CHAP. II: Earth’s atmosphere and gaseous envelopes

THE ATMOSPHERE

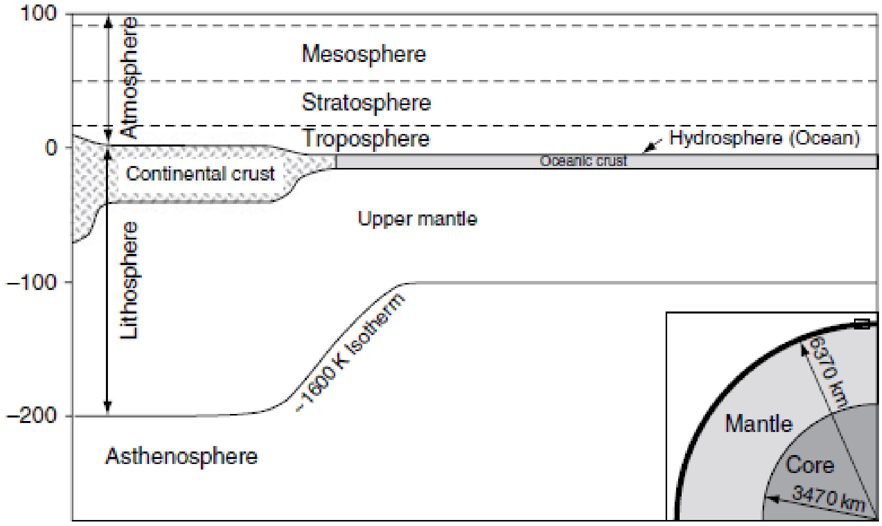


FIGURE 2.1. The spheres of the Earth. Inset on the lower right is a section of the Earth showing the core and mantle. The outer rind comprises the lithosphere, hydrosphere, and atmosphere, shown in the main panel.

1- Introduction

With the exception of Mercury, each planet in the solar system has its own atmosphere. The Earth is the only planet that has a discontinuous liquid envelope called the hydrosphere. Life on earth is closely linked to the presence of these two envelopes. It is within these two envelopes where atmospheric circulations take place, they play a capital role in the definition and regulation of the climate.

2-Heat balance of the earth

The energy on the surface of our planet has a double origin:

Internal origin: coming from the center of the earth, its flux is 0.05 W m-2.

External origin: coming from the sun “solar energy”. It is 342 W m-2.

It should be noted that the earth releases as much energy to external space as it receives.

These radiated fluxes are influenced by two important effects: the **albedo**, which reduces the solar radiation reaching the ground and redirects it towards space, and **the greenhouse effect**, which intercepts part of the Earth’s infrared radiation towards space and returns it to the ground.

3- Composition of the atmosphere

The **atmosphere** is a gaseous envelope surrounding the Earth. Huge amounts of methane, ammonia, water vapor and carbon dioxide that make up our atmosphere come from the center of the Earth!

At first the Earth did not have an atmosphere. This must have escaped into space in the same way as the vapors of a boiling liquid. Indeed, the gases of the primitive atmosphere, helium and hydrogen, were light enough to escape the force of attraction of the Earth under the effect of the intense radiation of the Sun, and the majority of these gas was lost in space. Certain gases were also expelled by volcanoes at the beginning of the Earth's existence and by the first living beings.

The atmosphere plays several roles: it provides us with the air we breathe, its gases retain the heat from which the Earth benefits, and its protective ozone layer serves as a screen against the ultraviolet (UV) radiation emitted by the Sun.

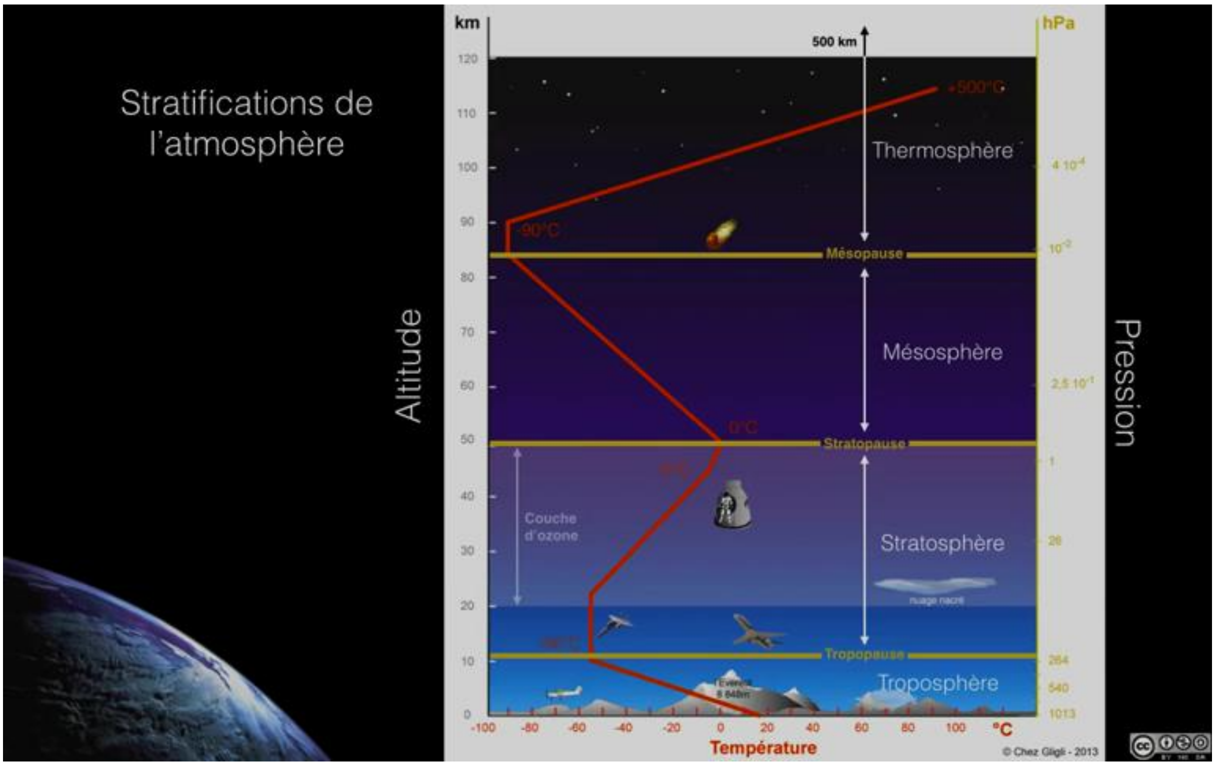
The atmosphere is mainly made up of a gas mixture: air. It includes:

- Carbon dioxide (CO2): 0.035%
- Nitrogen (N2) 78%
- Oxygen (O2) 21%
- Argon (A) 0.93%, Water vapor (H2O) 0 - 4%, Neon (Ne) 0.0018%, Krypton (Kr), 0.000114%, Hydrogen (H) 0.00005%, Nitrogen oxide (N2O) 0.00005%, Xenon (Xe) 0.0000087%, Ozone (O3) 0 - 0.000001%

4-Atmosphere's layered structure

The Earth's atmosphere has a layered structure whose limits are set to changes in the sign of temperature variations with altitude. The layers encountered from bottom to top are:

- **The troposphere**: Its thickness varies between 13 and 25 km depending on the region. It contains 80 to 90% of the air by mass and almost all of the water vapor. Most of the meteorological phenomena take place in the atmosphere. The temperature there decreases by around 6°/km to around -60°C. Its top boundary is the **tropopause**.
- **The stratosphere**: It extends up to 50 km altitude. Most of the atmospheric ozone is found this layer. The temperature is initially constant around -60° then rises to around 0°C. Its upper boundary is the **stratopause**.
- **The mesosphere** up to approximately 80 km. The temperature drops again to -90°C. It is the coldest part of the atmosphere. Its upper border is **the mesopause**.
- **The thermosphere**: Air molecules are very rare, its thickness and temperature depend on solar activity, it can extend from 350 to 800 km altitude and the temperature varies from several hundred to several thousands of degrees.
- The lower part of the thermosphere is called **the ionosphere**. The **ionosphere** reflects short waves (radio waves). These waves, emitted by a transmitter, bounce off the ionosphere and are sent back to Earth. If they are turned over at a certain angle, they can go almost around the globe. The ionosphere therefore makes it possible to communicate with very distant regions.



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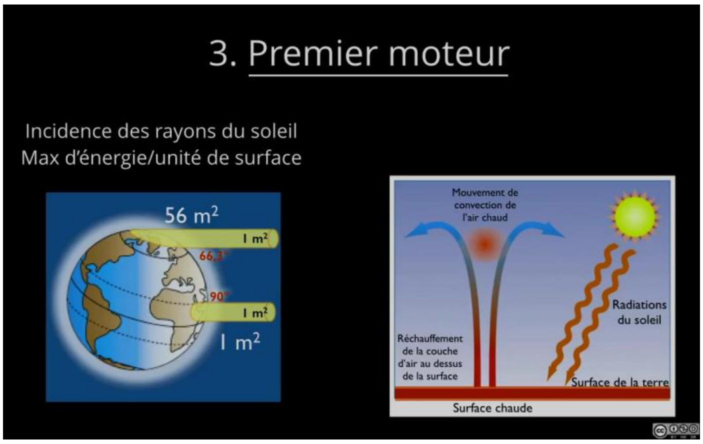
5- Atmospheric circulations



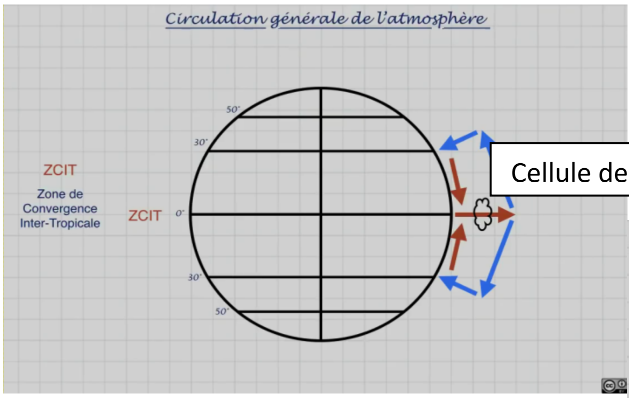
The first cause of the circulation of the masses of air in the atmosphere is the difference in the energy the earth receives, from the sun, in the equatorial and polar zone.

If the earth is immobile, atmospheric circulation, linked to thermal imbalances between the equator and the poles, would be a simple convection system with winds blowing from the poles towards the equator and the heated air which rises up at the equator returns to the poles. The presence of Coriolis forces fragments this convection cells to give a latitudinal climatic zonation.

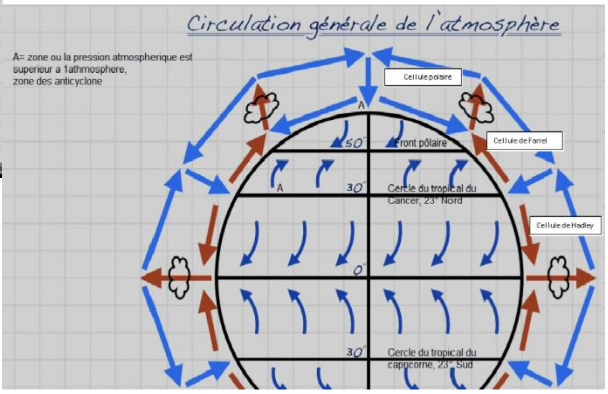
In the equatorial zone, it is hot. Evaporation is intense. Hot air loaded with humidity rises in altitude then moves towards the poles and descends when it has cooled sufficiently, generally at the level of the tropics (Cancer (23°26′10.3″) and Capricorn). Part of these dry air masses returns towards the equator forming what are called **Hadley cells** and another goes towards the polar front. The latter, hot and light and humid, meets the air masses coming from the pole, rises in altitude or part of it moves towards the tropics and descends thus forming the

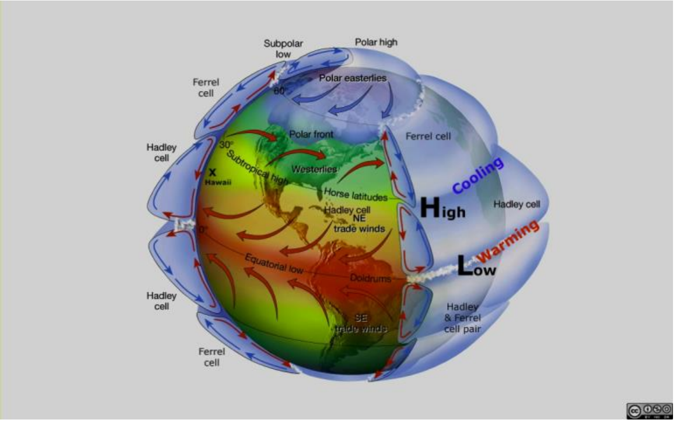
Ferrel cells and the part which moves towards the pole to forms the **polar cells**. The air masses which descend to the level of the tropics create high atmospheric pressures (dry zone) (P>1atm) and those which rise to the level of the equator and the polar front create Anti-cyclones (P<1atm) with lots of rain.

The winds leaving the tropical circle **of Cancer towards the equator** will be deflected to **their right** while those coming from **Capricorn** will be deflected **to their left** thus forming **the inter-tropical convergence** zone. These winds are otherwise **called trade winds**.



Cellule de Hadley





6- Astronomical control of the earth's climate

The earth is currently subject to a regime of contrasting climates which corresponds to an interglacial period. Climates are controlled in the first place by the degree of insolation which depends on the latitude and the place of the earth in relation to the sun. Seasonal variations are due to fluctuations in insolation linked mainly to the inclination of the earth's axis of rotation.

The Serbian astronomer Milutin Milankovitch demonstrated between 1920 and 1941 that the Earth undergoes three variations which are the cause of glaciations and warm periods:

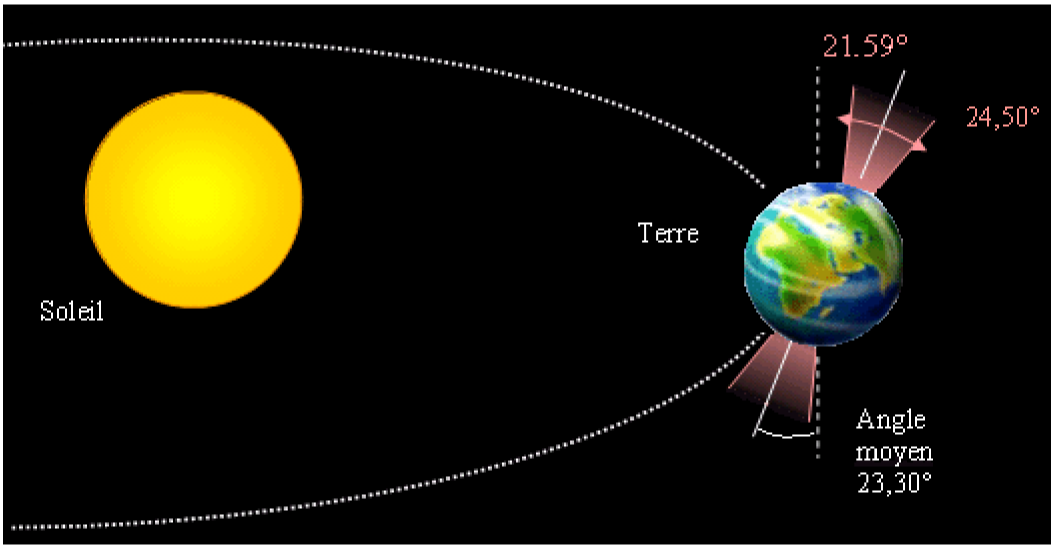
1- The obliquity of the axis of rotation of the earth;

2- The eccentricity due to the variation of the Earth’s orbit;

3- The precession of the equinoxes

6-1 The obliquity of the earth’s axis of rotation

The Earth's axis of rotation is currently tilted at 23°27'. But it varies between 21°59' and 24°50' over a period of 41,000 years. This fluctuation affects the distribution of the energy received at different latitudes depending on the seasons, in particular the duration of the polar nights at the highest latitudes. When the obliquity reaches 24°50' this leads to harsh winters in mid-latitudes. But when the obliquity is less significant it favors glaciations and reverses when it is greater.

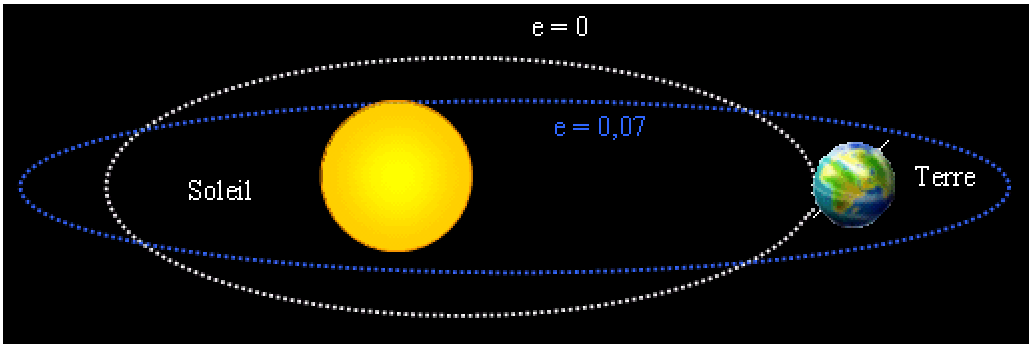


L'obliquité de l’axe de rotation de la Terre

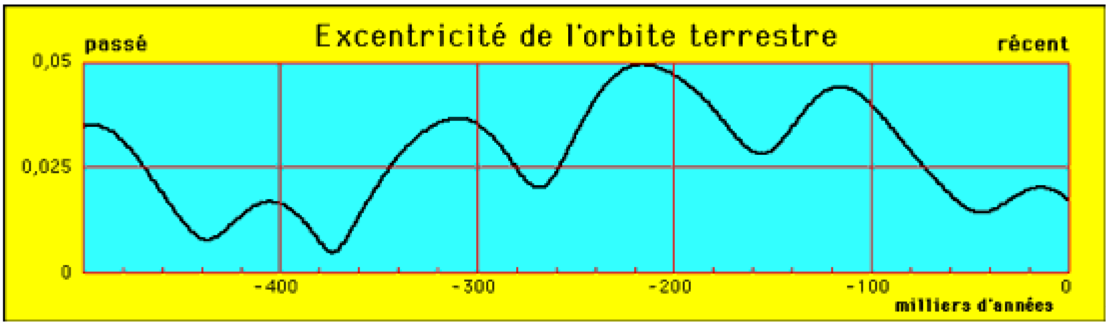
6-2 Eccentricity (the variation of the Earth's orbit)

The mass of the Sun controls the movement of the Earth in space, but the presence of other planets (especially Jupiter) in the Solar System disrupts this movement and causes long-term variations in the parameters of the Earth's orbit. The eccentricity, which is 0.02, measures the difference between the Earth's orbit and a perfect circle. It varies between 0 and 0.07. Its period varies according to a period of 400,000 years and one of 100,000 years. Therefore the overall flux of radiation that it receives from the Sun varies, depending on its location in space and time.

The Serbian astronomer Milutin Milankovitch demonstrated between 1920 and 1941 that all these variations are the cause of the glaciations that the Earth has undergone. The last great glaciation peaked 22,000 years ago, temperatures were about six degrees lower than today, and we can expect the ice to return in several tens of thousands of years.



Excentricité : le caractère elliptique de l'orbite a été exagéré



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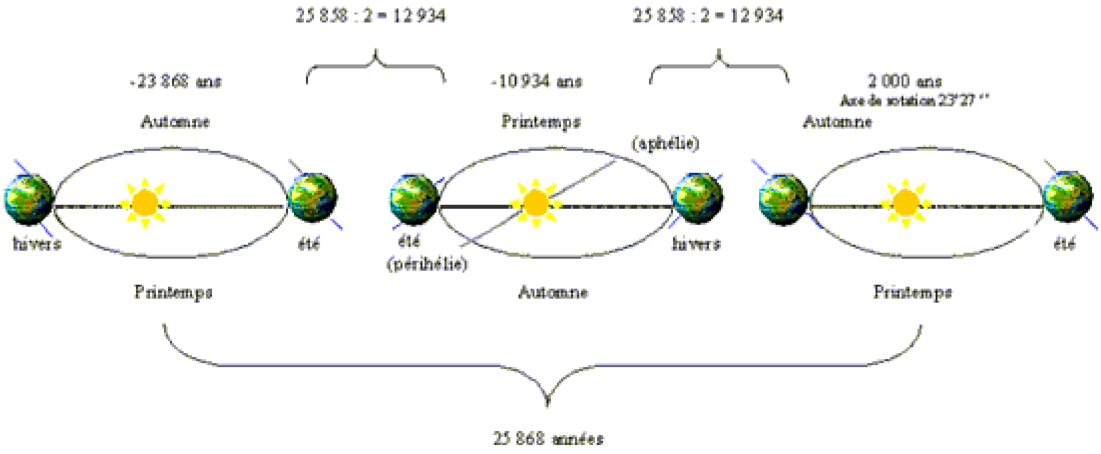
L'excentricité lors de ces 500 000 dernières années

6-3 The Precession of the Equinoxes

The Earth's axis of rotation, which is inclined by 23.27°, justifies the existence of different seasons. But its axis varies over time; it describes a cone in 25,868 years: the seasons move on the Earth's orbit and the result is that the solstices and equinoxes occur each year 25 minutes earlier. This movement, called axial precession, is due to the combined attraction of the Sun and the Moon on the equatorial rim. This movement resembles that of a top at the end of its rotation. Thanks to our satellite, the variation of the axis of rotation is slower and allows life to exist on our planet. So without the Moon the Earth's axis would describe a cone in less than 10,000 years which would have effects on the earth’s climate.

In the Northern Hemisphere, the distance to the Sun is minimum in winter and maximum in summer, and vice versa in the Southern Hemisphere. We are in a situation which softens the winters and cools the summers in the Northern Hemisphere, while it increases the seasonal contrasts in the Southern Hemisphere. On the contrary, about 10,000 years ago, the Earth passed through the closest point to the Sun at the time of the boreal summer solstice (الأنقلاب) and not at the winter solstice as today. The Northern Hemisphere then received more solar energy in summer and less in winter.



L'évolution de l'inclinaison de l'axe des pôles

L'**aphélie** (nom masculin) est le point de la trajectoire d'un objet céleste en orbite héliocentrique qui est le plus éloigné du centre de masse[1], donc du Soleil (dans le cas du système solaire). Le **périhélie** est l'inverse de l'aphélie

7- Paleoclimates

The term "paleoclimate" designates an ancient climate, as opposed to the current climate, on the scale of geological time. Past climates have been studied using paleontological, sedimentological and geochemical methods. These methods make it possible to clearly reconstruct the climate prevailing during a given period in a well-defined location. They also make it possible to trace the evolution of the earth's climate over any geological period.

The major climatic periods of the earth

Among the many factors that intervene in the control of the earth's climate and its fluctuations, we can cite four groups according to the amplitude of the temperature variations that they are likely to cause and the duration of their action cycle.

1- First order climate control: Corresponds to the establishment of the general climate conditions of the earth, such as the distance from earth to the sun, the luminosity of the sun, the presence of greenhouse gases.

2- Second order climate control: Corresponds to the distribution of continents and oceans on the earth's surface. This distribution modifies ocean circulations and the redistribution of heat on the surface of the globe. The periodicity of second-order climatic fluctuations is of the order of 100,000 years.

3- Third order climate control: The temperature varies from around 5 to 15 C°. corresponds to fluctuations in Milankowitch type orbital parameters.

4- Fourth order climate control: Temperature variations of 1 – 5 C° develop over very short periods of time. These variations are caused by the cycle of solar activity, volcanic eruptions, oceanic oscillations, meteorite impacts, and human activities.

8 - The hydrosphere

The hydrosphere is the part of the planet occupied by liquid water (oceans, seas, lakes, rivers, groundwater) and solid water (polar caps, glaciers, ice floes). This sphere extends from about 8 km in altitude (the tops of the highest mountains) to almost 11 km in depth (oceanic trenches).

The water of the hydrosphere is in perpetual movement: currents, waves and tides agitate the seas, lakes and rivers, glaciers slide on the continents, icebergs drift, pushed by winds and currents, and a thousand rivulets seep into the rock, carving caves and loading them with salt as they run towards the sea.

The dynamics of the oceans are mainly driven by atmospheric circulation and the rotation of the Earth. Pressure and especially wind explain to a notable extent the existence and direction of surface currents. The movements of the latter are also linked to the density of the water, which varies according to temperature and salinity.

CHAP III :

SEISMOLOGY AND THE INTERNAL STRUCTURE OF THE EARTH

(SISMOLOGIE ET STRUCTURE INTERNE DE LA TERRE)

It is only possible to study directly the upper first few km of depth of the Earth. For the internal structure of the Earth, geologists have therefore used indirect methods, such as seismology (study of earthquakes), gravimetry, etc.

3. 1. Seismology:

Seismology is the science which study earthquakes either natural or induced by explosions. Seismology studies more particularly the wave propagation velocity through the different media of the Earth.

3. 1. 1. Earthquakes

3. 1. 1. 1 Definition:

An **earthquake** is a sudden shaking (trembling) of the ground caused by a sudden release of energy upon a slip movement of rock blocks past another. The energy is released as elastic waves called **seismic waves**.

The surface upon which the slip movement occurs is called the **fault** or **fault plane**. The location below the earth's surface where the earthquake starts is called the **hypocenter**, and the location directly above it on the surface of the earth is called the **epicenter**.

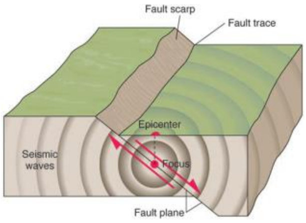
An earhquake is characterized by:

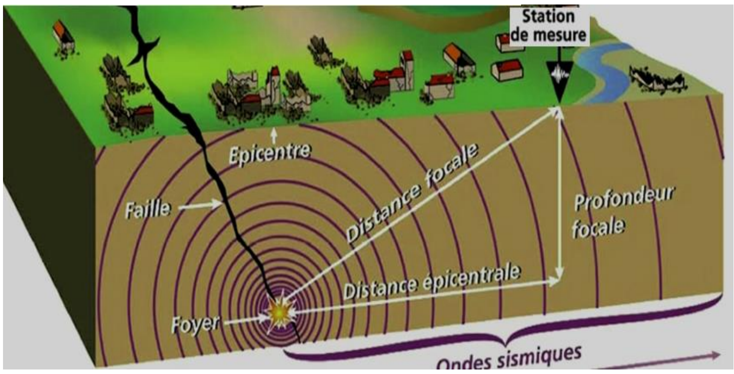
The focus (hypocentre) : The location below the earth's surface where the earthquake starts is called the **hypocenter**

The epicenter : the location directly above the focus, on the surface of the earth is called the **epicenter**.

Distance to focus : Distance between the focus and the observer (seismic measuring station)

Distance to epicenter : Distance between the epicenter and the observer (seismic measuring station).





-Most earthquakes occur along pre-existing faults. These are closed except for a brief period during the earthquake.

-Often large earthquakes are followed by smaller shocks called **aftershocks**. **Foreshocks** are light earthquakes that precede the major earthquake; they strike a few hours to a few days before the major event.

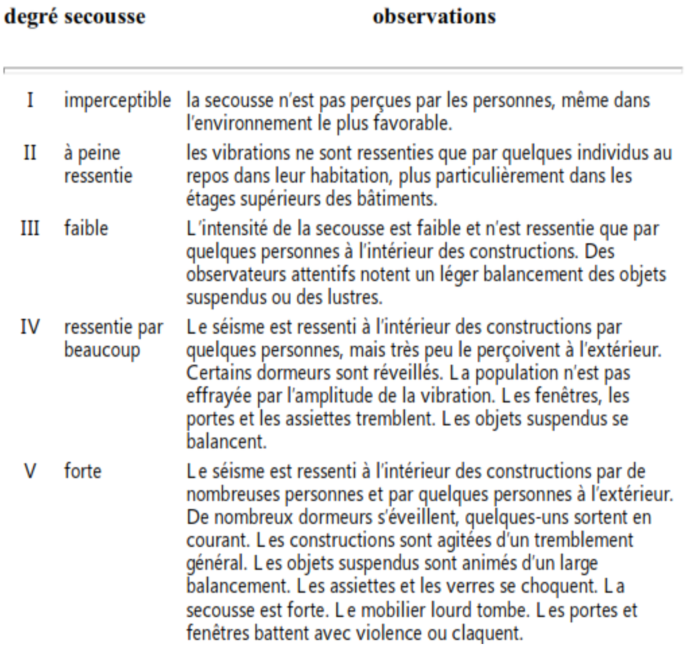
-The largest earthquakes are those caused by reverse and strike-slip faults; normal faults also cause earthquakes while their intensity is much less than the two previous ones.

3. 1. 2. Intensité d’un séisme

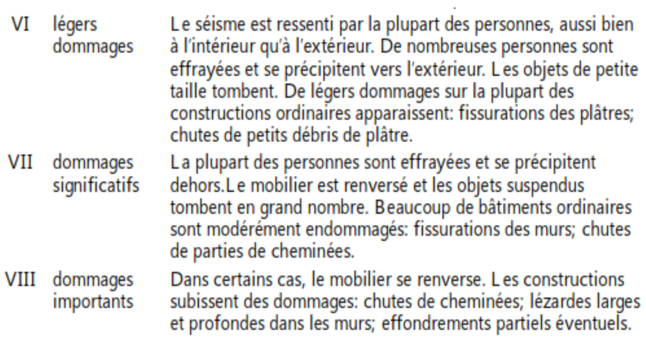
The **intensity of an earthquake** is a measure of its effect on people and buildings. Intensities are expressed as Roman numerals ranging from I to XII on the **modified Mercalli scale** (table 7.1); higher numbers indicate greater damage.

Moreover, the intensity of an earthquake , is defined by the effects it caused. These effects can only be observed or felt by humans (waking up, falling objects, cracks, etc.). These effects can also be assessed by the damage the earthquake induces to buildings. These are the macroseismic effects.

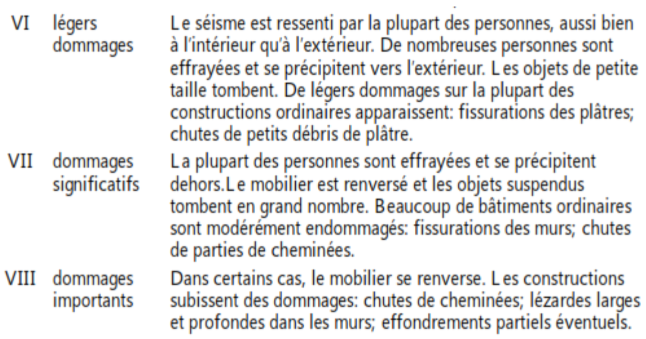
The European Macro-seismic Scale; EMS 92, is subdivided into 12 degrees.



degré	secousse	observations
I	imperceptible	la secousse n’est pas perçues par les personnes, même dans l’environnement le plus favorable.
II	à peine ressentie	les vibrations ne sont ressenties que par quelques individus au repos dans leur habitation, plus particulièrement dans les étages supérieurs des bâtiments.
III	faible	L’intensité de la secousse est faible et n’est ressentie que par quelques personnes à l’intérieur des constructions. Des observateurs attentifs notent un léger balancement des objets suspendus ou des lustres.
IV	ressentie par beaucoup	Le séisme est ressenti à l’intérieur des constructions par quelques personnes, mais très peu le perçoivent à l’extérieur. Certains dormeurs sont réveillés. La population n’est pas effrayée par l’amplitude de la vibration. Les fenêtres, les portes et les assiettes tremblent. Les objets suspendus se balancent.
V	forte	Le séisme est ressenti à l’intérieur des constructions par de nombreuses personnes et par quelques personnes à l’extérieur. De nombreux dormeurs s’éveillent, quelques-uns sortent en courant. Les constructions sont agitées d’un tremblement général. Les objets suspendus sont animés d’un large balancement. Les assiettes et les verres se choquent. La secousse est forte. Le mobilier lourd tombe. Les portes et fenêtres battent avec violence ou claquent.



VI	légers dommages	Le séisme est ressenti par la plupart des personnes, aussi bien à l'intérieur qu'à l'extérieur. De nombreuses personnes sont effrayées et se précipitent vers l'extérieur. Les objets de petite taille tombent. De légers dommages sur la plupart des constructions ordinaires apparaissent: fissurations des plâtres; chutes de petits débris de plâtre.
VII	dommages significatifs	La plupart des personnes sont effrayées et se précipitent dehors. Le mobilier est renversé et les objets suspendus tombent en grand nombre. Beaucoup de bâtiments ordinaires sont modérément endommagés: fissurations des murs; chutes de parties de cheminées.
VIII	dommages importants	Dans certains cas, le mobilier se renverse. Les constructions subissent des dommages: chutes de cheminées; lézardes larges et profondes dans les murs; effondrements partiels éventuels.



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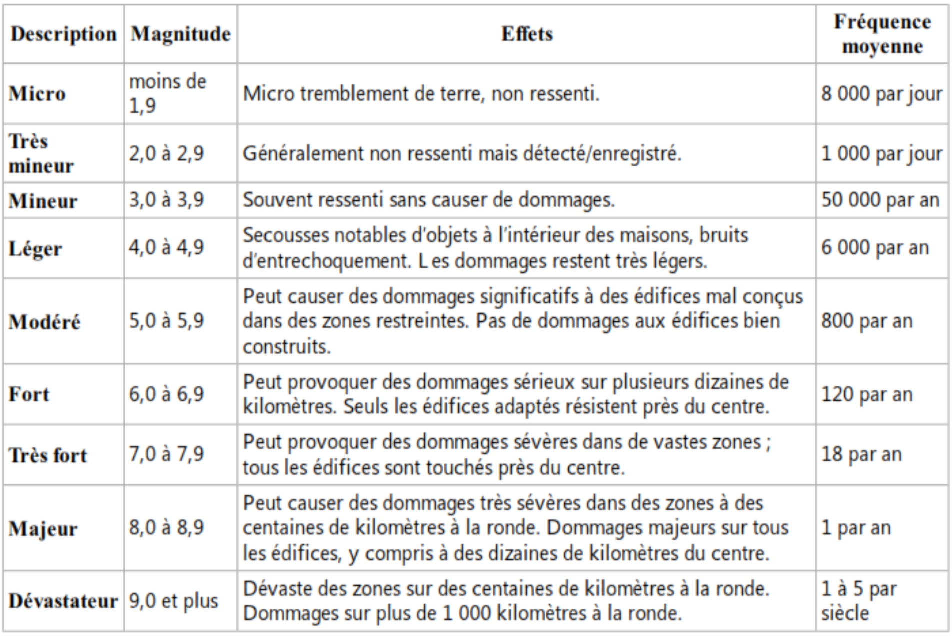
The Richter Scale (magnitude):

The Richter scale is an open logarithmic scale. But in general earthquakes greater than 9 are exceptional, the most powerful earthquake recorded was that of Chili in 1960 which had a magnitude of 9.5.



Description	Magnitude	Effets	Fréquence moyenne
Micro	moins de 1,9	Micro tremblement de terre, non ressenti.	8 000 par jour
Très mineur	2,0 à 2,9	Généralement non ressenti mais détecté/enregistré.	1 000 par jour
Mineur	3,0 à 3,9	Souvent ressenti sans causer de dommages.	50 000 par an
Léger	4,0 à 4,9	Secousses notables d'objets à l'intérieur des maisons, bruits d'entrechoquement. Les dommages restent très légers.	6 000 par an
Modéré	5,0 à 5,9	Peut causer des dommages significatifs à des édifices mal conçus dans des zones restreintes. Pas de dommages aux édifices bien construits.	800 par an
Fort	6,0 à 6,9	Peut provoquer des dommages sérieux sur plusieurs dizaines de kilomètres. Seuls les édifices adaptés résistent près du centre.	120 par an
Très fort	7,0 à 7,9	Peut provoquer des dommages sévères dans de vastes zones ; tous les édifices sont touchés près du centre.	18 par an
Majeur	8,0 à 8,9	Peut causer des dommages très sévères dans des zones à des centaines de kilomètres à la ronde. Dommages majeurs sur tous les édifices, y compris à des dizaines de kilomètres du centre.	1 par an
Dévastateur	9,0 et plus	Dévaste des zones sur des centaines de kilomètres à la ronde. Dommages sur plus de 1 000 kilomètres à la ronde.	1 à 5 par siècle

3. 1. 3. Magnitude of an earthquake

Richter magnitude is directly related to the energy released form the focus in the form of **elastic waves**. Knowing that during an earthquake, most of the energy is dissipated in the form of heat. Only part of it propagates far in the form of elastic waves. The ratio between

elastic wave energy and **total energy**, called seismic efficiency, is estimated between 20 and 30%.

In terms of magnitude, a magnitude 7 earthquake is ten times stronger than a magnitude 6 earthquake. In terms of energy, a magnitude 7 earthquake releases 30 times more energy than a magnitude 6 earthquake.

The local Richter magnitude:

The original definition is given by Richter in 1935. Now called local magnitude or ML, is:

$ML = \text{Log}(A) - \text{Log}\, A_0 + C\, \text{Log}(C)$

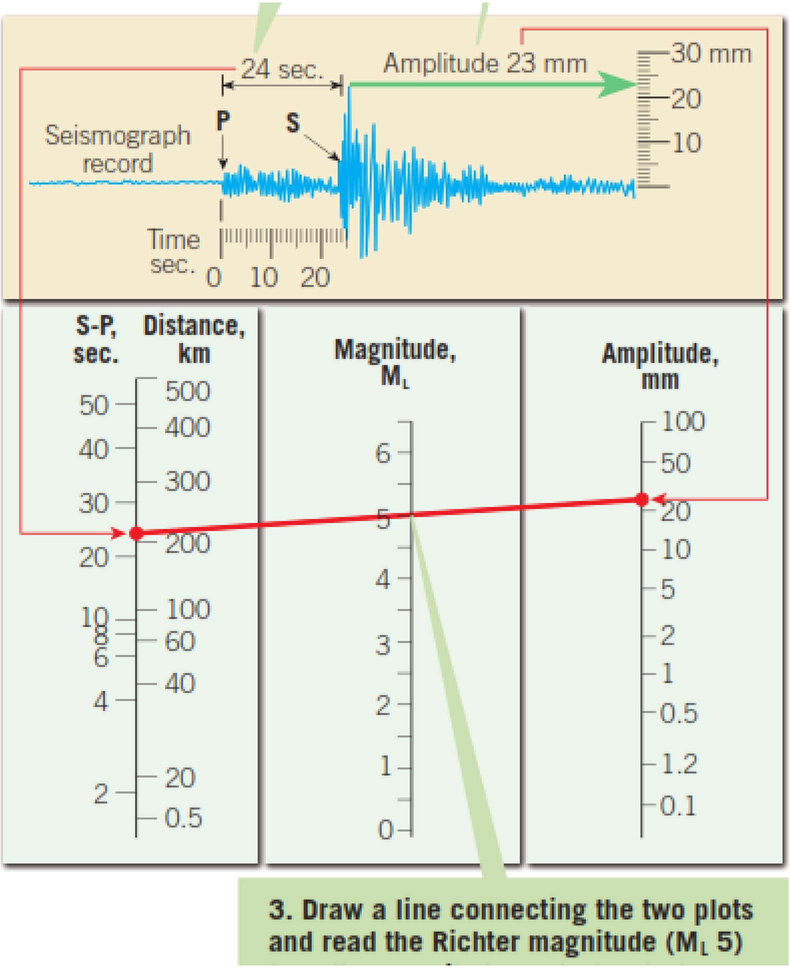
where (A) represents the maximum amplitude measured on the seismogram,

(A_0) is a reference amplitude corresponding to an earthquake of magnitude 0 distant to 100 km,

A, is the distance from the epicenter in (km) and C is a calibration constant.

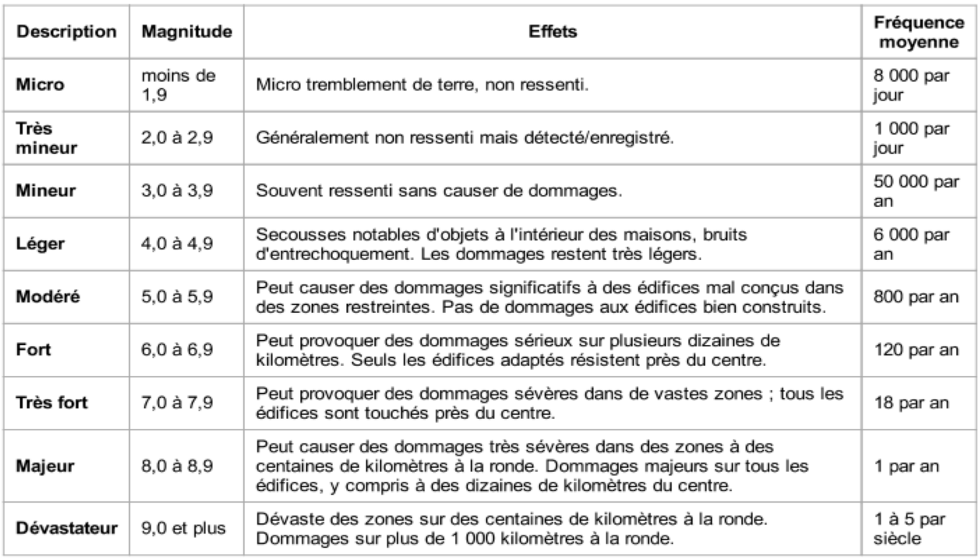
In addition to the inhomogeneity of this equation, further highlighting its empirical character, the calibration constants A_0 and C make this formula valid only locally. For example, in the original definition where the calibration is carried out on moderate earthquakes in Southern California recorded with a Wood-Anderson type seismograph, $A_0 = 2.48$ and $C = 2.76$.

In terms of energy, an increase in the magnitude by one unit corresponds to an increase in energy of 30 times.



3. Draw a line connecting the two plots and read the Richter magnitude (M_L 5)

3. **1. 4**



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Dévastateur	9,0 et plus	Dévaste des zones sur des centaines de kilomètres à la ronde. Dommages sur plus de 1 000 kilomètres à la ronde.	1 à 5 par siècle

Frequency of earthquakes

The frequency of earthquakes increases as their magnitude decreases.

3. 2. The propagation of seismic waves

The instrument used to record seismic waves during an earthquake is called a seismograph or seismometer (see figure below). The graph given by the seismograph is called a seismogram.

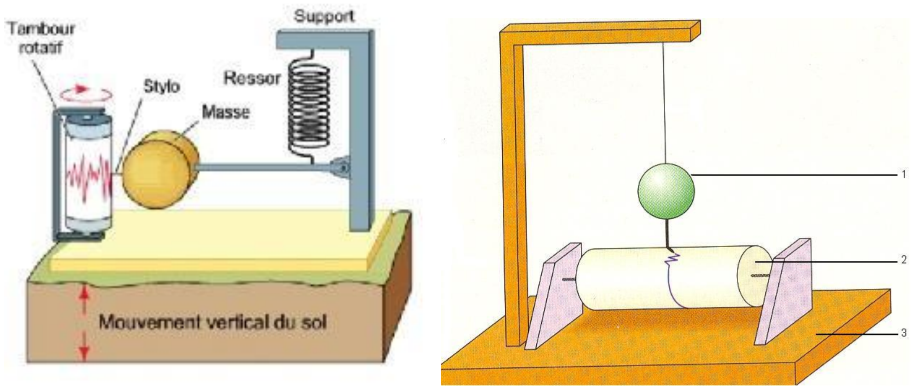


Schéma montrant le Principe de fonctionnement d'un sismographe

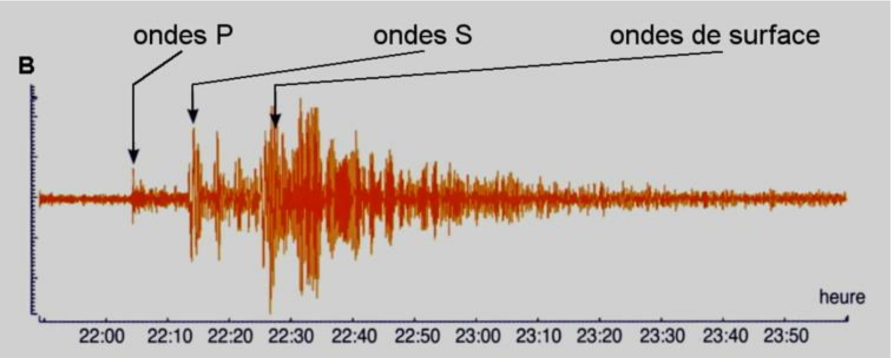
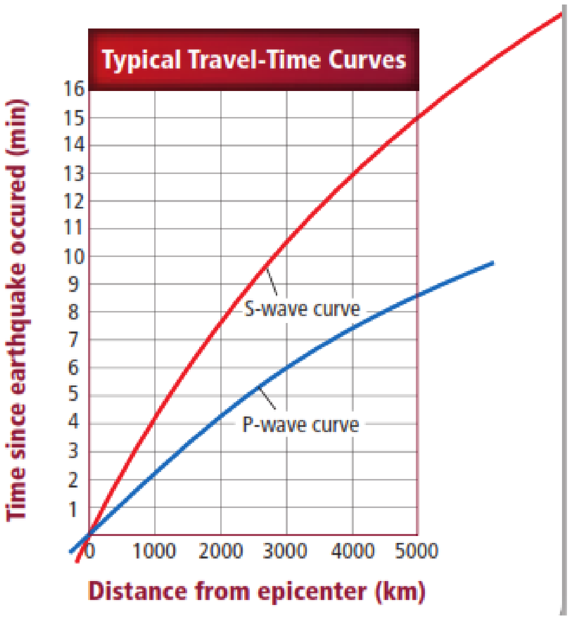


Figure montrant un sismogramme enregistré par un sismomètre



The study of a seismogram shows two **wave packets** (also known as a **wave train** or **wave groups**).

The first waves recorded by the seismograph are the fastest.

They are called **P (primary) waves**.

The second wave train recorded represents the **S waves (shear waves)**, they propagate at a slower speed than P waves.

P and S waves are called **body waves** because they propagate in the earth.

We also record a third wave train, even slower, called Surface Waves (L and R).

P waves: The fastest, longitudinal, compression and decompression waves propagate in solids and fluids: $V_p = (k + 4/3\ G)/\ \rho)^{1/2}$, k = incompressibility modulus, G = shear modulus , ρ = the density of the medium. They have the smallest amplitudes.

S waves: Transverse **shear waves** (or secondary waves) propagate only in solids (not in liquid media); $V_s = (G/\rho)^{1/2}$

Love waves (L): surface waves. The slower ones correspond to a twisting movement. They have the greatest amplitudes and cause the greatest damage.

Rayleigh waves (R): propagate with oscillation in a vertical plane with an elliptical movement of the particles.

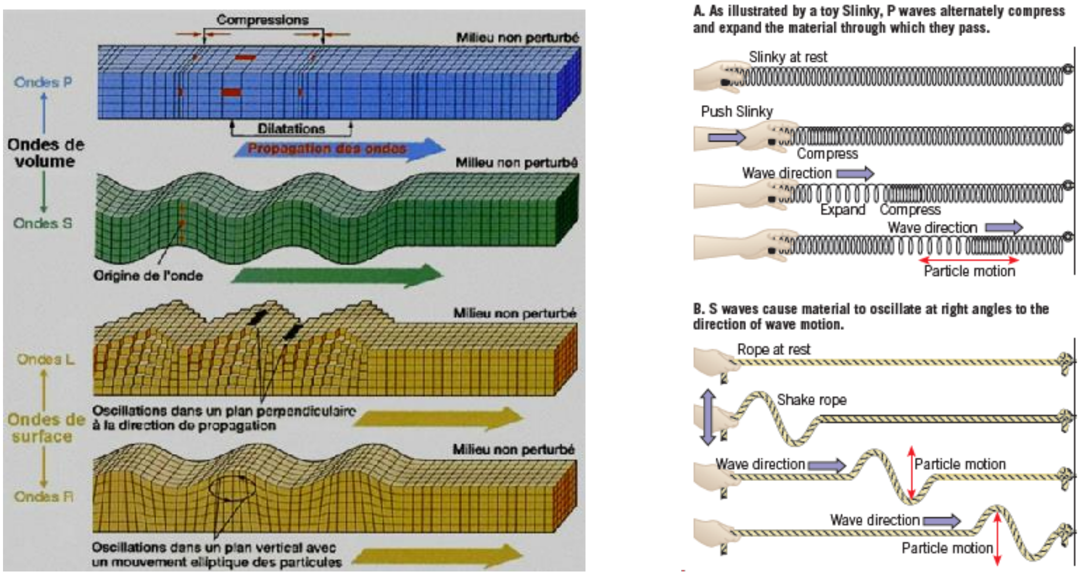
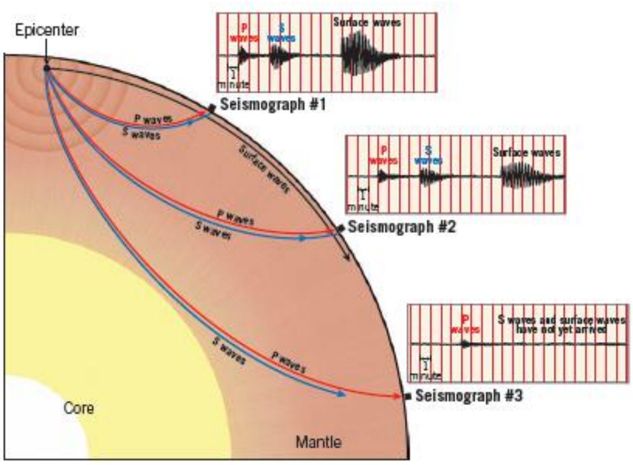


Schéma montrant mode de propagation des différents types d'ondes sismiques



SMARTFIGURE 11.10 Body waves (P and S waves) versus surface waves
P and S waves travel through Earth's interior, while surface waves travel in the layer directly below the surface. P waves are the first to arrive at a seismic station, followed by S waves, and then surface waves.

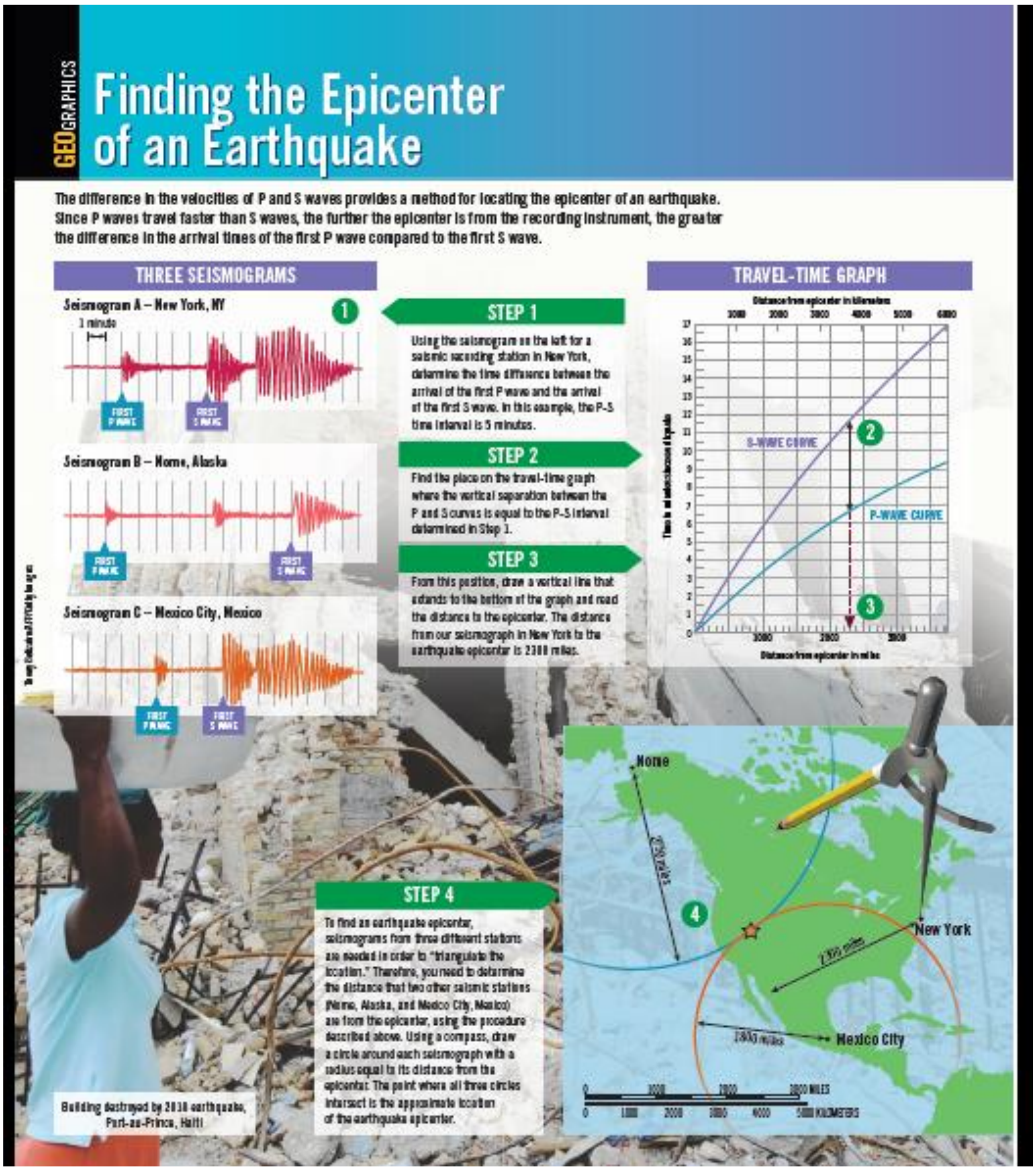
3.4 Finding of the epicenter of an earthquake

The following exercise shows us how to locate the epicenter of an earthquake.

Exercise

Establish the epicenter of an earthquake knowing that for this earthquake the time interval separating P and S waves recorded in three stations was:

Paris : 2 min 30 s ; Warsaw : 3 min 20 s ; Lisbon : 4 min 40 s.



GEOGRAPHICS

Finding the Epicenter of an Earthquake

The difference in the velocities of P and S waves provides a method for locating the epicenter of an earthquake. Since P waves travel faster than S waves, the further the epicenter is from the recording instrument, the greater the difference in the arrival times of the first P wave compared to the first S wave.

THREE SEISMOGRAMS

TRAVEL-TIME GRAPH

STEP 1

Using the seismogram on the left for a seismic recording station in New York, determine the time difference between the arrival of the first P wave and the arrival of the first S wave. In this example, the P-S time interval is 5 minutes.

STEP 2

Find the place on the travel-time graph where the vertical separation between the P and S curves is equal to the P-S interval determined in Step 1.

STEP 3

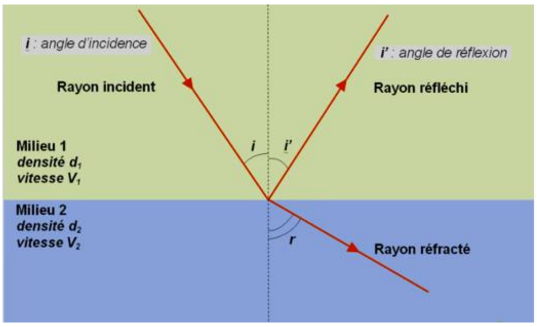
From this position, draw a vertical line that extends to the bottom of the graph and read the distance to the epicenter. The distance from our seismograph in New York to the earthquake epicenter is 2300 miles.

STEP 4

To find an earthquake epicenter, seismograms from three different stations are needed in order to "triangulate the location." Therefore, you need to determine the distance that two other seismic stations (Nome, Alaska, and Mexico City, Mexico) are from the epicenter, using the procedure described above. Using a compass, draw a circle around each seismograph with a radius equal to its distance from the epicenter. The point where all three circles intersect is the approximate location of the earthquake epicenter.

Building destroyed by 2010 earthquake, Port-au-Prince, Haiti

3.5 Earthquakes and internal structure of the Earth:



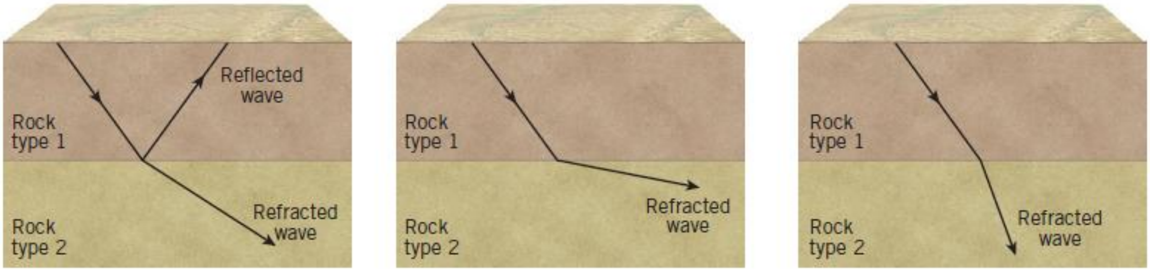
The study of the elastic wave velocity as a function of depth:

When a wave reaches a discontinuity (border separating 2 mediums with different physical properties), the wave will be reflected and (or) refracted.

During an earthquake, seismic waves (rays) propagate in all directions, when they meet a boundary between two materials with different properties (different velocities) such as air and water, the rays are divided into reflected and refracted rays.

We know that

The angle of incidence `= the angle of reflection

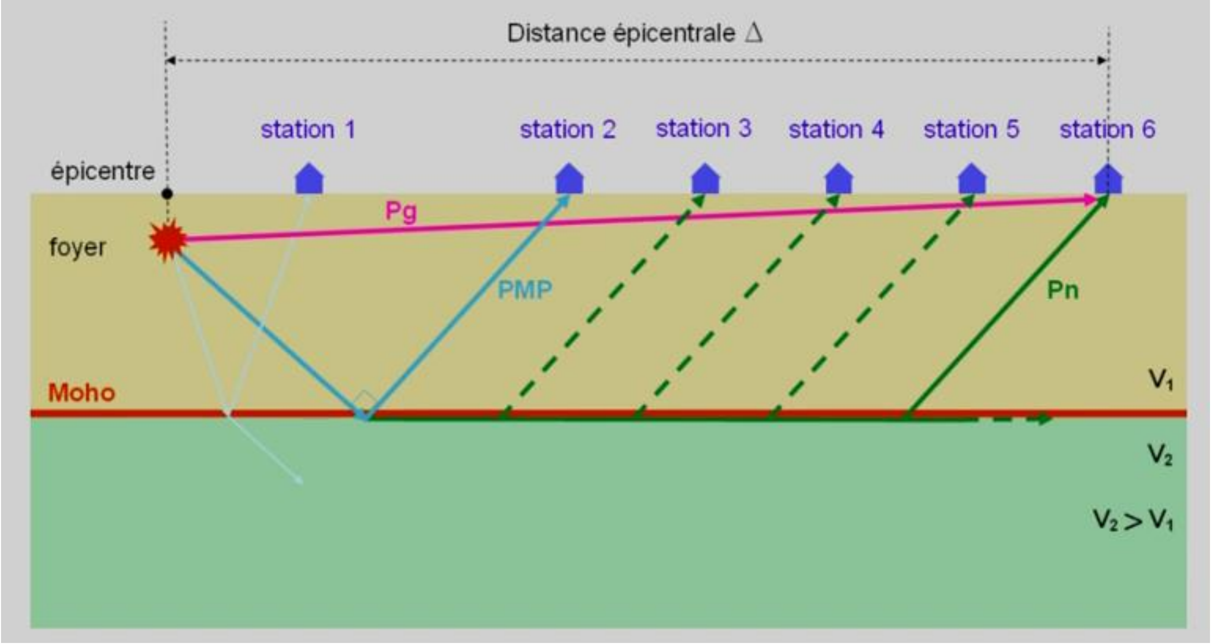


Lorsque les ondes sismiques (rayons) rencontrent une limite entre deux matériaux aux propriétés différentes comme l'air et l'eau, les rayons se divise en rayons réfléchies et réfractées (courbées).

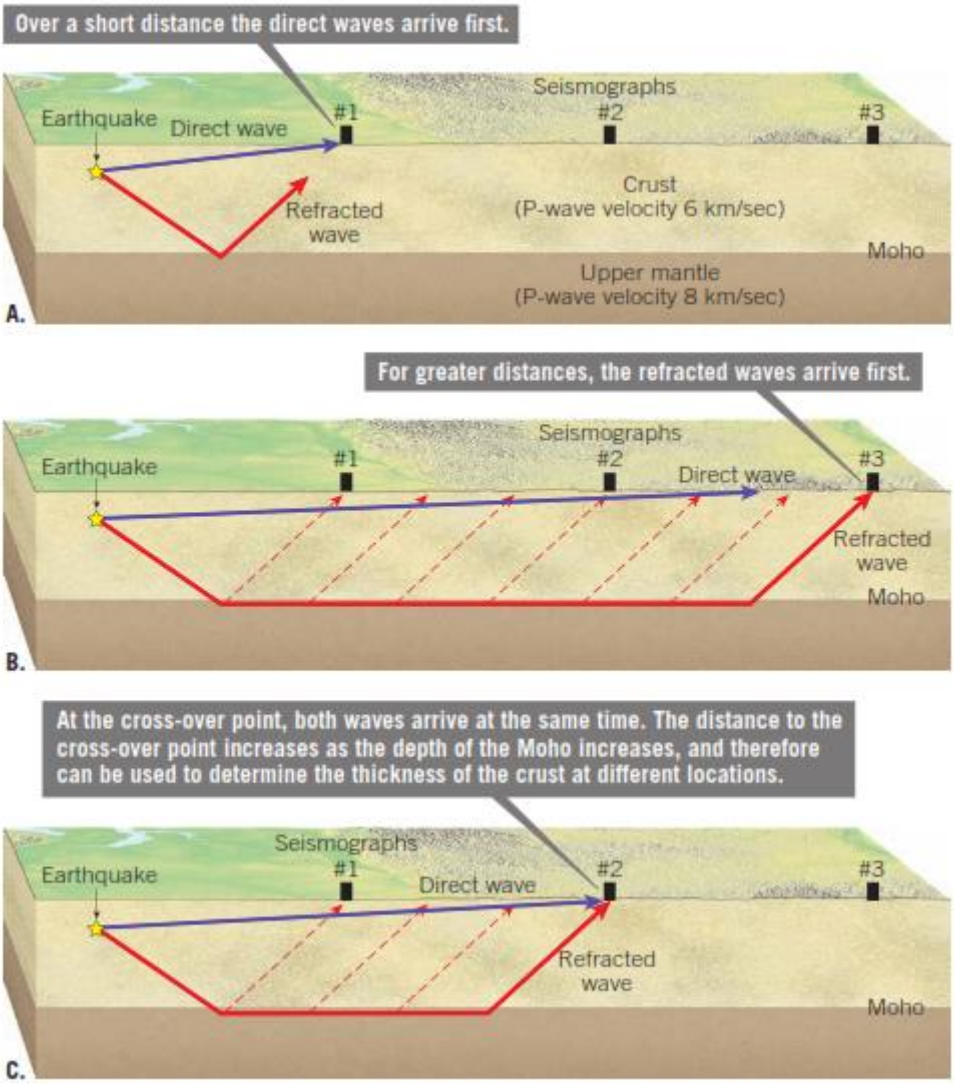
Lorsque la vitesse des ondes sismiques augmente à mesure qu'elles passent d'une couche à une autre les ondes se réfractent (se plient) vers la limite séparant les couches.

Lorsque la vitesse des ondes sismiques diminue au fur et à mesure qu'elles passent d'une couche à une autre, les ondes se réfractent (se courbent) loin de la frontière qui les sépare.

Schéma montrant la réflexion et la réfraction d'un rayon sismique (ou optique) quand il rencontre une discontinuité.



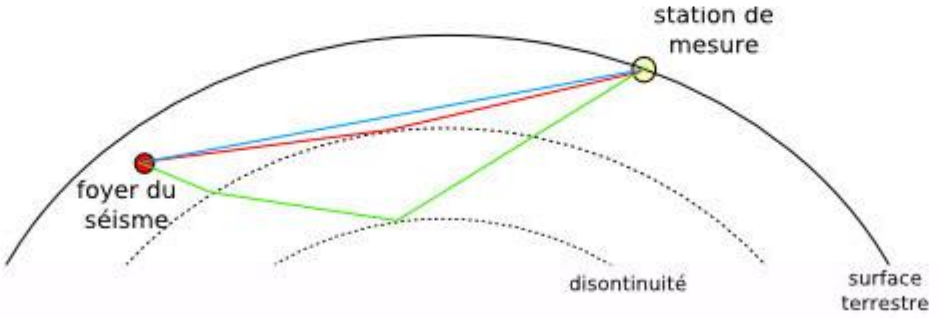
Schema montrant la propagation des rais sismiques le long d'une discontinuité (le Moho).



Over a short distance the direct waves arrive first.

For greater distances, the refracted waves arrive first.

At the cross-over point, both waves arrive at the same time. The distance to the cross-over point increases as the depth of the Moho increases, and therefore can be used to determine the thickness of the crust at different locations.



The wave propagation velocity depends on the characteristics of the medium in which it propagates:

- Pressure,

- Temperature,

- Composition.

So the propagation velocity of waves increases with depth.

When the seismic station is relatively close to the epicenter, ordinary P and S (direct) waves are recorded. When the seismograph is relatively far from the epicenter (between 200 and 800 km) the P and S waves seem to arrive with greater velocities (they arrive rather earlier than expected). The calculations made by Mohorovicic (1903) reveal the existence of a discontinuity (separation surface at approximately 7 to 10 km depth). This discontinuity after which the density of materials increases has since been called the **Mohorovicic discontinuity**. This discontinuity separates the Earth's crust from the upper mantle.

The shadow zone:

Stations located up to 11,500 km (105°) from the epicenter of an earthquake record direct P and S waves. Beyond this limit and up to 14,500 km (142°), there is what is called the shadow zone, which is an area where stations do not record P waves nor S waves generated by the earthquake and beyond 14,500 km (142°) only P waves reappear.

This shadow zone is due to the fact that the waves are refracted twice on an internal discontinuity. Calculations show that this discontinuity is located at a depth of 2900 km; it is called the **Gutenberg discontinuity**, separating the **mantle from the core**.

The fact that the S waves do not reappear leads to the conclusion that this core is liquid (S waves do not propagate in liquids).

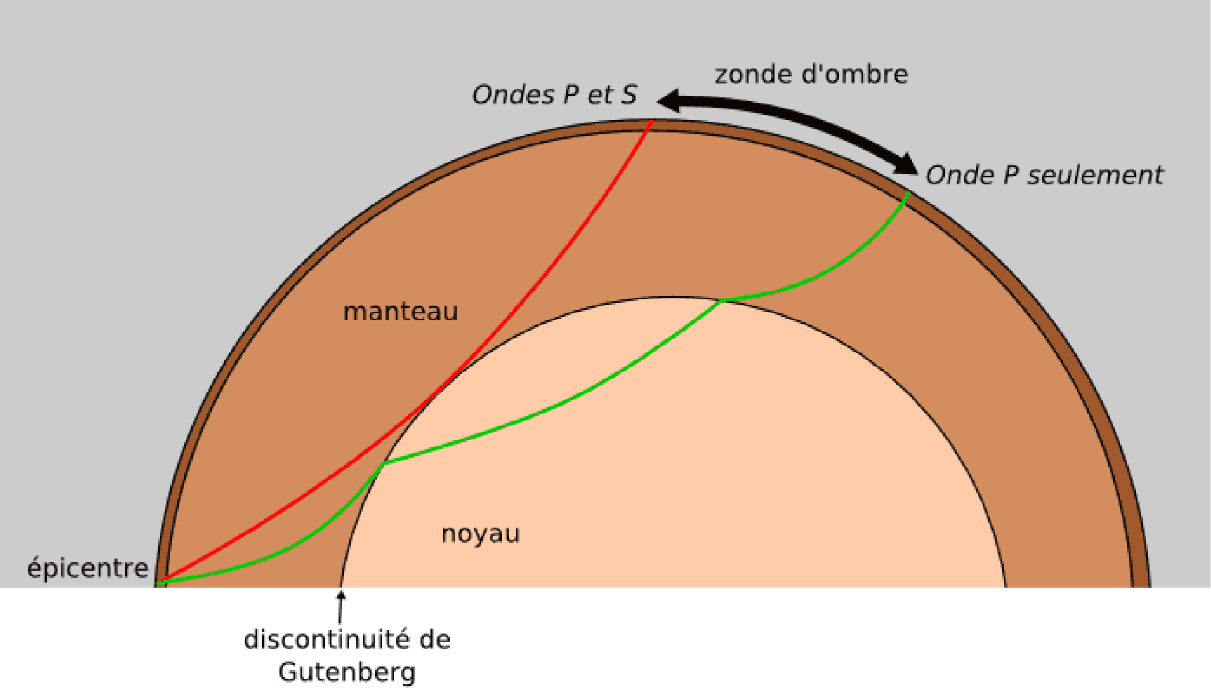
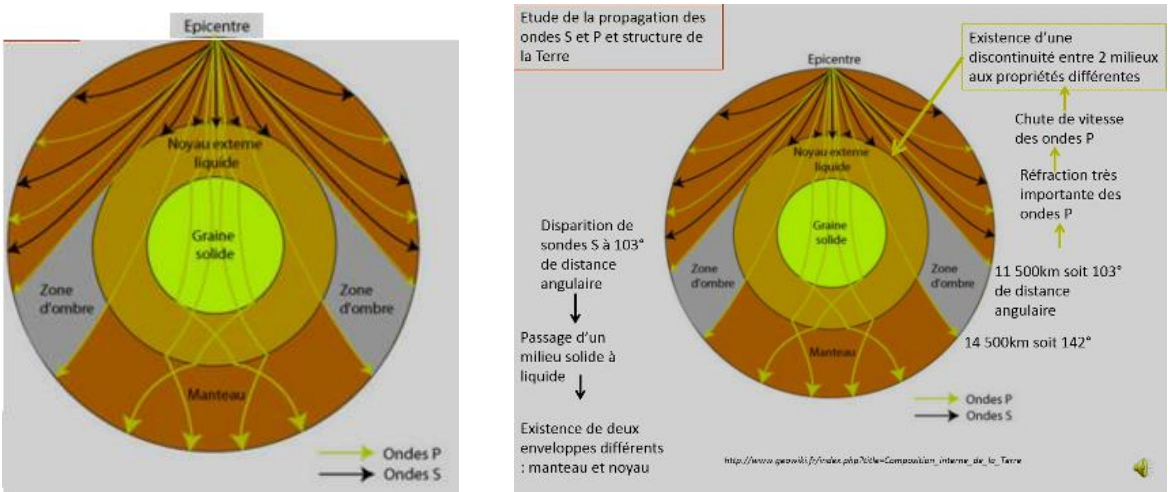


Schéma montrant la zone d'ombre



Etude de la propagation des ondes S et P et structure de la Terre

Existence d'une discontinuité entre 2 milieux aux propriétés différentes

Chute de vitesse des ondes P

Réfraction très importante des ondes P

11 500km soit 103° de distance angulaire

14 500km soit 142°

Disparition de sondes S à 103° de distance angulaire

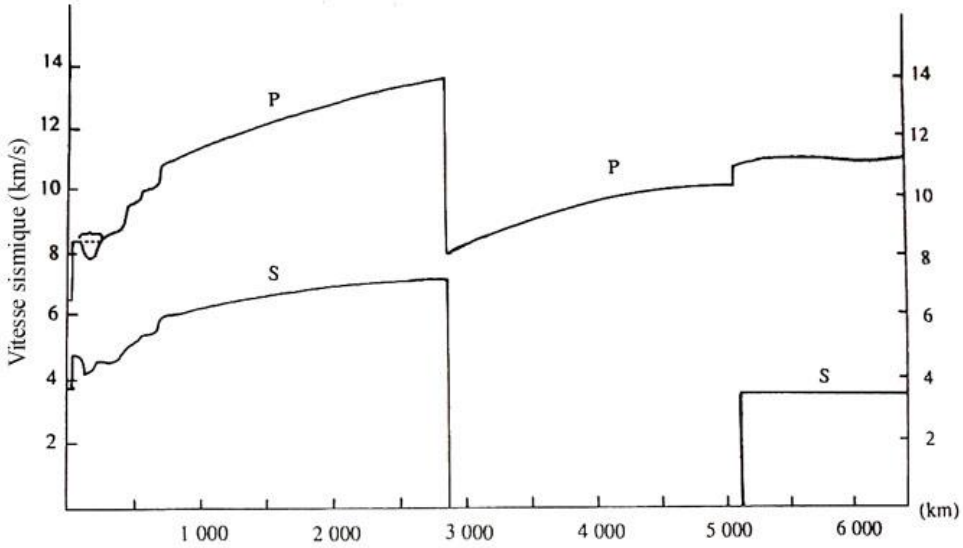
Passage d'un milieu solide à liquide

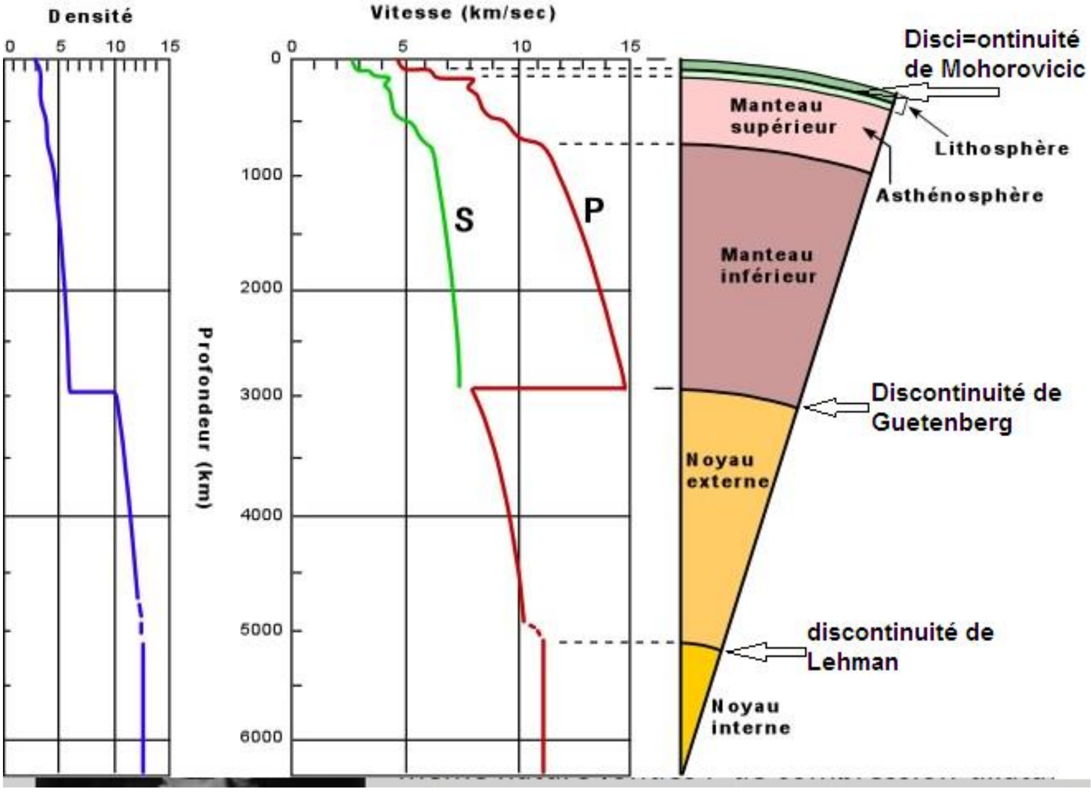
Existence de deux enveloppes différents : manteau et noyau

http://www.geowiki.fr/index.php?title=Composition_interne_de_la_Terre

propagation des ondes P et S dans la Terre

The next figure shows the variation of P and S wave velocities as a function of depth.





We can notice three clear "breaks" in the curves:

- At the start of the curve (between 10 and 70 km depth) we notice a very rapid increase in P and S wave velocities; This rapid increase corresponds to the **Mohorovicic discontinuity**

- At a depth of 2,900 km, a large drop in the velocity of P waves and disappearance of S waves is recorded. This charp decrease in P wave velocity and the desappearence of the S waves showed the **Gutenberg discontinuity**, separating the **mantle from the core**. Moreover, the disappearance of S waves shows that materials at this discontinuity are in fusion (liquids).

- At a depth of 5,400 km, we record a sudden increase in the velocity of P waves and reappearance of S waves. This shows that the core is of solid consistency. This coincides with the **Lehman Discontinuity** at 5400 km.

These breaks highlight 3 discontinuities in the constitution of the earth:

- The **Mohorovicic discontinuity** between 10 and 70 km deep,

- The **Gutenberg Discontinuity** at 2900 km,

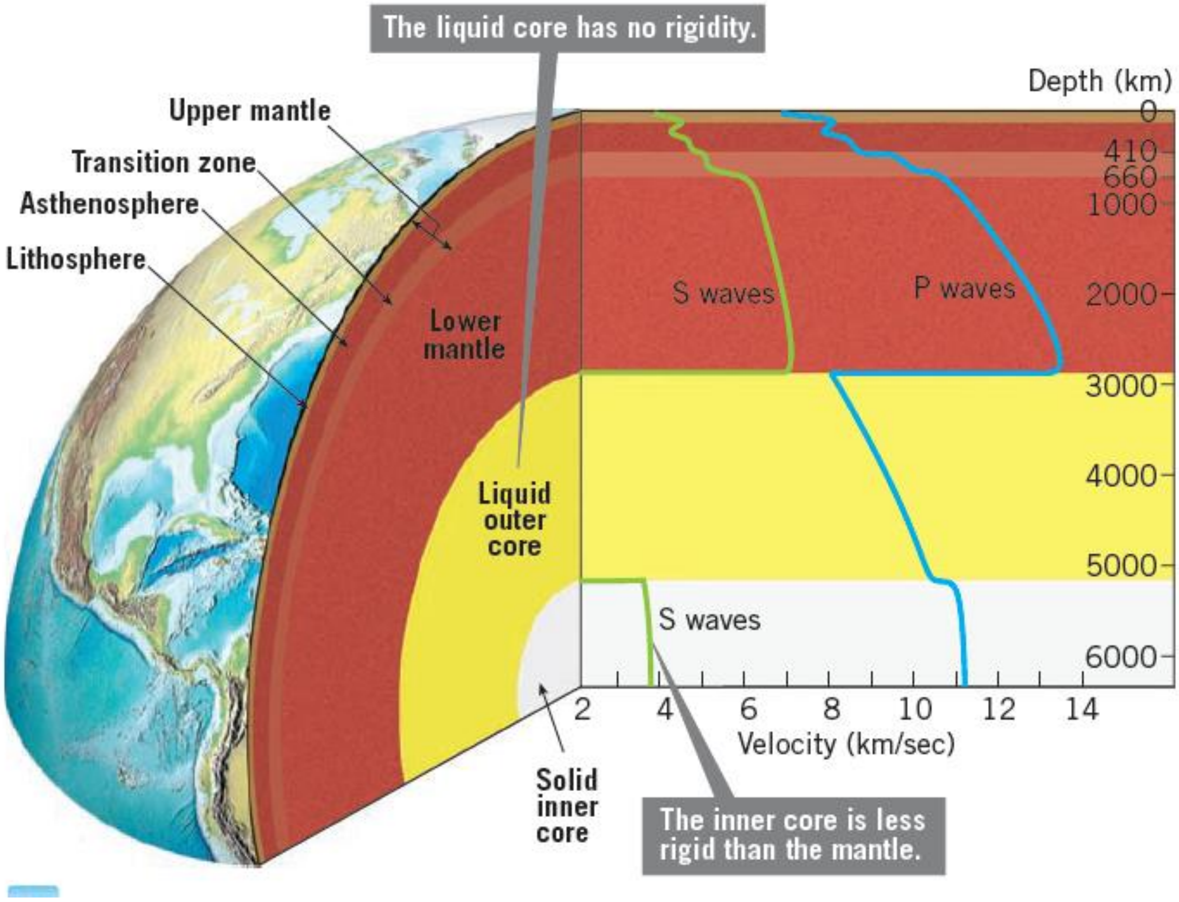
- The **Lehman Discontinuity** at 5400 km.

These 3 discontinuities delimit 4 concentric envelopes constituting the globe:

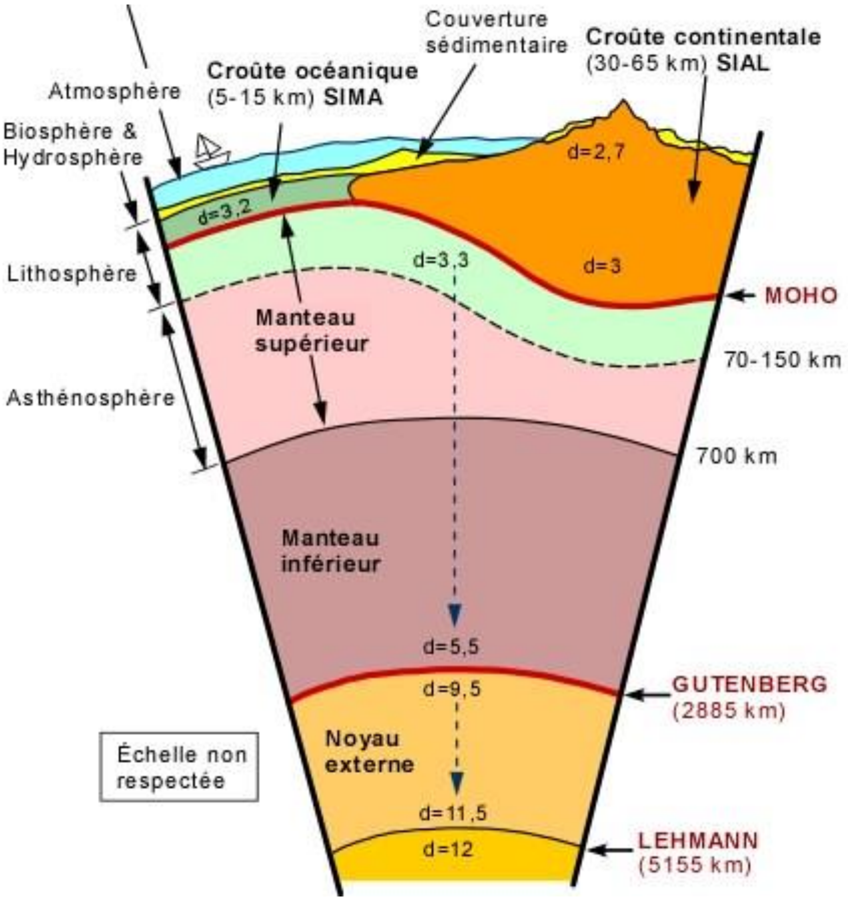
- The crust,

- The mantle (upper and lower mantle)

- The outer core,
- The inner core.



The structure of the earth



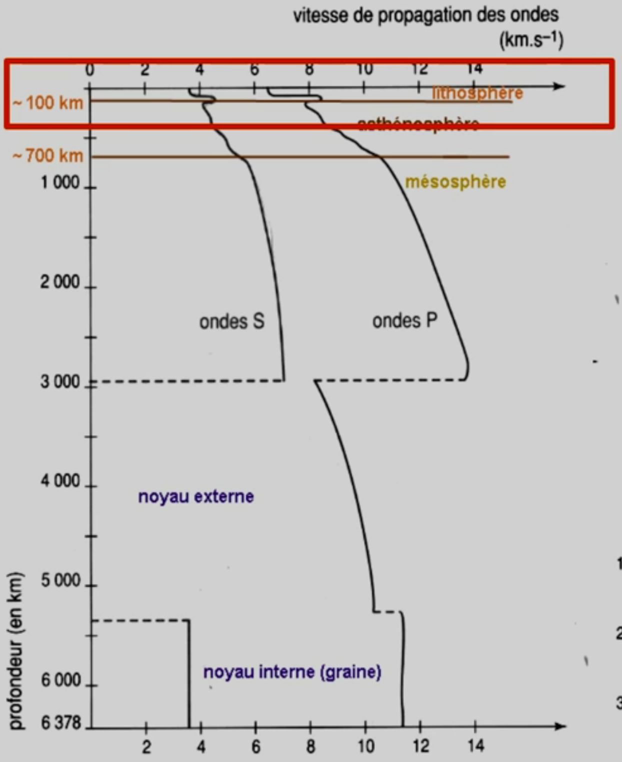
- **The crust**: We recognize two types of earth's crust:

a- **The continental crust**, the outer layer of the earth, it is a shell like layer that forms the continents. It is thicker because of its lower density (granite to intermediate rocks with density 2.7 to 3) and which is called SIAL (silicon-aluminum) .

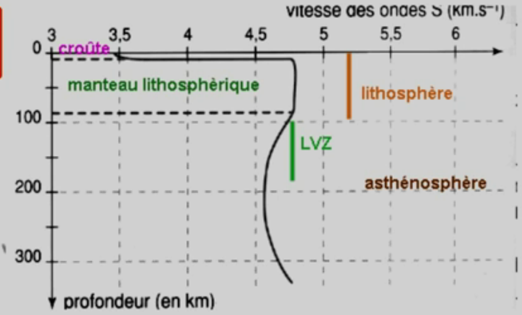
b- **The oceanic crust**, It is roughly located under the oceans. It is formed of basaltic rocks with a density of 3.2. It is also called SIMA (silicon-magnesium).

- The Asthenosphere: This is the plastic layer of the upper mantle. It is separated from the lithosphere by the low velocity zone (LVZ low velocity zone located between 70 and 150 km depth)

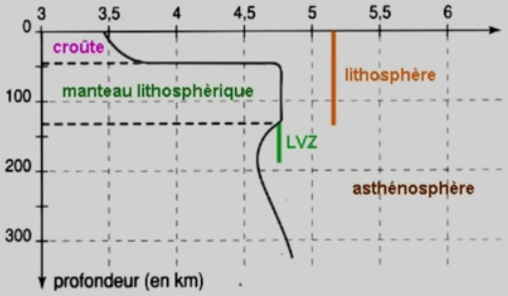
- If we look at the framed part in the figure below, we notice that it contains an area where the speed shows a progressive drop then an increase; this is the low velocity zone. This discontinuity is actually due to the variation in the consistency of the material from the solid state to the plastic state.

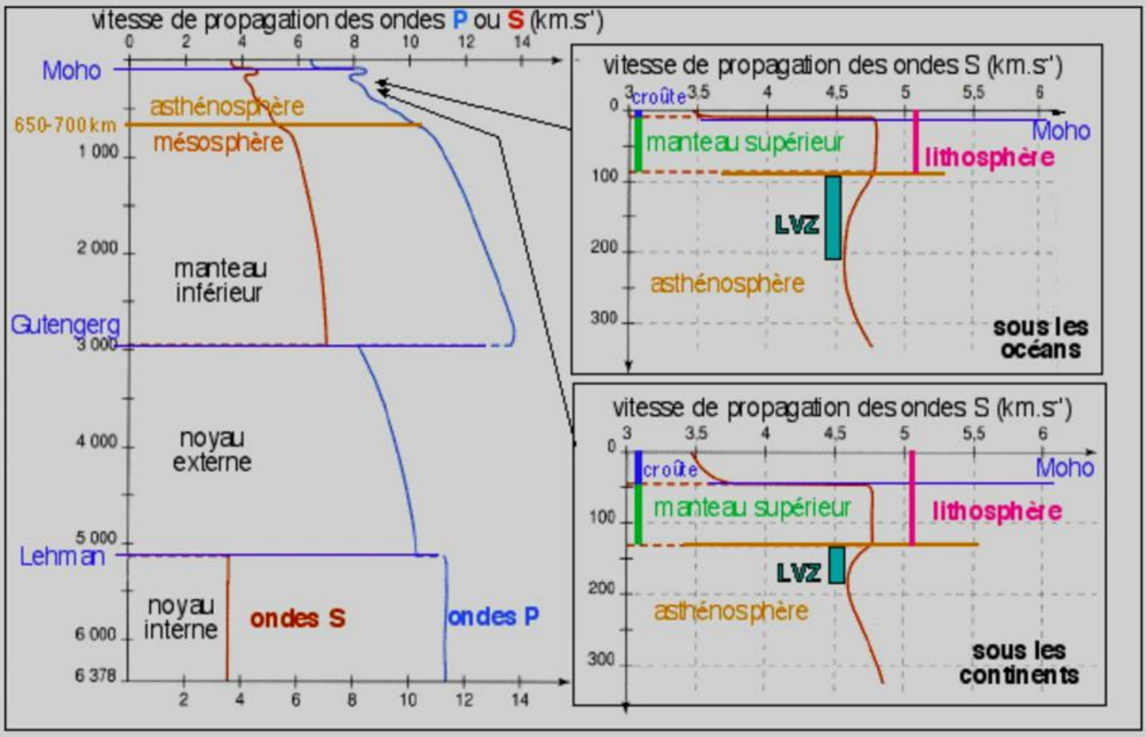


Sous les océans



Sous les continents





In conclusion, the terrestrial globe is made up of:

1-**The Lithosphere**: it is composed of **the crust** plus **upper part of the upper mantle** 70 to 150 km deep. It is composed of:

11- **The crust**: This is the outermost part of the earth. Its thickness varies from 5 a to 15 k under the oceans and from 30 to 65 under the continents.

12- **The upper part of the upper mantle**: between the base of the crust and the zone of low velocity. It is located between 70-150 and 700 km.

2- **The mantle**: is subdivided into two parts:

21- **The upper mantle**: It is located between the **Moho** and the **lower mantle**; it extends from the Moho (Mohorovicic discontinuity) to the lower mantle. That is to say between 30 and 700 km under the continents and between 5 and 700 km under the oceans.

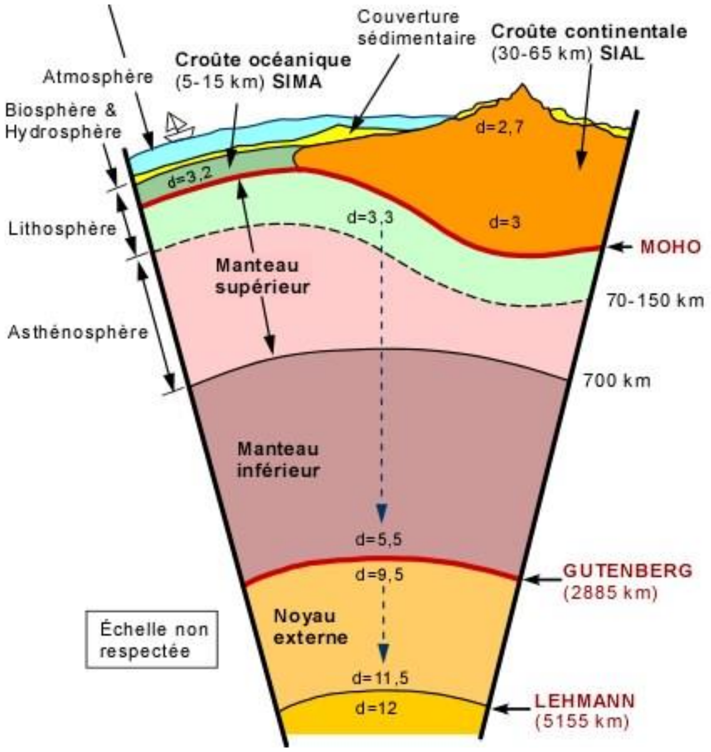
211-**The Asthenosphere**: It is part of the upper mantle, it begins with the low velocity zone and ends in the lower mantle. That is to say between 70 and 700 km deep under the oceans and between 150 and 700 km deep under the continents

. 22-**The Lower Mantle**: is located between 700 and 2885 km deep

3- **The Core**: The core is subdivided into two concentric parts:

31- **The external Core**: It is located between the **Gutenberg discontinuity** and that of **Lehman**. Between 2885 and 5155 km deep. S waves do not propagate in this medium, which suggests that it is liquid.

32- **The inner core**: It is located between the **Lehman discontinuity** and the center of the earth. It has a solid consistency.



En conclusion le globe terrestre est constitué de :

1-La Lithosphère composé de la croute plus partie supérieur du manteau supérieur de 70 à 150 km de profondeur. Elle est composé de :

11- la croute : C'est la partie la plus externe de la terre. Son épaisseur varie de 5 a à 15 k sous les océans et de 30 à 65 sous les continents.

12- La partie supérieure du manteau supérieur : entre la base de la croute et la zone de moindre vitesse. Elle est situé entre 70-150 et 700 km.

2- Le Manteau : se subdivise en deux parties **:**

21- Le Manteau superieur se situe entre le Moho et le manteau inférieur ; il s'étend depuis le Moho (discontinuité de Mohorovicic) jusqu'au manteau inferieur. C'est-à-dire entre 30 et 700 km sous les continents et entre 5 et 700 km sous les océans.

211-L'Asthénosphère : Elle fait partie du manteau supérieur, elle commence avec la zone à faible vitesse (low velocity zone) et se termine au manteau inférieur. C'est-à-dire entre 70 et 700 en profondeur sous les océans et entre 150 et 700 km en profondeur sous les continents

.

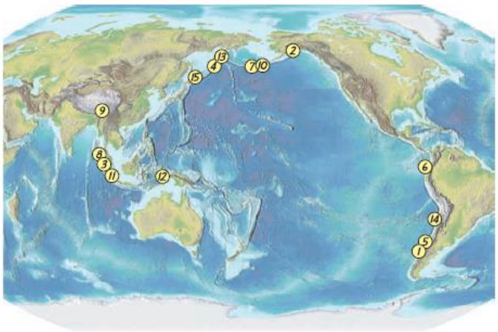
22-Le Manteau Inférieur : se situe entre 700 et 2885 km de profondeur

3- Le Noyau : Le noyau se subdivise en deux parties concentriques :

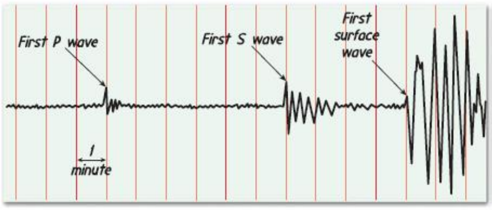
31- Le Noyau externe : Il est situé entre la discontinuité de Gutenberg et celle de Lehman. Entre 2885 et 5155 km de profondeur. Les ondes S ne se propagent pas dans ce milieu ce qui laisse supposer qu'il est liquide.

32- La Graine (noyau interne) : Elle est située entre la discontinuité de Lehman et le centre de la terre. Il est de consistance solide.

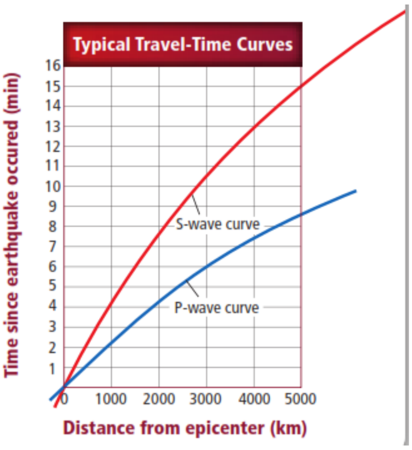
1. Draw a sketch that illustrates the concept of elastic rebound. Develop an analogy other than a rubber band to illustrate this concept.
2. The accompanying map shows the locations of many of the largest earthquakes in the world since 1900. Refer to the map of Earth's plate boundaries in Figure 2.12 (p. 52) and determine which type of plate boundary is most often associated with these destructive events.



3. Use the accompanying seismogram to answer the following questions:
   - a. Which of the three types of seismic waves reached the seismograph first?
   - b. What is the time interval between the arrival of the first P wave and the arrival of the first S wave?
   - c. Use your answer from Question b and the travel-time graph on page 371 to determine the distance from the seismic station to the earthquake.
   - d. Which of the three types of seismic waves had the highest amplitude when they reached the seismic station?

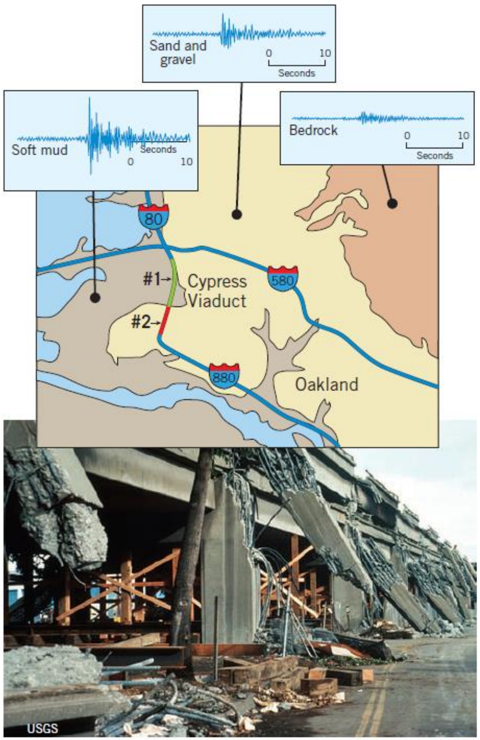


4. You go for a jog on a beach and choose to run near the water where the sand is well packed and solid under your feet. With each step, you notice that your footprint quickly fills with water but not water coming in from the ocean. What is this water's source? For what earthquake-related hazard is this phenomenon a good analogy?
5. Make a sketch that illustrates why a tsunami often causes a rapid withdrawal of water from beaches before the first surge.
6. Why is it possible to issue a tsunami warning but not a warning for an impending earthquake? Describe a scenario in which a tsunami warning would be of little value.
7. Using the accompanying map of the San Andreas Fault, answer the following questions:
   - a. Which of the four segments (1–4) of the San Andreas Fault do you think is experiencing fault creep?
   - b. Paleoseismology studies have found that the section of the San Andreas Fault that failed during the Fort Tejon quake (segment 3) produces a major earthquake every 135 years, on average. Based on this information, how would you rate the chances of a major earthquake occurring along this section in the next 30 years? Explain.
   - c. Do you think San Francisco or Los Angeles has the greater risk of experiencing a major earthquake in the near future? Defend your selection.



Graph on page 371

8. The accompanying image shows a double-decked section of Interstate 880 (Nimitz Freeway) that collapsed during the 1989 Loma Prieta earthquake and caused 42 deaths. About 1.4 kilometers of this freeway section, commonly called the Cypress Viaduct, collapsed, while a similar section survived the vibration. Both sections were subsequently demolished and rebuilt as a single-level structure, at a cost of $1.2 billion. Examine the map and seismograms from an aftershock that shows the intensity of shaking observed at three nearby locations to answer the following questions:
   - **a.** What type of ground material experienced the least amount of shaking during the aftershock?
   - **b.** What type of ground materials experienced the greatest amount of ground shaking during the same event?
   - **c.** Which of the two sections of the Cypress Viaduct shown on the map do you think collapsed? Explain.



USGS

9. Strike-slip faults, like the San Andreas Fault, are not perfectly straight but bend gradually back and forth. In some locations, the bends are oriented such that blocks on opposite sides of the fault pull away from each other, as shown in the accompanying sketch. As a result, the ground between the bends sags, forming a depression or basin. These depressions often fill with water.
   - **a.** What name is given to the depression in the accompanying photo?
   - **b.** Describe what would happen if these two blocks began moving in opposite directions.

Michael Collier

CHAPTER IV

GRAVIMETERY, GEODESY AND THE SHAPES OF THE EARTH

The study of gravity leads to a better understanding of the form of the Earth and the structure of its external layers. It also provides information on the dynamics of the planet. The study of the gravity gives us the gravimetric shape of the earth which tells us about the distribution of masses within and to treat the Earth as an oblate ellipsoid.

Geodesy is the science which studies the shape of the earth and gives the value of the gravity field at all points on the earth's surface.

Gravimetry aims to measure the intensity of gravity field around the earth. The study of its spatial variations provides information on the distribution of masses within the globe and on vertical movements.

4 1 Gravity

We call gravity the apparent attraction of any body by the earth. It is the result of two phenomena: Universal attraction and the axifuge force linked to the rotation of the earth. The intensity of gravity known by **g** varies according to the latitude, the distribution of masses inside the Earth, the rotation of the Earth on itself (speed and position of the axis of rotation) , as well as the relative position of the Moon and the Sun, which generate the tidal forces. The relative or absolute determination of **g** is of crucial importance in different areas of scientific research. The analysis of local variation of **g** has many applications in geology.

On the surface of the earth the constant **g** varies according to:

- Altitude;

- Latitude

-Landforms.

We measure the value of **g** with an instrument called the **gravimeter**.

4 2 Gravimetric representation of the earth:

The geoid and the reference ellipsoid

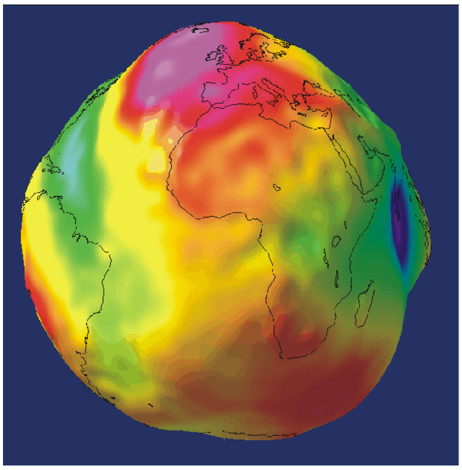
4 2 1 Gravity and the Geoid

Weight is the attraction of any body by the Earth.

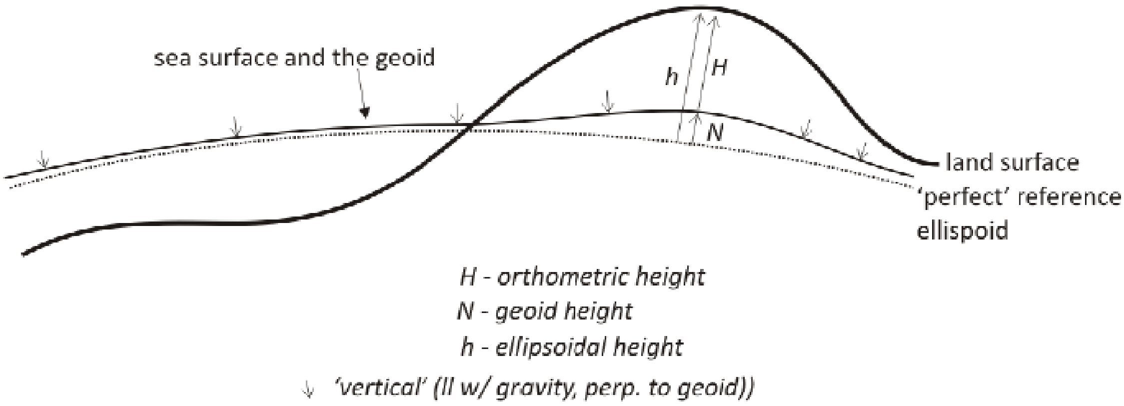
Gravity is the intensity of this weight. On the surface of the Earth, gravity varies depending on altitude and latitude.

The term geoid is conventionally used for the equipotential surface (surface of equal gravity) corresponding to the average sea-level. The geoid corresponds to the gravimetric surface of the earth.

The geoid is an irregular envelope surface, fluctuating with the non-uniform distribution of masses within the globe. This surface is recalculated regularly using absolute gravity measurements. This shape is not spherical due to the rotation of the earth and variations in masses inside the Earth.



Gravimetric shape of the Earth



4 2 2. The reference ellipsoid:

If the earth is homogeneous, its surface would be a perfectly spherical equipotential of gravity (constant **g**). Due to the rotation of the earth, this theoretical surface is no longer a sphere but an ellipsoid of revolution flattened at the poles. Clairaut (1743) showed that for a fluid mass (same dimensions and rotation velocity of the earth) in uniform rotation subject to its own attraction has a spheroidal shape which he called **reference ellipsoid**. This ellipsoid makes it possible to compute mathematically the theoretical value of $\mathbf{g}_{\text{th}}$ at any point on the earth according to the following formula:

$\mathbf{g}_{th}$ = 978,0498 (1 + 0,0053024 $\sin^2\lambda$ – 0,0000058 $\sin^2 2\lambda$) gal
Any discrepancy between the calculated and the measured values of **g** is called a gravitational anomaly and is imputed (attributed) to the distribution of masses in the Earth's interior.

4 3 Gravity Anomalies

The values of **g** obtained by the measurements carried out by the instruments (gravimeters) can be compared with the values theoretically calculated (by the previous formula on the Cléraut ellipsoid) and then corrected in relation to the altitudes and apparent excess of masses (reliefs).

The difference between the measured value of **g** at any point A on the earth $\mathbf{g}_{(MA)}$ and that calculated theoretically at the same point A $\mathbf{g}(_{th\ A})$ then corrected is known by **Gravimetric Anomaly**.

Therefore, any deviation of the measured value of g and its calculated value is called an anomaly. It is attributable to an inhomogeneity in the distribution of masses within the Earth.

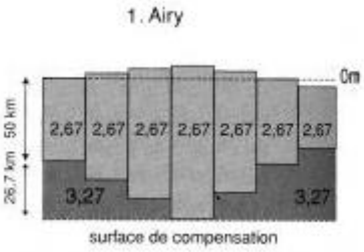
4 3 1 Corrections of gravity anomalies

All of the corrections, namely the Faye correction, the plateau correction and the topographic correction are known by the Bouguer corrections. The Bouguer anomaly is the difference between the value of the **g**(th A) calculated and the $\mathbf{g}(_{MA})$ measured thus corrected.

Theoretically, the measured values $\mathbf{g}(_{MA})$ after being corrected should be close to the calculated values of g ($g_{th\ a}$). Conversely, Bouguer's corrections have been found to exaggerate the difference between $\mathbf{g}(_{MA})$ tus correcetd and **g** ($g_{th\ a}$). In reality the corrections we make are useless because everything happens as if everything is in balance and the effect of the mountain masses or the abyssal plains and the ditches is compensated by something in depth. How to explain this? Two hypotheses, that of Pratt and that of Airy, attempt to explain these gravity anomalies.

4 3 2 The Hypotheses (1855)

Airy hypothesis



Airy proposes that mountains, like the entire earth's crust, float on high density material (we call light material that of the crust and heavy material the underlying material). Topographic

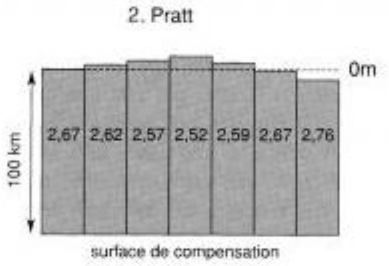
Airy's model

elevations (mountains) would be compensated for by roots embedded in dense material). There is an obvious comparison here with cubes of ice floating in a glass of water: the more that emerges above the surface, the more there must be below.

Airy suggested that at a certain depth the influence of relief is no longer felt and inequalities at the surface are compensated for. Gravity readings here would match those provided by calculation. This surface is known by a **compensation surface** below which masses are distributed homogeneously. In this model the compensation surface where the materials are homogeneous and **g** calculated and **g** measured will be identical is located at 76.7 km depth.

Pratt's hypothesis

J. H. Pratt suggested that the equilibrium between the high rise mountains, the plains and the abyssal plaines could be explained if the mountains were not homogeneous masses sitting on a deeper surface but were formed from an expansion of crustal material. Rather like a well-cooked soufflé, a small mass would provide a large volume. At depth, expansion would not occur but there would be a **compensation surface** where gravity would be homogeneous. At this point, the measured value would equal the calculated theoretical value. Below the compensation surface, masses would be homogeneous. Below this surface, the masses have a homogeneous distribution; the calculated $\mathbf{g}_{\text{(MA)}}$ is equal to the measured $\mathbf{g}_{\text{(th)}}$.



Pratt's Model

4 4 Isostasy

We call the isostasy theory the hypotheses which interpret the compensations in depth of the superficial reliefs. Two main models, that of Airy and that of Pratt, explain well the gravity anomalies due to the non-homogeneous distribution of masses within the Earth. Both models make it possible to account for the depth compensation of significant reliefs.

The corrections to **g** that are made taking into account depth compensation are called **isostatic corrections.**

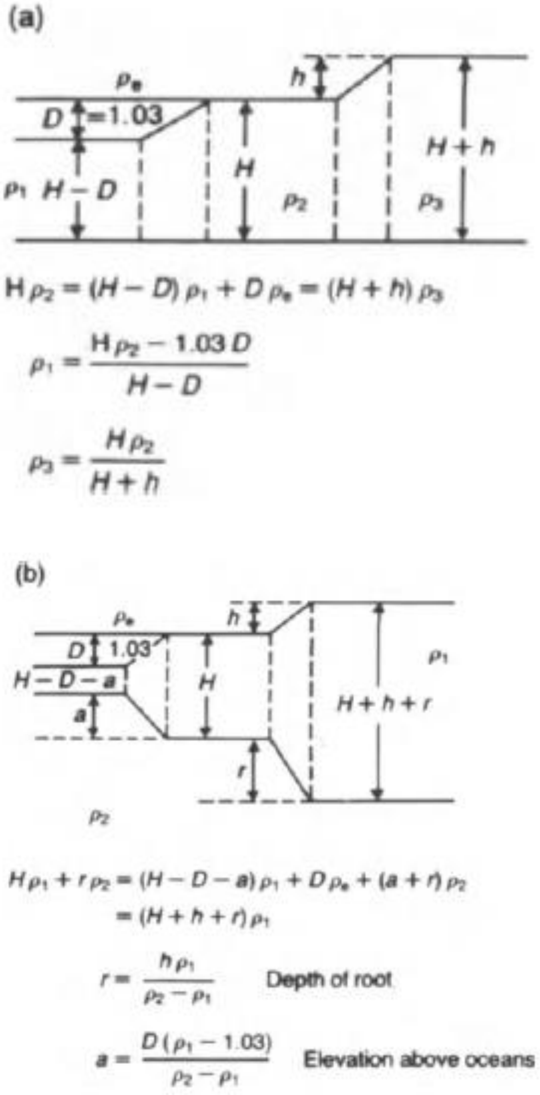
So the **isostatic corrections** at a point are the sum of the Bouguer corrections and the effect of the compensating masses at depth.

4 5 Isostatic Anomalies

The difference between the measured value of **g** $_{(MA)}$ and its calculated value **g** $_{(th)}$ thus corrected is called **isostatic anomaly**.

A **negative isostatic anomaly** means that there is a mass deficit (excess of low density material compared to what should exist if there is isostatic compensation) vertically below the measuring station.

A **positive isostatic anomaly**, however, means that there is excess mass (excess of high density material compared to what should exist if there is isostatic compensation) vertically below the measuring station.



$$H\rho_2 = (H-D)\rho_1 + D\rho_w = (H+h)\rho_3$$

$$\rho_1 = \frac{H\rho_2 - 1.03D}{H-D}$$

$$\rho_3 = \frac{H\rho_2}{H+h}$$

$$H\rho_1 + r\rho_2 = (H-D-a)\rho_1 + D\rho_w + (a+r)\rho_2$$
$$= (H+h+r)\rho_1$$

$$r = \frac{h\rho_1}{\rho_2-\rho_1}$$

$$a = \frac{D(\rho_1-1.03)}{\rho_2-\rho_1}$$

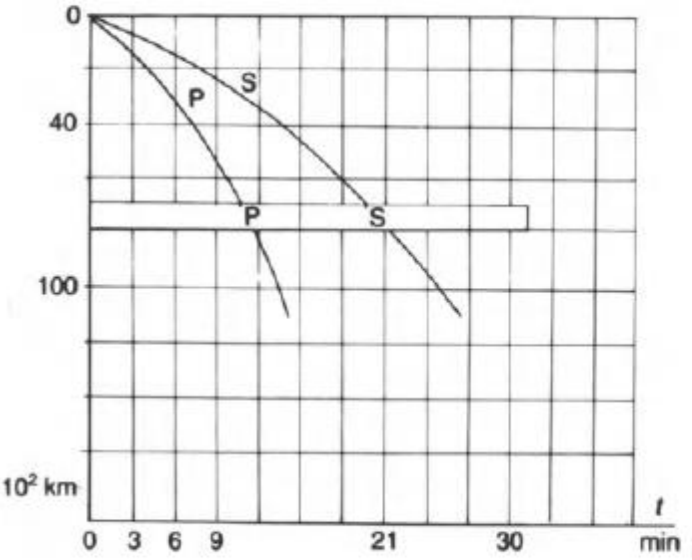
Conditions for isostatic equilibrium: (a) Pratt's; (b) Airy's.

Exercises

EX 1-

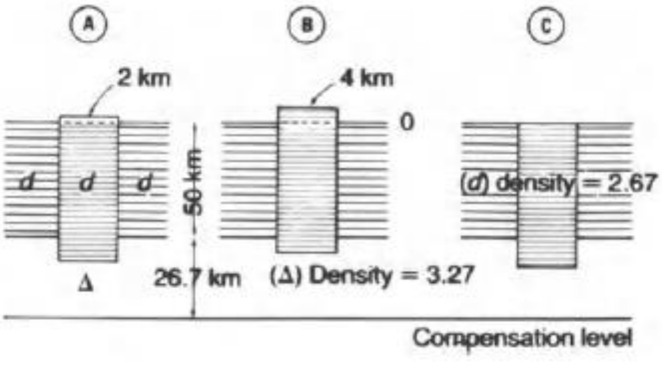
Establish the epicenter of an earthquake knowing that for this earthquake the arrival time interval between P waves and S waves recorded in three stations was:

Paris: 2 min 30 s; Warsaw: 3 min 20 s; Lisbon: 4 min 40 s.



EX 2-

If we consider that the block A is in isostatic equilibrium state (figure 1):
2 1- What is the reference model chosen?
2 2- Do blocks B and C present isostatic anomalies?
- In what sense?
- What movement will they undergo if isostatic equilibrium can be achieved?



EX 3-

We choose the Pratt model with a compensation surface located at 100 km for a column with an average density of 2.67 perpendicular the mean sea level.

Calculate the density that the column of materials must have:

1- Under a 5 km deep ocean.

2- For chains located at 2, 4 and 6 km altitude. These calculations will be carried out so that there is isostatic equilibrium.

EX4-

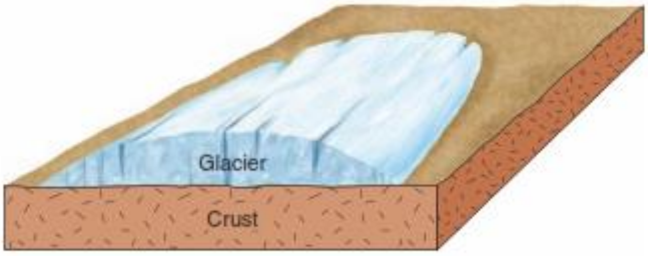
We choose the Airy model with a compensation surface located at a depth of 76.7 km for a column located vertically under the mean sea level (coast 0) and made up of a superficial part of density 2.67 over 50 km, and a deep part with density of 3.27.

Calculate the height of light material (2.67) and heavy material (3.27) for the columns corresponding to the following cases:

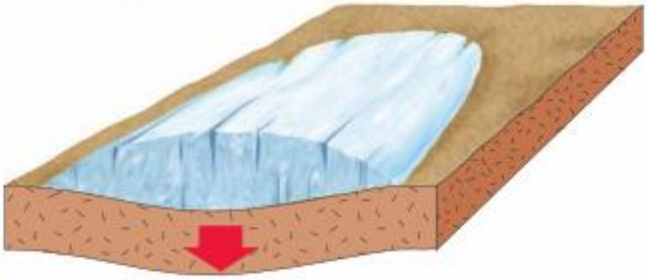
1- Mountain of 2 and 4 km altitude;

2- Abyssal plain 5 km deep;

3- Give a diagram, to the scale where the columns are joined (we will take from right to left the following altitudes: 0, 2, 4 6, 4, 0, and -5 km).



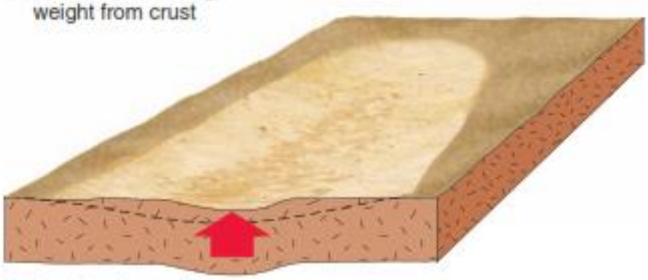
A Glacier forms, adding weight to crust



B Subsidence due to weight of ice

C Ice melts, removing weight from crust

C Ice melts, removing weight from crust



D Crustal rebound as crust rises toward original position

FIGURE 2.13

The weight of glaciers depresses the crust, and the crust rebounds when the ice melts.

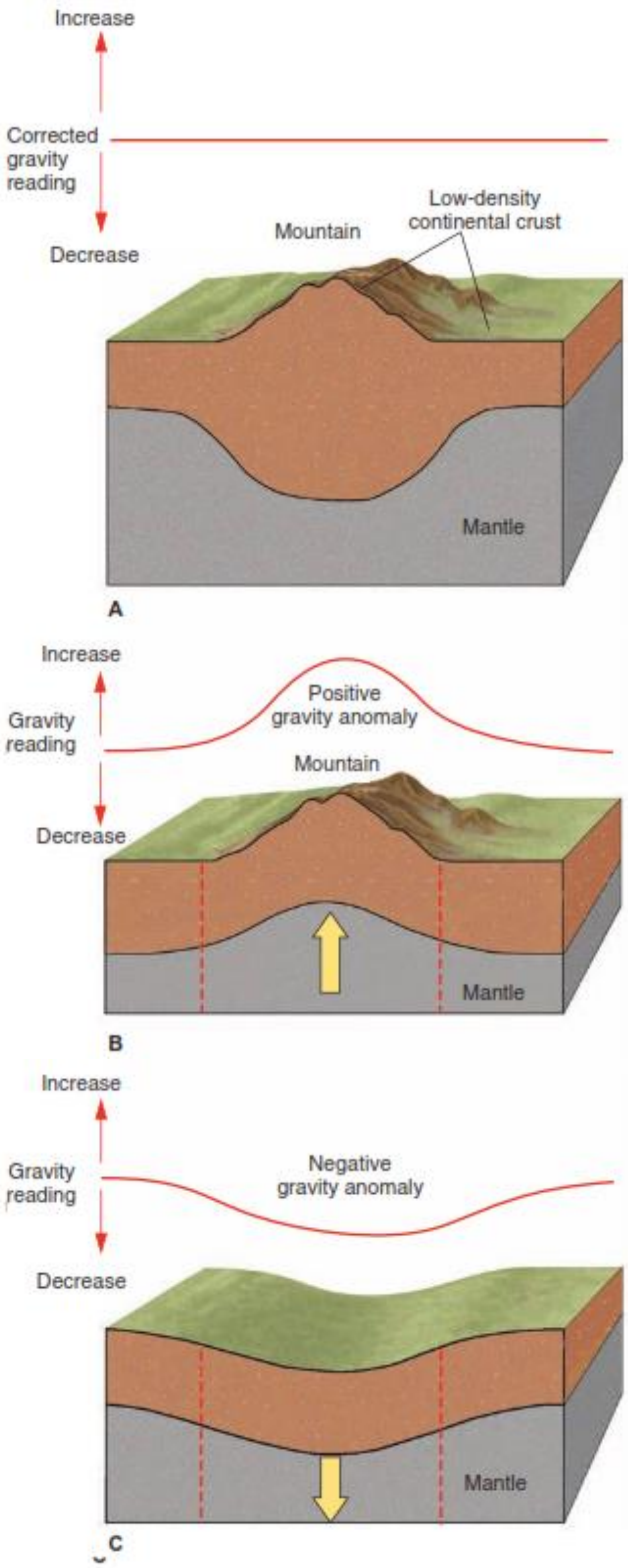
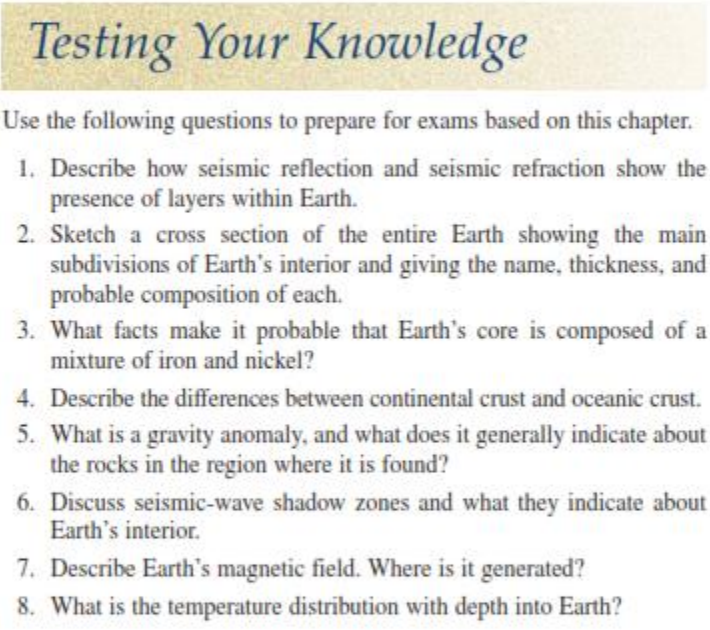


FIGURE 2.17

(*A*) A region in isostatic balance gives a uniform gravity reading (no gravity anomalies), after correcting for differences in elevation. (*B*) A region being held up out of isostatic equilibrium gives a positive gravity anomaly. (*C*) A region being held down out of isostatic equilibrium gives a negative gravity anomaly.



Testing Your Knowledge

Use the following questions to prepare for exams based on this chapter.

1. Describe how seismic reflection and seismic refraction show the presence of layers within Earth.
2. Sketch a cross section of the entire Earth showing the main subdivisions of Earth's interior and giving the name, thickness, and probable composition of each.
3. What facts make it probable that Earth's core is composed of a mixture of iron and nickel?
4. Describe the differences between continental crust and oceanic crust.
5. What is a gravity anomaly, and what does it generally indicate about the rocks in the region where it is found?
6. Discuss seismic-wave shadow zones and what they indicate about Earth's interior.
7. Describe Earth's magnetic field. Where is it generated?
8. What is the temperature distribution with depth into Earth?

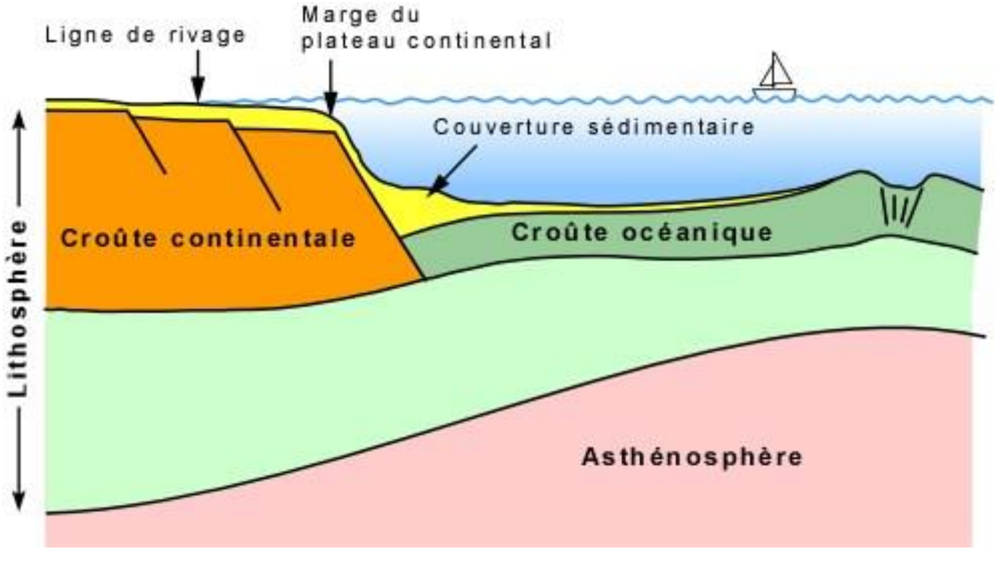
Traduction :

1-Expliquer comment les données sismiques ont révélé les différentes couches de la terre.

R- Augmentation des vitesses des ondes P et S a quelques kilometres de profondeur==➔ **discontinuité de Mohorovicic** – correspond à la limite croute –manteau supérieur.

-

9. Heat flow has been found to be about equal through continents and the sea floor. Why was this unexpected? What might cause this equality?
10. What is the Mohorovičić discontinuity?
11. What is the asthenosphere? Why is it important?
12. How does the lithosphere differ from the asthenosphere?
13. What is a magnetic reversal? What is the evidence for magnetic reversals?
14. What is a magnetic anomaly? How are magnetic anomalies measured at sea?
15. *Felsic* and *mafic* are terms used by some geologists to describe
    a. composition of continental and oceanic crust.
    b. behavior of earthquake waves.
    c. regions in the mantle.
16. The boundary that separates the crust from the mantle is called the
    a. lithosphere b. asthenosphere
    c. Mohorovičić discontinuity d. none of the preceding
17. The core is probably composed mainly of
    a. silicon b. sulfur
    c. oxygen d. iron
18. The principle of continents being in a buoyant equilibrium is called
    a. subsidence b. isostasy
    c. convection d. rebound
19. A positive gravity anomaly indicates that
    a. tectonic forces are holding a region up out of isostatic equilibrium
    b. the land is sinking
    c. local mass deficiencies exist in the crust
    d. all of the preceding
20. A positive magnetic anomaly could indicate
    a. a body of magnetic ore
    b. the magnetic field strength is higher than the regional average
    c. an intrusion of gabbro
    d. the presence of a granitic basement high
    e. all of the preceding
21. Which of the following is not an example of the effects of isostasy?
    a. deep mountain roots
    b. magnetic reversals
    c. the postglacial rise of northeastern North America
    d. mountain ranges at subduction zones
22. The S-wave shadow zone is evidence that
    a. the core is made of iron and nickel
    b. the inner core is solid
    c. the outer core is fluid
    d. the mantle behaves as ductile material


Ligne de rivage
Marge du plateau continental
Couverture sédimentaire
Lithosphère
Croûte continentale
Croûte océanique
Asthénosphère