™
- scale (optional)
- slide gauge (optional)

9. Background

Students have to face a problem when they are given two clay ball of the same size but different weight. They are asked to provide hypothesis that could fit with the fact that two spheres that look externally the same (apart from their colour) have a very different physical propertes (mass and, therefore their density).

Then they are asked to suggest methods to test what is the internal structure of both balls and to decide which of those could be useful when studying the internal structure of a planet like the Earth or Mars.

10. Procedures

Give to every group of three students two plasticine balls of different colours but the same size and ask them if they feel any difference between the two balls. They easily realize that the weight, and therefore, the density is different.

Figure 1: Two balls: the same size, different weight. Green lighter, red heavier

Ask them to suggest hypothesis that could explain the difference between the two balls. They can provide five different solutions:

- the two balls are made of two types of plasticine with different densities
- one of the balls has something heavier inside
- one of the balls has something lighter inside
- the density of one of the balls increases gradually as you go deeper in it
- the density of one of the balls decreases gradually as you go deeper in it

(The right answer is the that the heavier one contains a bar bearing inside)

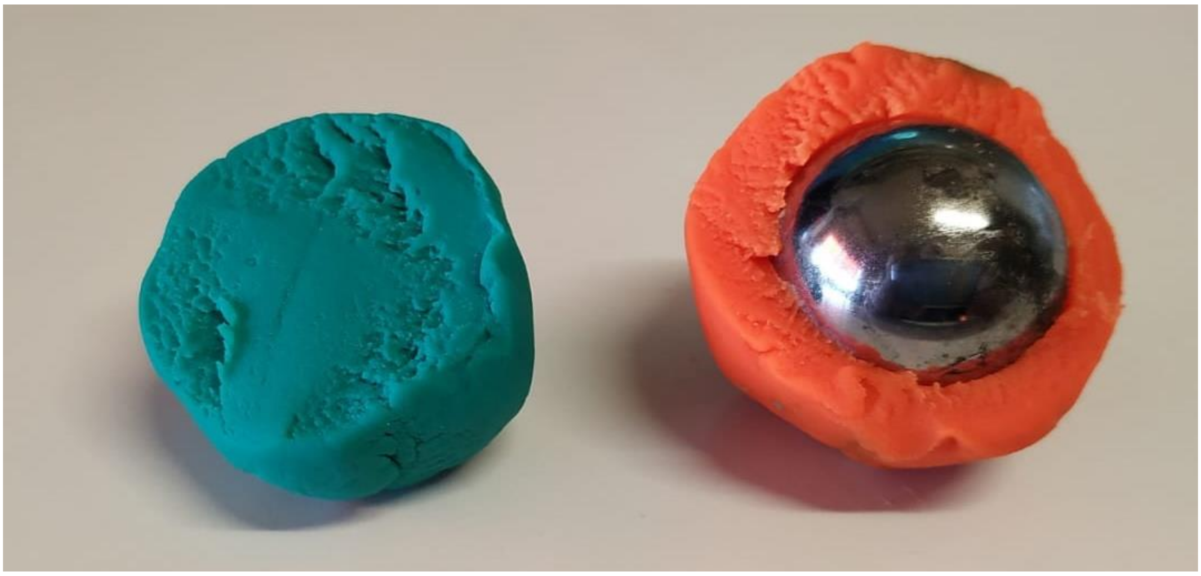


Figure 2: The two balls cut to show their internal structure: green, pure Plasticine™; red ball bearing inside.

Now ask them how, with all the apparatus and technologies available in the Earth, could they test which is the difference between the two balls.

Possible answers:

- weighting the two balls (with a scale) and calculating their density
- drilling them (with toothpicks, for example)
- testing its magnetism (with a small compass)
- using X-rays
- ultrasounds (like the one used to see embryos inside the uterus)
- electromagnetic resonance (EMR) like the ones used in many hospitals
- ionising radiation (alpha, beta or gamma radiation)
- how the Earth spins

Then, ask the students which of these methods are suitable for studying the internal structure of the Earth.

Possible answers:

- weighting the two balls (with a scale) and calculating their density. *Yes, astronomical calculations allow scientists to know the mass of the Earth and, knowing the Earth radius, its possible to calculate the volume, and therefore, the density of the Earth.*

- drilling them (with toothpicks, for example). *Not much, as we have not been able to drill more than 13 km deep.*
- testing its magnetism (with a small compass). *Yes, there's a general magnetic field in the Earth, related with its outer (liquid) and inner (liquid) iron core. It can be detected with a compass.*
- using X-rays. *No, they can't penetrate the Earth.*
- ultrasounds (like the one used to see embryos inside the uterus). *No, they can't penetrate the Earth. However, infrasounds or seismic waves can penetrate the Earth and provide a very useful information about its layers as well as their physical state (solid or fluid).*
- electromagnetic resonance (EMR) like the ones used in many hospitals. *No, they can't penetrate the Earth*
- ionising radiation (alpha, beta or gamma radiation). *No, only gamma radiation can penetrate a few meters into concrete.*
- How the Earth spins. *Yes, the way the Earth spins suggest a denser core inside it.*

Now provide the students with two more clay balls of different colours: one lighter than the lighter they already have (with a ball of expanded polystyrene, EPS, inside) and another one the same weight as the heavier they already have (with a magnet bar inside).

Ask them to order them by increasing density; the results should be:

1. EPS core
2. Plasticine™ core
3. Ball bearing and magnet cores (approximately the same density)

Now, ask them which of these four should be the less suitable to model the internal structure of a planet. (*Answer: 1 and 2, as usually, gravity pushes the heaviest materials to "sink" deep in the core of the planets*).

Provide them with a small compass and ask them wich of the balls 3 or 4 fits better with the internal structure of the Earth and which fits better with Mars. (*Answer: the one with the magnet inside fits better with the model of the Earth as our planet has a general magnetic field related to a liquid iron outer core, while Mars seems to have an iron core but completely solid and, therefore it has no general magnetic field*)

11. Discussion of the results and conclusions

Students can compare the physical properties both of Earth and Mars, discuss which methods are the best to study them, which are available in each planet and compare the degree of knowledge about the internal structure of the Earth and Mars.

12. Follow up activities

Students can use an Internet search engine to research for the equipment of the probe Insight landed on Mars. From this information they can discuss which of the methods suggested for studying the internal structure of the Earth could apply in Mars according with this equipment.

They can also, using a scale and a slide gauge, calculate the density of the four spheres knowing that the formula to calculate the volume of a sphere is:

$$V = \frac{4}{3} \cdot \pi \cdot r^3$$

… and that de density (D) is:

$$\rho = \frac{m}{V}$$

13. Explore More (additional resources for teachers)

- This activity has been developed from the Earthlearningidea “From clay balls to the structure of the Earth” in www.earthlearningidea.com.
- https://www.nasa.gov/. Official website of the National and Aeronautics Space Administration (NASA)
- All the relevant information about InSight Mission in https://www.nasa.gov/feature/jpl/for-insight-dust-cleanings-will-yield-new-science .

Plasticine balls: comparing planets

1. Introduction & Pb

This activity is intended to be carried out after “Activity 4A. How can we explore inside Mars” in which pupils have learned about the different methods for studying the internal structure of a planet. Nevertheless, this activity can be carried out individually and completely apart of the other one.

Two aspects of the study of the internal structure of a planet have been developed along this activity: the distribution of masses inside it and the presence or absence of a general magnetism.

2. Age of students

14 to 18 years old

3. Objectives

Students can:

- propose hypothesis and discuss them with the rest of students
- suggest methods for testing these hypothesis
- understand how these properties allow or not to distinguish between the Earth and Mars
- calculate the density of different clay balls and compare them
- decide which ball models better the Earth and Mars

4. Primary subjects

- Earth science
- Physics
- Maths

5. Additional subjects

Technology

6. Time required

20 minutes

7. Key terms.

Internal structure, Earth, Mars, scientific hypothesis, testing, probing, density, magnetism, spheres, meteorites.

8. Materials

- plasticine™ of different colours
- small bar bearings
- magnets
- small balls of Expanded Polystyrene (EPS)
- a Magnaprobe™
- scale

9. Background

Students are given four plasticine balls of different colours and they are informed about the composition of the four balls.

They have to decide which of the four balls models better the features (distribution of masses and magnetism) of the two planets, Mars and the Earth.

10. Procedures

Provide your students with the four balls but without telling them which colour each sphere is. The four spheres are approximately the same size and their respective composition is:

- *sphere 1*: all of it is made of pure Plasticine™
- *sphere 2*: the Plasticine™ ball contains a ball of Expanded Polystirene (EPS) inside
- *sphere 3*: contains a ball bearing inside it
- *sphere 4* contains a magnet weighting about the same as the ball bearing of sphere 3

Balls 1 and 3 (green and red) as used in the Activity 3

Ball 3 showing the EPS ball inside

Ball 3 showing the magnet inside

Now, ask them which of the four balls fit better with what is expected about the distribution of layers in any planet and which of the four fit better with the internal structure of the Earth and of Mars respectively.

(The right answer is the that the heavier one contains a bar bearing inside)

Now ask them how, all the apparatus and technologies available in the Earth, could they test which is the difference between the two balls.

Possible answers:

- weighting the two balls (with a scale) and calculating their density
- drilling them (with toothpicks, for example)
- testing its magnetism (with a small compass)
- using X-rays
- ultrasounds (like the one used to see embryos inside the uterus)
- electromagnetic resonance (EMR) like the ones used in many hospitals
- ionising radiation (alpha, beta or gamma radiation)
- How the Earth spins

Then, ask the students which of these methods are suitable for studying the internal structure of the Earth.

Possible answers:

- weighting the two balls (with a scale) and calculating their density. *Yes, astronomical calculations allow scientist to know the mass of the Earth and, knowing the Earth radius, its possible to calculate the volume, and therefore, the density of the Earth.*
- drilling them (with toothpicks, for example). *Not much, as we have not been able to drill more than 13 km deep.*
- testing its magnetism (with a small compass). *Yes, there's a general magnetic field in the Earth, related with its outer (liquid) and inner (liquid) iron core. It can be detected with a compass.*
- using X-rays. *No, they can't penetrate the Earth.*
- ultrasounds (like the one used to see embryos inside the uterus). *No, they can't penetrate the Earth. However, infrasounds or seismic waves can penetrate the Earth and provide a very useful information about its layers as well as their physical state (solid or fluid).*
- electromagnetic resonance (EMR) like the ones used in many hospitals. *No, they can't penetrate the Earth*
- ionising radiation (alpha, beta or gamma radiation). *No, only gamma radiation can penetrate a few meters into concrete.*
- How the Earth spins. *Yes, the way the Earth spins suggest a denser core inside it.*

Now provide the students with two more clay balls of different colours: one lighter than the lighter they already have (with a ball of expanded polystyrene, EPS, inside) and another one the same weight as the heavier they already have (with a magnet bar inside).

Ask them to order them by increasing density; the results should be:

1. EPS core
2. Plasticine™ core
3. Ball bearing and magnet cores (approximately the same density)

Now, ask them which of these four should be the less suitable to model the internal structure of a planet. (*Answer: 1 and 2, as usually, gravity pushes the heaviest material to "sink" deep in the core of the planets*).

Provide them with a small compass and ask them with of the balls 3 and 4 fits better with the internal structure of the Earth and which fits better with Mars. (*Answer: the one with the magnet inside fits better with the model of the Earth as our planet has a general magnetic field related to a liquid iron outer core, while Mars seems to have an iron core but completely solid and, therefore it has no general magnetic field*)

11. Discussion of the results and conclusions

Students can compare other physical properties both of Earth and Mars, discuss which methods are the best to study them, which are available in each planet and compare the degree of knowledge about the internal structure of the Earth and Mars.

12. Follow up activities

Students can, also, using a scale and a slide gauge, calculate the density of the four spheres knowing that the formula to calculate the volume of a sphere is:

$$V = \frac{4}{3} \cdot \pi \cdot r^3$$

… and that de density (D) is: $\rho = \frac{m}{V}$

13. Explore More (additional resources for teachers)

- This activity has been developed from the Earthlearningidea "From clay balls to the structure of the Earth" in www.earthlearningidea.com.
- https://www.nasa.gov/. Official website of the National and Aeronautics Space Administration (NASA)
- All the relevant information about InSight Mission in https://www.nasa.gov/feature/jpl/for-insight-dust-cleanings-will-yield-new-science .

The seismogram: a complex signal

1. Introduction & Pb

The ground motion is the result of arrivals of many waves, which have their own frequency. Seismometers record ground motion continually and this continue signal, without arrival of seismic waves, is considered as the ambient seismic noise.

When an earthquake is well recorded, seismic waves are clearly identified relative to the continue seismic noise. But sometimes, these waves had been recorded, but they are not perceptible. Knowing frequencies ranges of seismic waves, it is possible to find an hidden earthquake in the seismic noise.

2. Age of students 15 – 17 years

3. Objective

Filtering a seismogram with adapted bandwidth to observe seismic waves.

4. Primary subjects

Earth science - Physics

5. Additional subjects

Informatics: Audacity software

6. Time required 2hrs

7. Key terms

Wave – Frequency - Seismograms

8. Materials

Supports used:

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

Data:

- The Mw 4.8 January 1, 2019 earthquake (Greece), recorded at the station CALF (Observatoire de la Côte d'Azur, Calern, France).
- The Mw 6.3 December First, 2018 earthquake (Indonesia), recorded at the station CALF.

9. Background

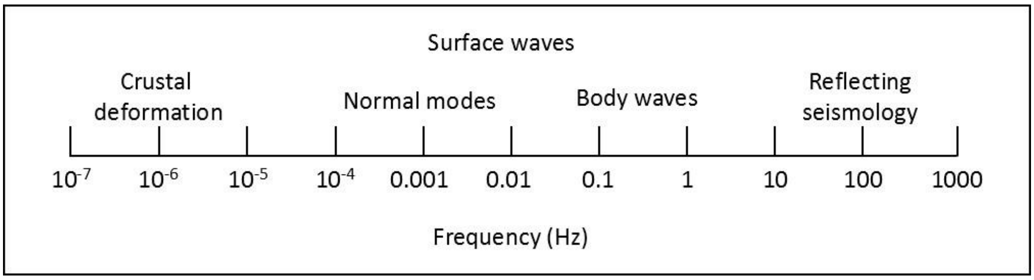
Seismogram2K -

10. Procedures

Step one: processing of the Greek earthquake to display P waves

The raw seismograms are extractions of continuous seismic signal where seismic waves should be perceptible. On each component, no seismic waves are observable. Related to the magnitude (Mw 4.8) and the epicentral distance (15.87°). By considering an average P wave velocity of 8 km/s (related to the epicentral distance), first P wave should arrive on 11:45:43 a.m.

By providing the following frequencies scale to students, they can estimate a specific frequencies range for body waves.

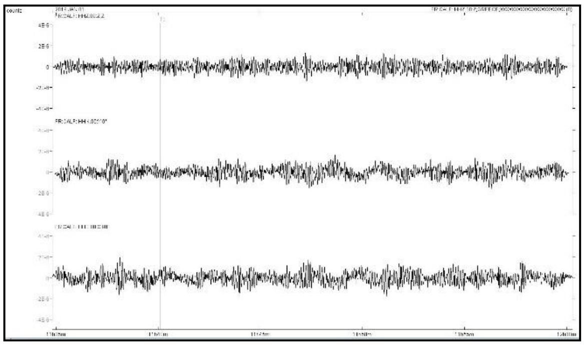


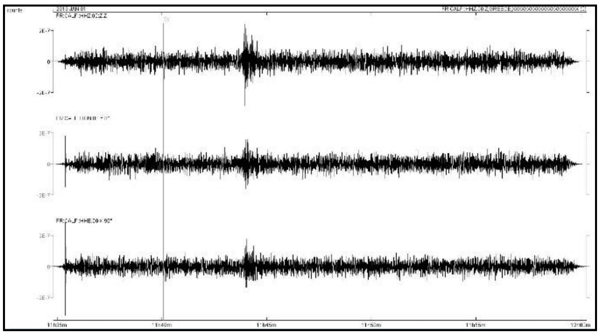
This scale (from Stein and Wysession, 2013) is an indicative scale. Student can observe that the body waves frequencies spread out from values lower than 0.01 Hz and upper than 1 Hz.

Exercise: test different bounding values for a bandpass filtering in order to highlight seismic waves.

In this case, the lower value for a bandpass filtering must be greater than or equal to 1 Hz. The greater value has no influence on the emergence of seismic waves.

Results:





Step two: processing of the Indonesian earthquake to display P waves

As previously, no seismic waves are observable in raw data.

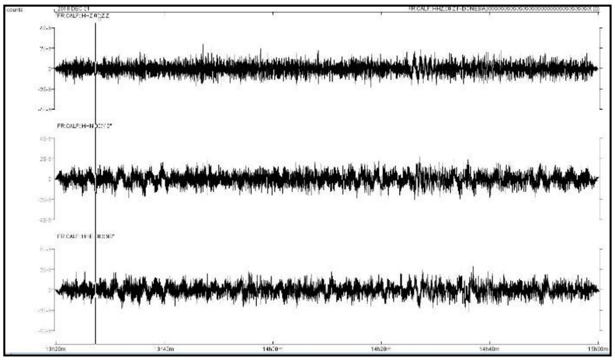
Exercise: students are again asked to found adapted values for bandpass filtering which allow highlighting seismic waves.

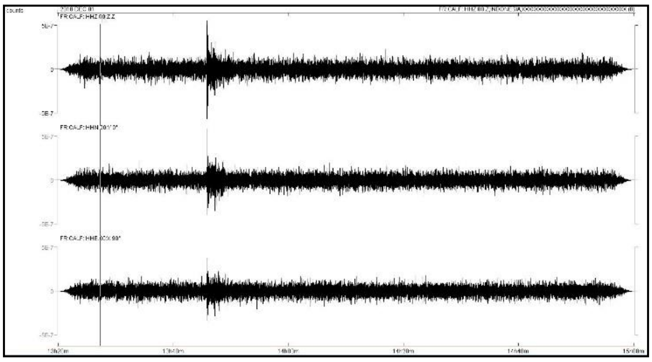
In this case, the lower value for bandpass filtering to display P wave can be greater than or equal to 0.5 Hz.

First conclusion: although seismic waves are not observable in seismograms, they can be highlighted with an adapted processing. These two steps show that P waves are easly observable in frequencies range greater than 1 Hz.

But what about S waves and surface waves ?

Results:

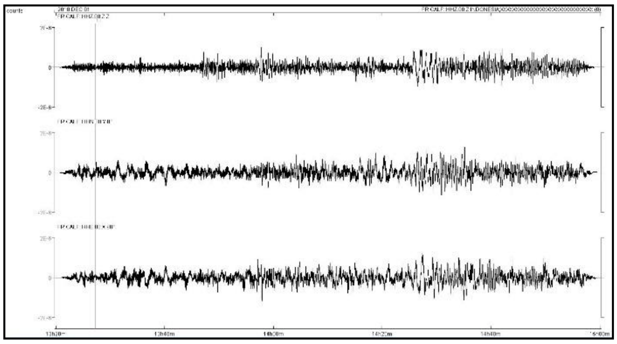


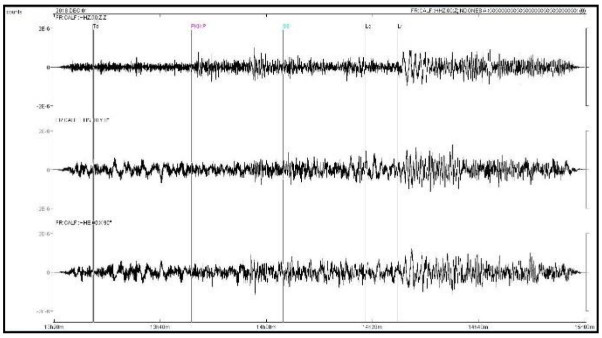


Step three: processing of the Indonesian earthquake to display P, S and surface waves

Exercise: students are asked to find adapted values in order to highlight P, S, and surface waves.

In this case, range values between 0.01 and 0.1 Hz allows displaying body and surface waves. Pick of theorical arrival times with SeisGram2K allows to easy identifying the different waves packs. For this teleseismic event P waves are in fact PKIKP waves, and S waves are SS waves. Rayleigh waves are well display and easly identifying.





11. Discussion of the results and conclusions

Seismograms contain a large frequency content, and seismic waves could be hidden in the seismic noise, on Earth as on Mars. Scientists will have to process future data with accuracy in order to detect waves from future impacts and marsquakes.

Main conclusion:

Seismograms contain a large frequency content, and seismic waves could be hidden in the seismic noise, on Earth as on Mars. Scientists will have to process future data with accuracy in order to detect waves from future impacts and marsquakes.