STRATIGRAPHY

Chapter I: Time in geology

Stratigraphy: Stratigraphy (from the Latin *stratum*, “layer”, and the Greek *graphein*, “to write”) is the science of describing the layers of soil that make up the earth's crust (Les Strates). The strata, or geological layers, have recorded, during their formation, the multiple characteristics of their near and/or distant environment. These strata are like the pages of a book written in different languages, which we are trying to decipher. Their study leads to environmental (reconstitution of environments), chronological (correlation and position in time) and paleogeographic (reconstitution of landscapes) considerations. The stratigrapher is a historian and geographer of rocks (lithosphere), but also of the hydrosphere, atmosphere and biosphere on Earth, and even on other planets.

Objective:

- Explain the organization and arrangement of the various elements of the earth's crust.
- Retrace the planet's history. To do this, it studies the spatial arrangement and temporal situation of the planet's outer layers.

The role of stratigraphy:

- Disregard subsequent transformations

- Go back in time to find the initial state and the events it recorded.

- Replace this “initial state” in a spatio-temporal framework.

Goals:

-Temporal (time): Dating of strata and layers by various methods (paleontology ...)

- Spatial (geographical): Paleogeography in the broadest sense

I. Geological time

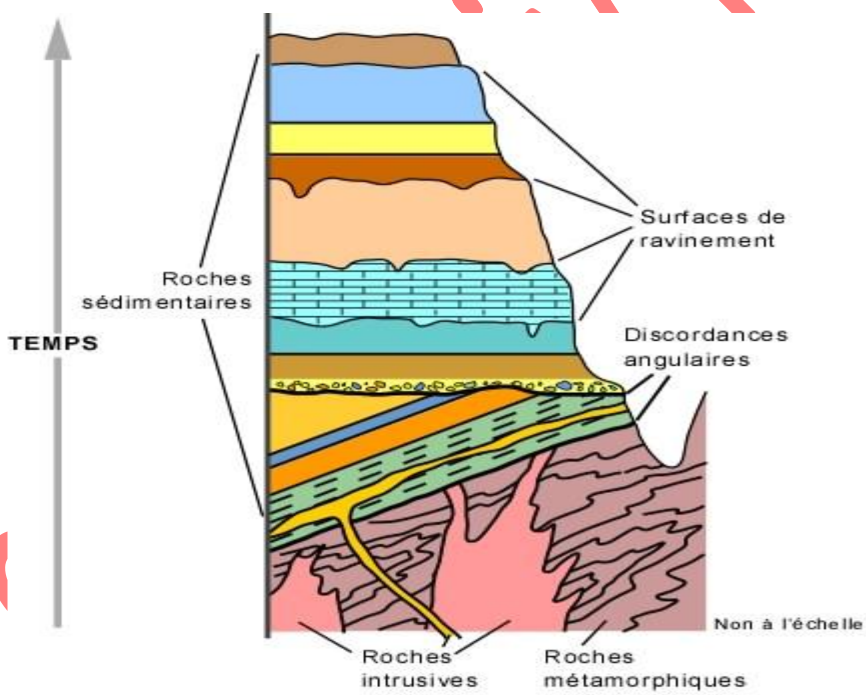
For us, time, an abstract notion, is most often materialized by the second hand of a clock, which marks the seconds, minutes or hours, and the calendar, which indicates the days, months and years. In geology, time is most often materialized by a sequence of rocks, such as the stack of layers clearly visible on the walls of Colorado's Grand Canyon.

This stacking embodies geological time: the deposition of a first succession of layers, metamorphism of these layers leading to the formation of a massif of metamorphic rocks, uplift and a long period of erosion of this massif embodied by an unconformity, deposition of a second succession of sedimentary layers, then recent erosion of the whole responsible for the spectacle that the Grand Canyon offers us today. A history that we now know to have spanned some 2.5 billion years.

The following photo shows the angular unconformity between the metamorphic rock mass and the overlying sedimentary rock sequence. This unconformity represents a long period of erosion (several hundred million years).

This last photo (below) shows part of the sedimentary sequence above the angular unconformity. There are several other, less important unconformities in this sequence, expressed by an absence of deposits corresponding to given periods of time, or by erosion (gully surfaces). Since the sequence has been well dated, we know that Ordovician and Silurian times, as well as part of Carboniferous and Permian times, are represented only by erosional unconformities.

The following diagram is a graphic representation of this sequence. Match what is said above with the elements in the diagram.



Sedimentary rocks reflect the time taken for sediments to be deposited. Intrusive rocks represent more punctual events, shorter in time. Gully surfaces and unconformities also represent time, but time in which the deposits were eroded. Such a succession constitutes the archive of the geologist as historian of the earth. The Grand Canyon sequence here represents 2.5 billion years of history.

Today, this figure can be put forward with certainty, but it took a long time for dating methods to be perfected and refined, and for a reliable geological calendar to be developed onto which the events deciphered in the rocks could be grafted. At first, dating methods were relative (cross-referencing, unconformities, fossils) before becoming "absolute" (radiometry).

I.1.Dating methods

Dating an archaeological site enables us to situate it within a given chronological period, and also to determine the different phases of its occupation, whether continuous or not.

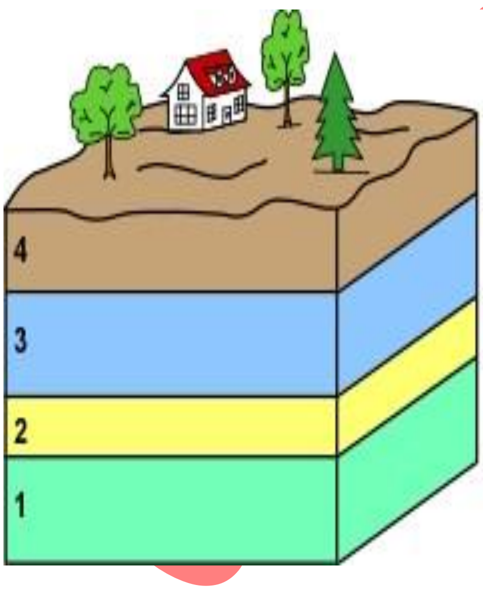
Dating methods are mutually supportive, and it is rare for a single method to be used. Thus, a typochronology can be clarified by a ^{C14} dating, just as a ^{C14} dating can be calibrated by other references.

I.1.1. Relative dating

As the term suggests, these methods establish the age of geological layers or bodies in relation to each other. In other words, they establish which of two geological bodies is younger or older, without any connotation of absolute age expressed in years. There are two main groups of relative dating methods: physical and paleontological.

I.1.1.1. Physical methods of relative dating.

The first concept of relative dating was presented in 1669 by a Danish physicist, Nicolas Steno. It is based on the principle of the **primary horizontality** of sedimentary layers and the **principle of superposition**.

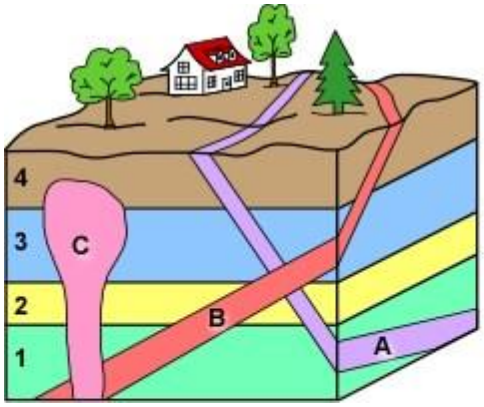


Le concept de Steno (1669) qui présente deux principes intimement liés apparaît simpliste, mais il est fondamental: les couches sédimentaires se sont d'abord déposées à l'horizontale (principe de l'horizontalité primaire); les couches se sont superposées les unes sur les autres, ce qui implique que celle qui est sous une autre est plus vieille que cette dernière (principe de la superposition).

C'est peut-être simpliste, mais il n'est pas toujours évident, dans des couches pliées verticalement ou renversées, renversées et même déposées par des mouvements orogéniques (formation des chaînes de montagnes), de savoir quel est le sens de la superposition originelle et, par conséquent, quelles sont les couches les plus anciennes et quelles sont les plus jeunes.

En 1830, dans son remarquable traité « The Principles of Geology », Charles Lyell propose un second concept pour la datation relative des couches géologiques, la **règle des chevauchements**:

un corps rocheux qui en chevauche un autre est nécessairement plus jeune que celui qu'il chevauche.

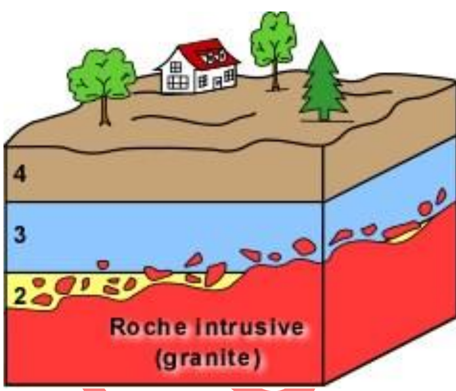


Ici, l'âge relatif des couches **1** à **4** est fourni par le principe de superposition. Les intrusifs **A**, **B** et **C** sont plus jeunes que les couches sédimentaires horizontales dans lesquelles ils se sont introduits. Leurs âges relatifs sont donnés par les recoupements: comme le dyke **B** recoupe le dyke **A** et que l'intrusif **C** recoupe le dyke **B**, on sait que **A** est plus ancien que **C**, même si ces deux dykes ne se recoupent pas; l'ordre d'intrusion est donc **A** **B** et finalement **C**.

Simplistic again, but fundamental. These observations are made on all scales, from a small outcrop of a few square meters to a region of several dozen square kilometers.

It was in the early 19th century that the importance of recognizing specific structures in rock successions, known as **unconformities**, became apparent, enabling us to establish relative dates. There are two main types of unconformity: erosional and angular.

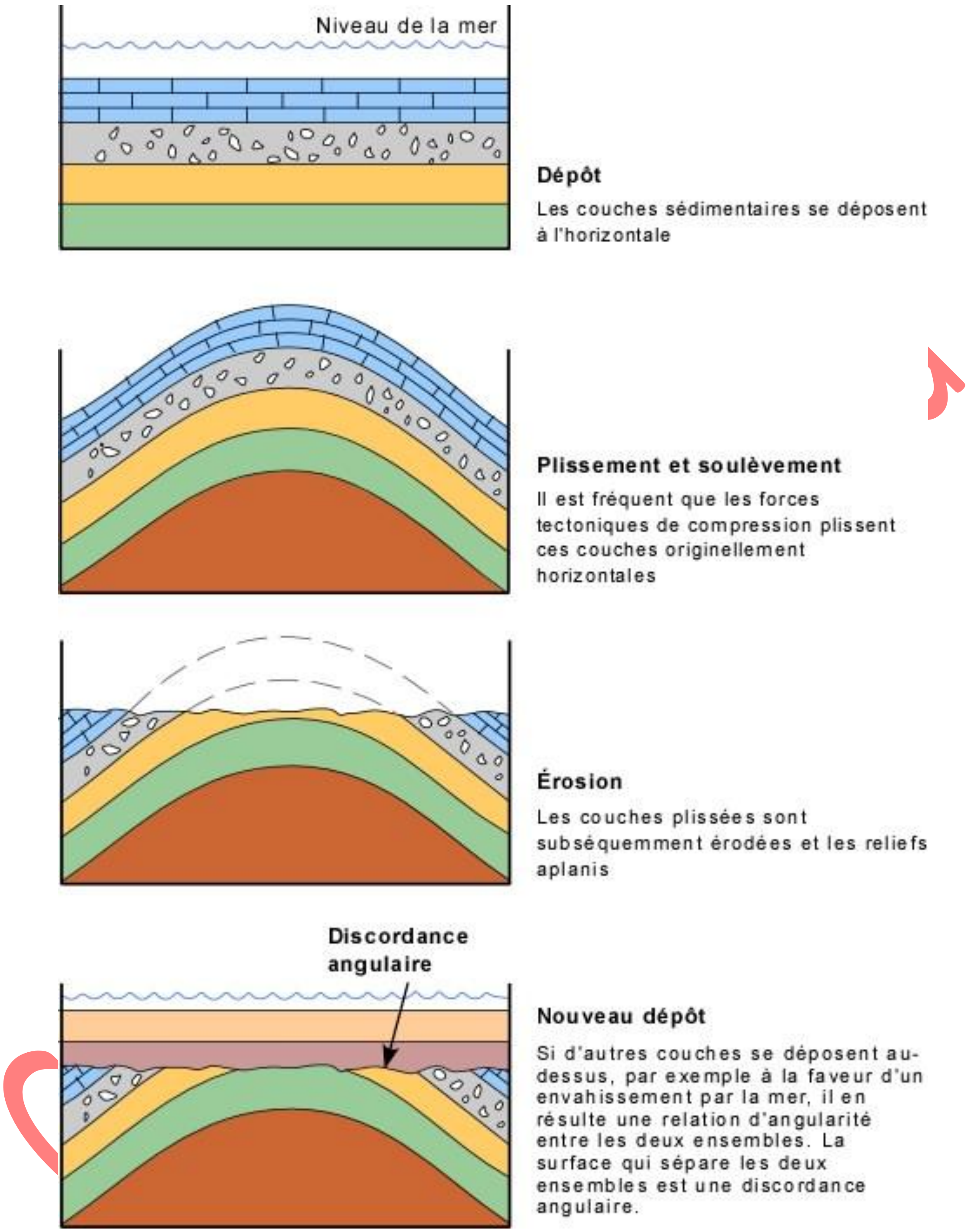
a) Erosional unconformity: the example below illustrates what is meant by this type of unconformity.



On a ici un contact irrégulier (discordant) entre une masse intrusive et une couche sédimentaire. Normalement on serait enclin à considérer que l'intrusif est plus jeune que les couches qui l'entourent ou le recouvrent. Mais ici, puisque la roche sédimentaire, qui représente un ancien sédiment, contient des fragments du granite, on se doit de conclure que le granite est plus ancien que les couches sédimentaires qui le recouvrent, ces dernières ayant incorporé des fragments de granite lors de leur dépôt.

This irregular surface between igneous and sedimentary rock, in the above example, is an erosional unconformity. In the previous examples, geological time is represented by the time of deposition of layers or by the emplacement of intrusions, which represent events that are short in time. Here, the erosional unconformity also represents geological time, but time when, not only was there no deposition, but there was erosion and depositional suppression.

b) Angular unconformity: the following example illustrates in sequence how such an unconformity is formed.



As in the previous case, this unconformity represents geological time, in this case, all the time of folding and erosion.

I.1.1.2. Paleontological methods for relative dating.

Parallel to the development of physical methods of relative dating by superposition, overlaps and unconformities, a method that was to become the most widely used, and is still the most widely used, emerged in the middle of the 18th century. This is the method of fossil dating.

While digging in horizontal layers to build canals in England, an engineer by the name of William Smith realized that, from one site to the next, he always found the same succession of rocks. It got to the point where, if he started digging in a given rock type, he could predict which rock he would find next. Not only was this true for the composition of the rock, but also for the fossils he found in it. Indeed, the layers in which he dug were very rich in fossils. Smith could see that, for any given layer, the fossil assemblages found there differed from those of the layers below and above. What's more, the vertical order in which he found these various assemblages was the same from one site to the next. He had just discovered the law of faunal succession... but without really knowing it.

Indeed, it was only a century later that Charles Darwin published his theory of evolution, which demonstrated that faunal assemblages had changed over time, and that each geological period was characterized by its own faunal assemblage. Consequently, once we know that a particular geological period is characterized by a particular faunal assemblage, we can say that a layer containing that assemblage dates from that period.

Fossils are the objects used for dating. Briefly defined, fossils are the remains of animals, including their tracks, found in sediment or rock.

Fossils can be very abundant in certain layers. They have long been the method par excellence for dating geological layers, and continue to be the preferred tool. In the time that we have been studying them, we have built up important archives, catalogs of sorts, listing the various genera and species, with the localities where they were collected, as well as their respective ages according to the relative scale of geological time. Among other things, it has been found that some fossils are very long-lived, while others have only been found in very short time intervals. The latter are useful for dating, since they represent a precise time, whereas long-lived fossils are of little use.

There are three common ways of dating layers by fossils: by pilot fossils, by fossil assemblages and by evolutionary lineages.

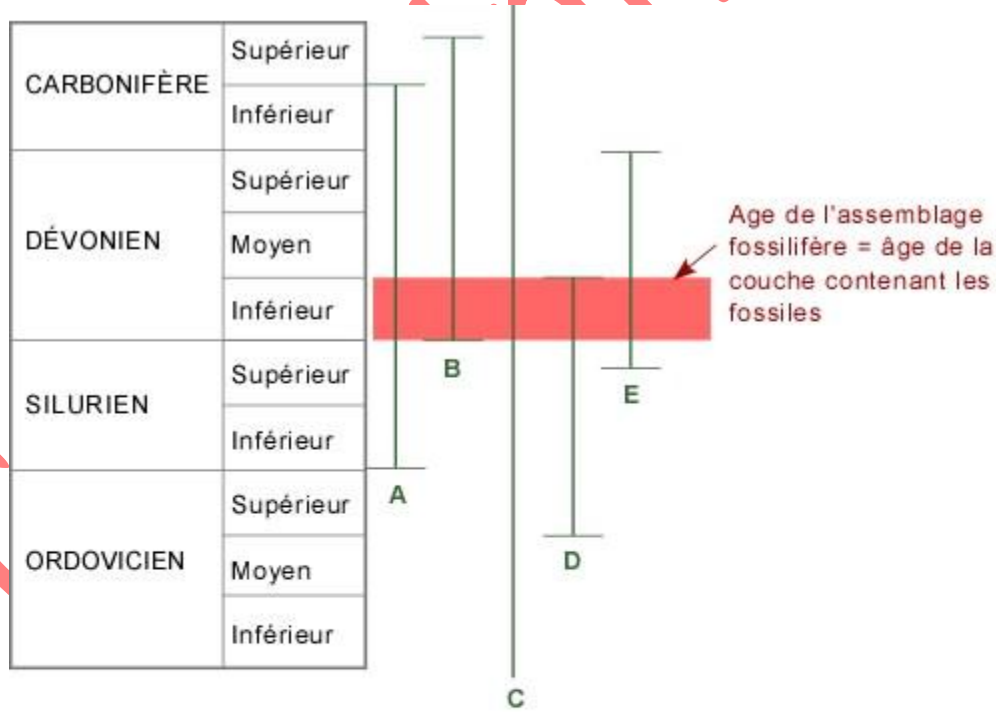
a) The pilot fossil method. This method obviously makes use of short-lived fossils that indicate specific ages. A layer containing one of these fossils can therefore be dated fairly accurately. However, such fossils are not always found.

b) The fossil assemblage method. This method is based on the sum of fossils found in a given layer. It assumes that all fossils found together in a sedimentary layer represent organisms that all lived at the same time. The following two diagrams explain the method.

Suppose we want to know when the following photo was taken.

The age of this family photo, i.e. when it was taken, is relatively easy to determine if you know that the father lived from 1903 to 1973 (green stripe), that his daughter was born in 1934 and is still alive, and that the grandson was born in 1972 but died in infancy, in 1980. The only time these three people were alive at the same time was in 1972-73, hence the age of the photo.

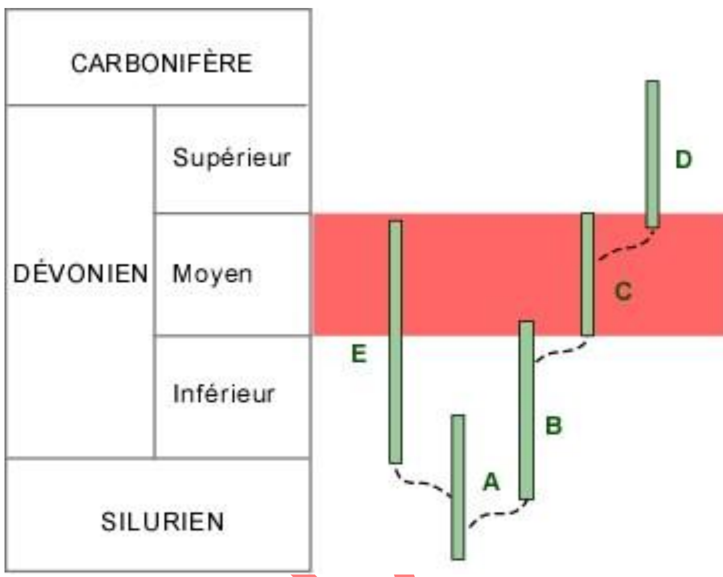
We do the same with fossils. Let's take an assemblage of fossils (A, B, C, D and E) found in the same layer. We consult the catalogs to find out how long each of the organisms they represent lived.



If we learn that A is known from the Lower Silurian to the Lower Carboniferous, that B is known from the Lower Devonian to the Upper Carboniferous, that C has a very long life span from the ante-Ordovician to the post-Carboniferous, D extends from Upper Ordovician to Lower Devonian, and E from Upper Silurian to Upper Devonian. The only time these forms could have been found together in the same environment was when they were all able to live at the same time, i.e. the

Lower Devonian. The assemblage and the layer containing it therefore date from the Lower Devonian. None of these fossils, taken individually, could have provided such a precise age.

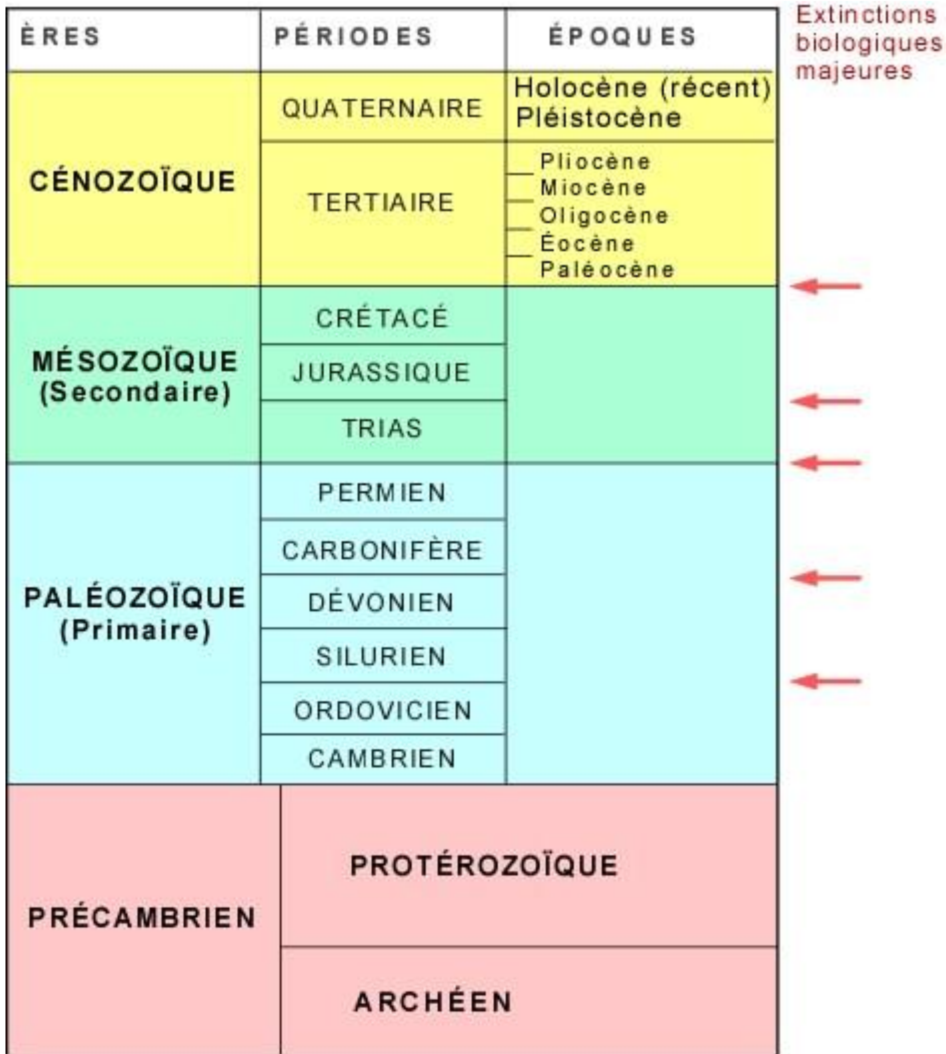
c) The evolutionary lineage method. Paleontological research into the evolution of various biological groups over geological time has revealed several evolutionary lineages, often over short periods of time. To illustrate the usefulness of these lineages for relative dating, let's take the example of an evolutionary lineage of the species of a given genus, i.e. species A, B, C, D and E, with a good control of the temporal distribution of each species.



Since we're talking about an evolutionary lineage, the lifespan of a species marks a very precise time. The presence of one of these species in a layer therefore sets a precise age limit for that layer; for example, if we found species C, we would know that the layer must have a Middle Devonian age.

A relative geological time scale.

Over the past century, geologists and especially paleontologists in Europe have used relative dating methods to construct a relative geological time scale. Here's the scale:



Note that there's no time here expressed in years. In fact, we had a very vague idea of the actual time involved. The boundaries between the main units were established mainly on the basis of major faunal changes (red arrows). Thus, the boundary between the Paleozoic (lit., early life) and the Mesozoic (lit., middle life) corresponds to the great extinction at the end of the Permian, when 95% of species disappeared from the surface of the globe, while the boundary between the Mesozoic and the Cenozoic (lit., recent life) corresponds to the disappearance of several groups, including the dinosaurs. The Proterozoic (lit., before life) was so named because it was believed at the time that life only began in the Cambrian (today, it is known to be much older).

Each geological period has a name that was given to it in the 19th century by geologists in Western Europe or Great Britain: Cambrian (Cambria, the Roman name for Wales), Ordovician and Silurian (after the names of the Celtic tribes, the Ordovices and Silures, who lived in Wales during the Roman conquest), Devonian (after Devonshire County, England, where these rocks were first studied), Carboniferous (coal-rich rocks), Permian (after the Perm province in Russia, where these rocks were first studied), Triassic (rocks divided into three units in Europe), Jurassic (after the Jura in France and Switzerland, where rocks of this age were first studied), Cretaceous (creta, Latin for chalk; first applied to the white cliffs along the English Channel).

I.1.2. Absolute dating

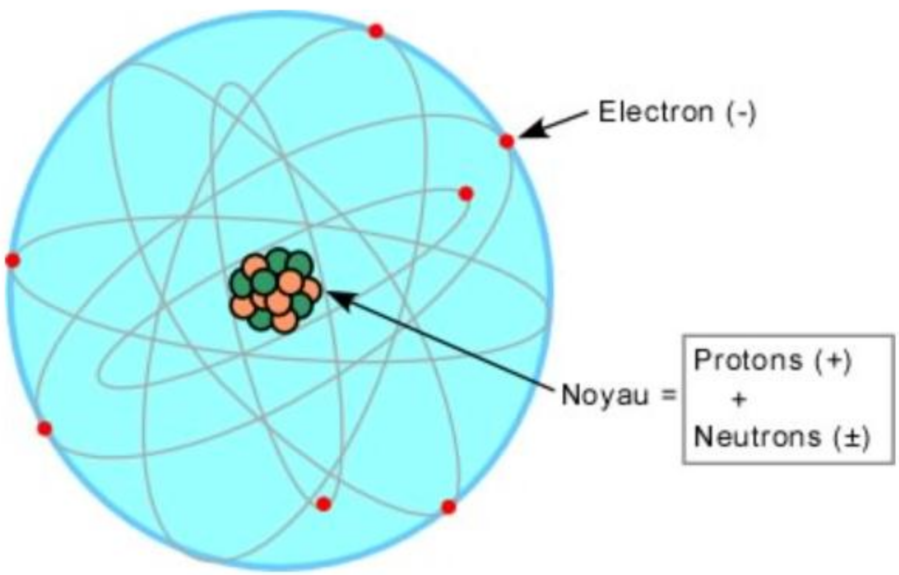
Relative dating methods, mainly using fossils, did not give us any idea of real geological time. Not only did we not know the age of the various geological layers, we didn't even know the age of the Earth.

It wasn't until the discovery of radioactivity by Marie and Pierre Curie, at the beginning of the 20th century, that we finally had the tool that enabled us to get a realistic idea of geological time, i.e. to obtain absolute geological ages, and to determine the venerable age of our planet.

This tool, radiometric dating, uses certain chemical elements that have the property of radioactive decay. By calculating the time taken for a certain portion of an element contained in a mineral to decay, we obtain the mineral's age of formation.

What is radioactivity?

The atom is made up of a nucleus (protons + neutrons) around which electrons gravitate. All the atom's mass is concentrated in the nucleus, while the electrons have negligible mass.



By definition:

atomic mass = nucleus = number of protons (+) + number of neutrons (±)

atomic number = number of protons (+)

Radioactivity is due to the instability of the nucleus, which disintegrates by emitting energy, mainly in two forms:

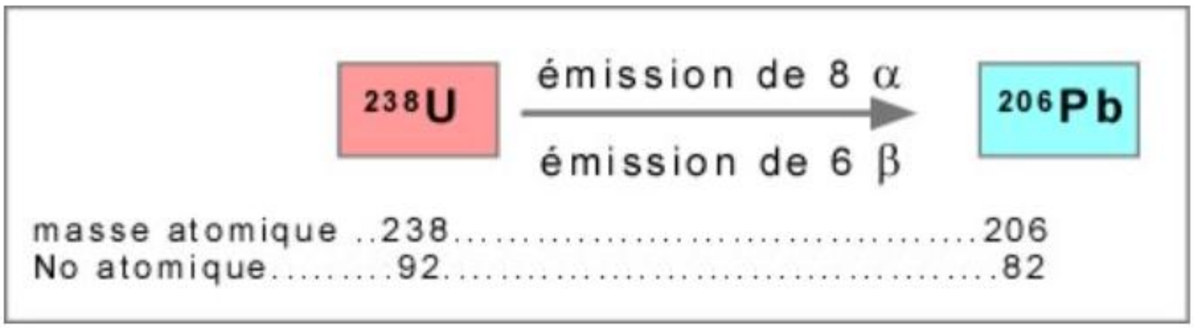
- particle α = 2 protons (+) + 2 neutrons (±) :

hence a loss of 4 in atomic mass and a loss of 2 in atomic number;

- particle β = 1 electron (-) :

this electron comes from the nucleus; it must therefore be taken from a neutron (±), which then becomes a proton (+). A proton is thus gained, resulting in a gain of 1 in atomic number, but no change in atomic mass, as the electron has negligible mass.

An example: the decay of uranium 238 (^{238}U) into lead 206 (^{206}Pb).



Emitting 8 α results in the loss of 8 x (2 protons + 2 neutrons), which means a loss of 32 in atomic mass, as well as the loss of 8 x 2 protons, which means a loss of 16 in atomic number.

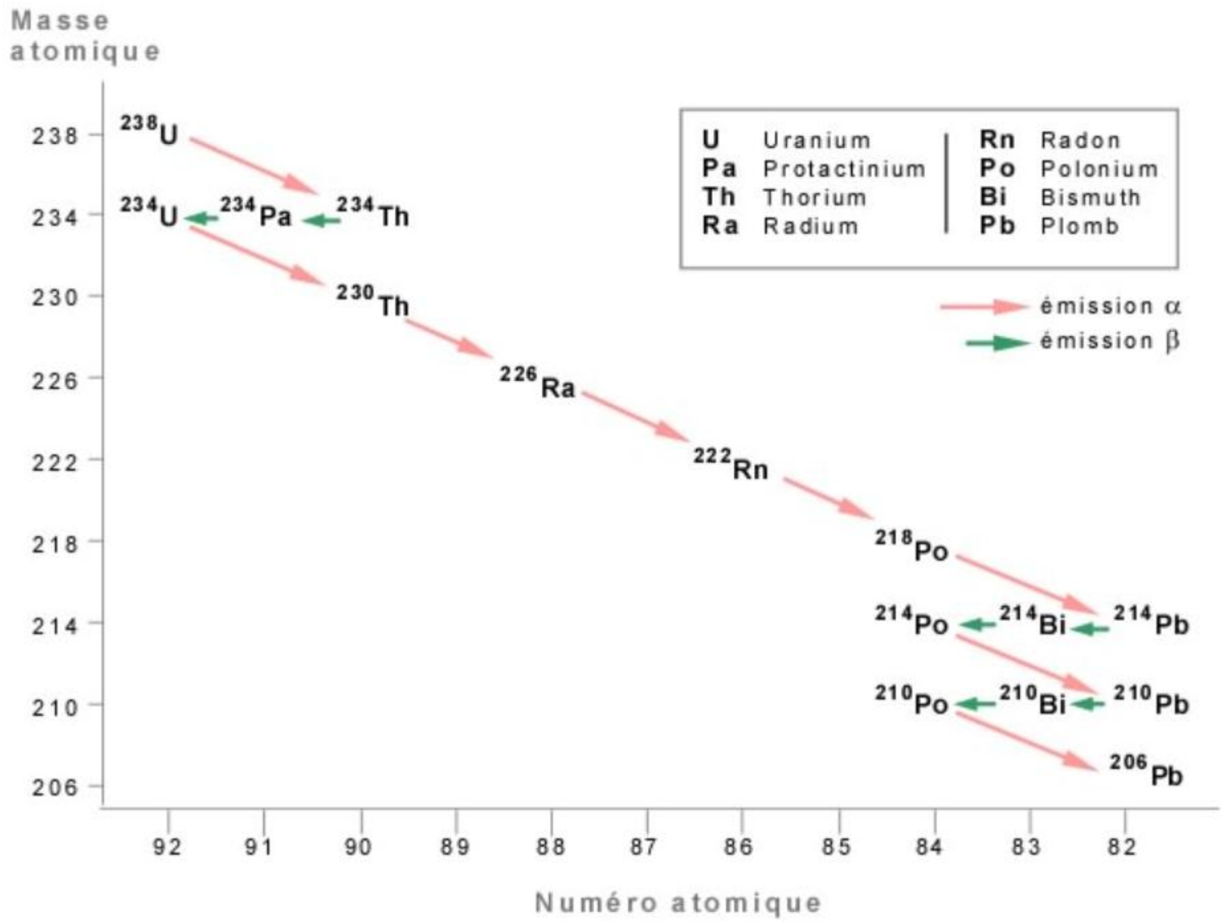
The emission of 6 β results in the loss of 6 electrons, so no change in atomic mass, but a gain of 6 in atomic number.

The balance of gains and losses is therefore as follows:

atomic mass: 238 - 32 = 206

atomic number: 92 - 16 + 6 = 82 (atomic number of Pb)

Decay takes place in successive stages, as follows:

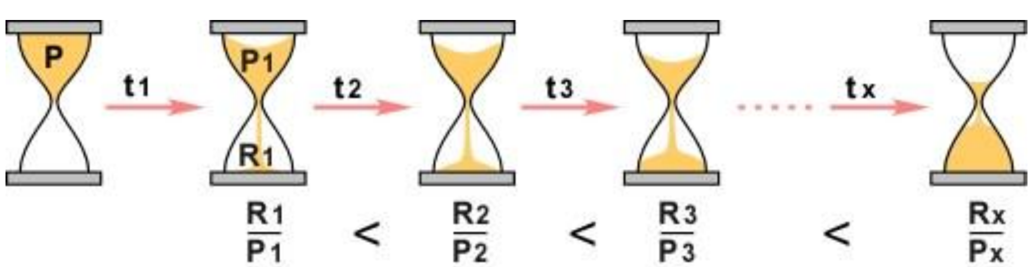


Radiometric dating

The decay reaction can be summed up as follows: a parent element (uranium in the above example) is gradually transformed into an offspring element (lead in this case). This decay takes a certain amount of time, and it's this time parameter that interests us.

Here, time is the total time it takes for the entire parent element to be transformed into the offspring element.

The progression of decay can be illustrated as follows:

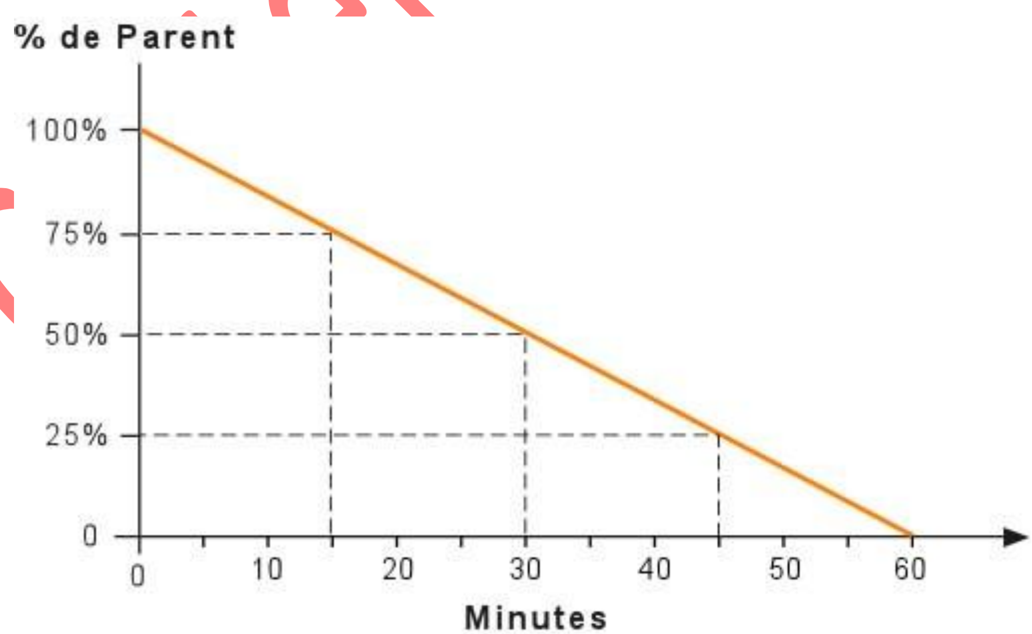


After a time 1 (t1), part of the original quantity of parent element (P) will have been transformed into a quantity R1 of offspring element; only a quantity P1 of the parent element will remain, which can be expressed by the ratio R1 to P1. After time 2 (t2), a ratio R2 to P2 will be obtained, greater than the previous one, and so on.

The value of the ratio R to P is therefore a function of the decay time. The rate of decay differs from one type of decay to another, but is always the same for a given decay. Since the decay constants for the various reactions in common use are well known, we can calculate the decay time for a given value of the ratio R to P, using these constants. What we calculate is the time taken for the decay to reach this ratio between offspring and parent. This is a very important point when it comes to radiometric dating: what is determined is **how long ago the decay took place** or, if you prefer, **how long ago the decay began**.

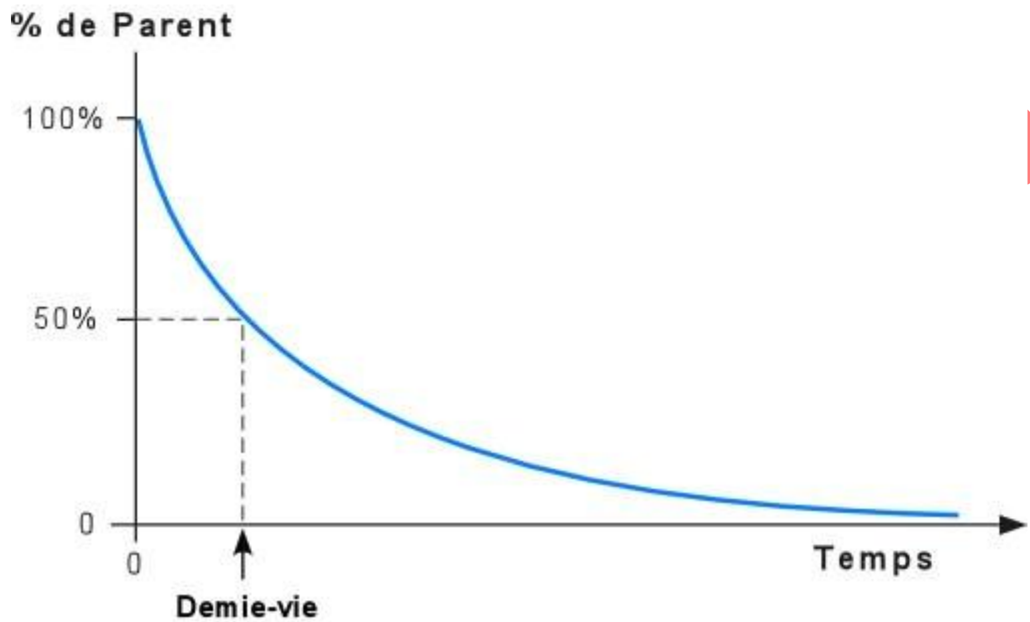
In practice, this means using minerals that contain radioactive elements, such as zircon, a zirconium silicate ($ZrSiO_4$). In this mineral, a certain amount of zirconium can be substituted by uranium, i.e. $(U,Zr)SiO_4$, making the mineral useful for dating. As the mineral crystallizes, it incorporates some uranium, but no lead. At this point, the uranium begins to decay radioactively. By determining the lead-to-uranium ratio (offspring/parent) by mass spectrometry analysis in a given zircon, which zircon is found, for example, in granite, we can calculate how long ago the decay took place or, in other words, how long ago the zircon crystallized. As it crystallized at the same time as the granite containing it, we can determine the age of the granite, i.e. when it was formed. This is why we speak of radiometric age, i.e. an age obtained by measuring the products of radioactivity.

In the case of our hourglass, the sand flow curve is expressed by a straight line, a linear relationship, represented on the graph below, where the percentage of the parent element and the time expressed in minutes are related.



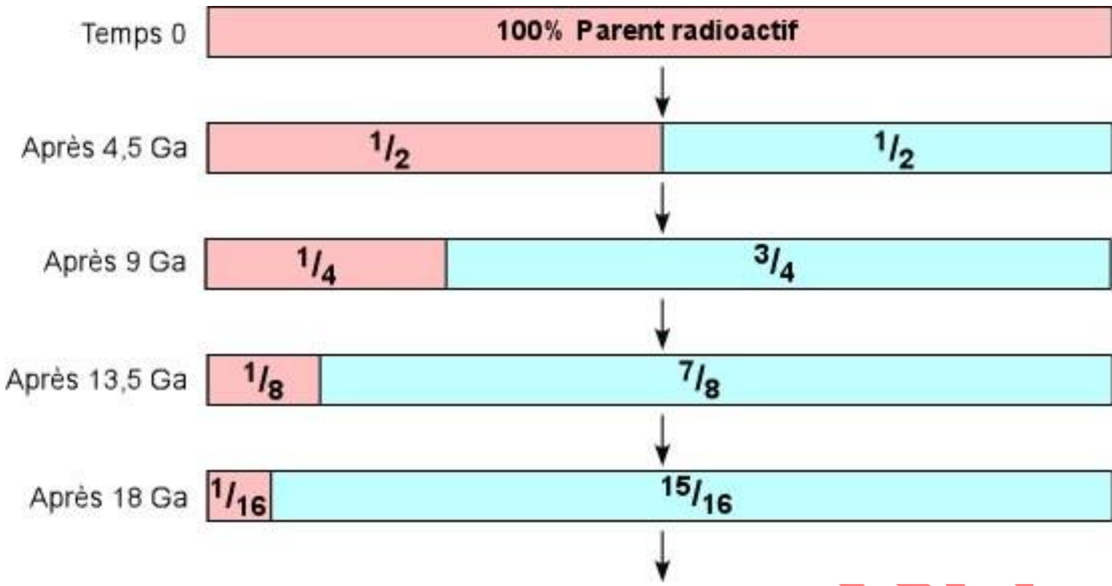
Let's suppose we're talking about a one-hour hourglass. After a quarter of an hour, a quarter of the sand volume will have run out, leaving 75% of the sand in the upper part of the hourglass. After half an hour, 50% will remain, and after three quarters of an hour, only 25%.

In the case of radioactivity, the decay reaction is not linear, but exponential: this is expressed by the curve below, which shows that the rate of decay decreases with time. The rate of decay is very rapid at the beginning, and decreases thereafter.



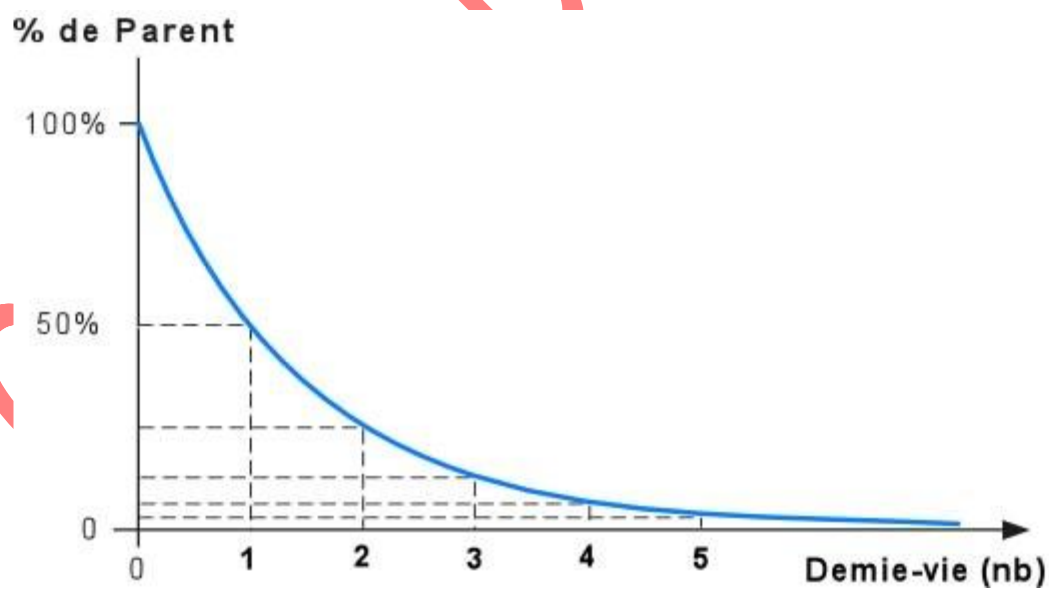
Laboratory measurements have shown that decay follows a simple rule: half of the parent atoms in a closed system disintegrate to form daughter atoms within a fixed time interval. This interval is called the **half-life**. Simply put, the half-life is the time it takes for half the parent element to disintegrate. Mind you, it's not the half-life of the disintegration, it's the time it takes for half the parent element to disintegrate.

Here's an illustration to help you visualize what is meant by half-life. Let's take the Uranium 238 - Lead 206 reaction, which has a half-life of 4.5 Ga.



After half a lifetime, i.e. 4.5 Ga, half of the parent element will remain. After another 4.5 Ga, i.e. a total of 9 Ga, half of what was left will disintegrate, leaving a quarter of the parent element. And so on.

This is expressed as follows on our decay curve. On the horizontal axis, the number of half-lives, each of equal length. Clearly, the quantities of parent element decrease progressively with each half-life.



Here are some of the most commonly used disintegrations:

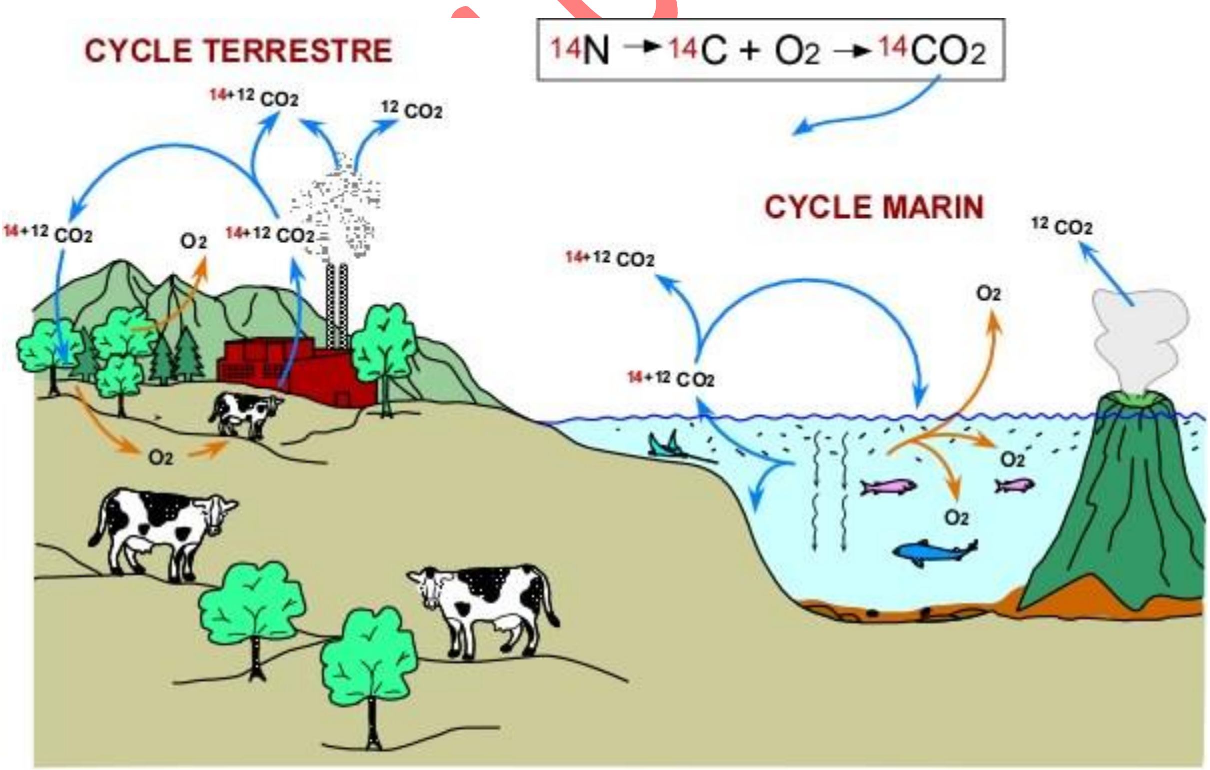
PARENT	REJETON	DEMIE-VIE
238 Uranium	206 Plomb	4,5 milliards d'années
87 Rubidium	87 Strontium	47 milliards d'années
40 Potassium	40 Argon	1,3 milliard d'années
14 Carbone	14 Azote	5730 années

And the famous Carbon-14?

Whenever there is talk of dating rocks or other ancient materials, we inevitably invoke the inevitable Carbon-14 (^{14}C). ^{14}C is indeed a very useful method for dating certain geological materials, and particularly archaeological materials.

The method uses the disintegration reaction of carbon-14 into nitrogen-14. It should be noted that the carbon common in nature has an atomic mass of 12 (^{12}C). It combines with atmospheric oxygen (O2) to form CO2 in which carbon has an atomic mass of 12, or $^{12}CO2$. But in addition to 12C, there is also, in much smaller quantities, carbon of mass 13 (^{13}C) and carbon of mass 14 (^{14}C); these three forms, of different atomic masses for the same element, are what we call isotopes. 12C and ^{13}C are stable isotopes, meaning they are not radioactive, while 14C is a radioactive isotope; it is the one used for dating.

To understand the method, we need to see where ^{14}C comes from and how this ^{14}C is fixed, with ^{12}C, by living organisms, plants and animals.



The bombardment of gases in the upper atmosphere by cosmic rays causes nitrogen, with an atomic mass of 14 (^{14}N), to transform into ^{14}C, which combines with free oxygen (O2) to form CO2, but a particular CO2 where the carbon is of atomic mass 14, namely ^{14}CO2. This ^{14}CO2 mixes with CO2 that comes from other sources, such as volcanoes and the oxidation of organic matter or, today, the combustion of hydrocarbons. The CO2 that comes from the photosynthesis-oxidation cycle of organic matter is also particular. Indeed, photosynthesis consumes atmospheric CO2, that is to say a CO2 that contains partly ^{12}C and partly ^{14}C. This means that the organic matter of plants and animals (which consume plants) will contain a certain quantity of ^{14}C. It is this ^{14}C that is used for dating.

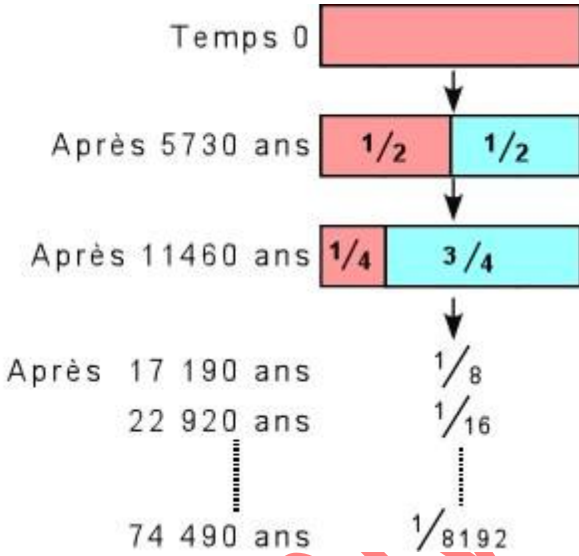
Initially, all living organic matter (plants or animals) contains ^{12}C and ^{14}C (as well as a small amount of ^{13}C). The proportion between ^{14}C and ^{12}C in the organic tissues and skeleton metabolized by the organism remains the same throughout the life of the organism, a ratio corresponding to that found in atmospheric CO2. In practice, we can therefore say that the clock starts with the death of the organism; the proportion then begins to change because of the disintegration of ^{14}C and the fact that ^{12}C remains stable. The product of the disintegration of ^{14}C, nitrogen 14, is a gas that escapes into nature. In practice, since ^{12}C is stable, we measure the ratio between ^{14}C and ^{12}C. Knowing the ratio that exists in nature between ^{14}C and ^{12}C, as well as the disintegration constant, we can, as in the other methods, calculate the time that has elapsed since the death of the organism that fixed the carbon in its tissues or skeleton. Consequently, the age that we obtain with the ^{14}C method is the age of death of the organism (of wood, shells, peat, linen, cotton, wool fabrics, etc.).

But has the ^{14}C/^{12}C ratio really remained constant over geological time?

In the ^{14}C dating method, it is assumed that the ^{14}C/^{12}C ratio has not changed over geological time, which is not true. Indeed, we now know that this ratio has varied over time. We know this, for example, by comparing the age obtained from ^{14}C and the age obtained by counting tree rings (dendrochronology) or coral growth rings, or varves (seasonal deposits) in lakes. We know that ^{14}C production has been variable, and generally higher in the past, which implies that ages not calibrated in dendrochronological (solar) years are in reality often younger than they appear according to the ^{14}C chronology, and this in a non-linear manner. This is why ^{14}C dates need to be calibrated, a procedure also called calibration. Thus, a 5000-year ^{14}C date actually corresponds to about 5720 solar years, while a 10,000-year ^{14}C date actually corresponds to about 11,470 solar years. The Last Glacial Maximum, established at 18,000 years ^{14}C BP (Before Present = 1950 A.D.), thus actually dates back to about 21,000 years before the present (i.e. 1950 AD). Calibrating ^{14}C dates in solar years is therefore essential to establish the real age of the dated objects, the real duration of the events, and the rates of change over time. The difference diminishes for more recent ages. Even with a correction factor as large as 10% (which is not the case), the Turin Shroud could not be aged by ... 700 years! (see below).

Popular belief is that you can date anything with ^{14}C. It is important to note, and this is very important, that this method only applies to materials that were once alive, such as wood, shells, linen, etc. There is no point in thinking about dating metal tools or flint (SiO_2) arrowheads with this method.

There is another very important limitation to the method: the time involved. With the uranium-lead, rubidium-strontium or even potassium-argon methods (see above), the half-life is expressed in billions of years. With ^{14}C, we are talking about a half-life of 5730 years. The following diagram shows the implication of such a short half-life.



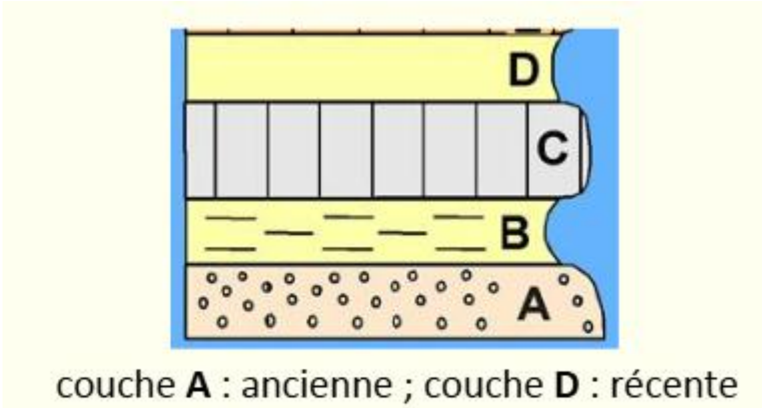
At time 0, we have 100% ^{14}C (pink bar). After 5730 years (the half-life of the decay), half of the ^{14}C has decayed. After another 5730 years (11,460 years in total), half of the half has decayed; a quarter of the original ^{14}C remains. After another 5730 years, 1/8 remains, and so on. After 74,490 years, 1/8192 (= 0.000122) of the original ^{14}C remains. This is not much, especially since the amount of ^{14}C compared to ^{12}C was already low to begin with. Analyzing such a small amount becomes very difficult. In practice, ^{14}C is therefore useful for dating objects that are no older than 75,000 years. We are no longer talking about billions, or even millions of years, but rather only a few tens of thousands of years.

^{14}C is a very useful method in archaeology and history. It has been useful in settling certain debates: the Turin shroud that is said to have been used to bury the body of Christ was dated in 1988 by three independent teams to be between 1260 and 1390 years old, so a shroud made in the Middle Ages. The wood of the so-called throne of St. Peter has also been dated to the Middle Ages. The method is also used in the geology of superficial deposits that are often younger than the 75,000-year limit. The deposits of the Champlain Sea, for example, are dated with ^{14}C, using the shells and fossil wood of these deposits. After calibration, these ^{14}C dates allow us to establish that the Champlain Sea was established about 13,100 years ago, and that it ended about 10,600 years before the present. It will therefore have lasted about 2500 solar years (but only 1700 radiometric years at ^{14}C; see above).

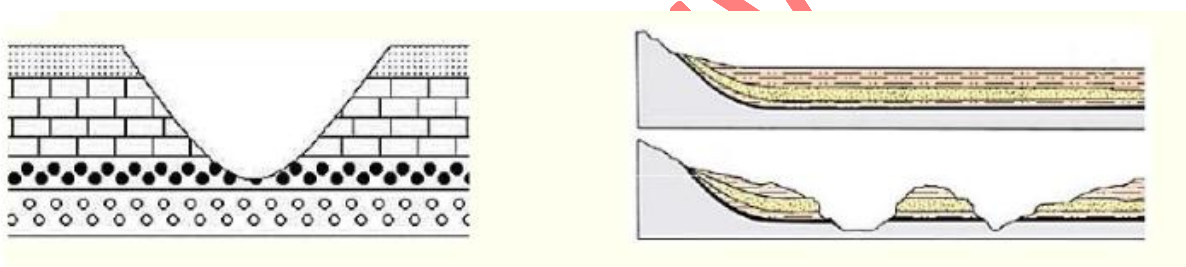
II. The principles of stratigraphy:

The transition from a geometric succession to a temporal succession is based on a few elementary but very important principles, called "Principles of Stratigraphy" because they are stated from the study of sedimentary rocks.

a) Principle of Superposition: in nature, the layers are deposited on top of each other, the first deposited is the oldest and the last deposited is the most recent "a layer is more recent than the one it covers and older than the one that covers it"

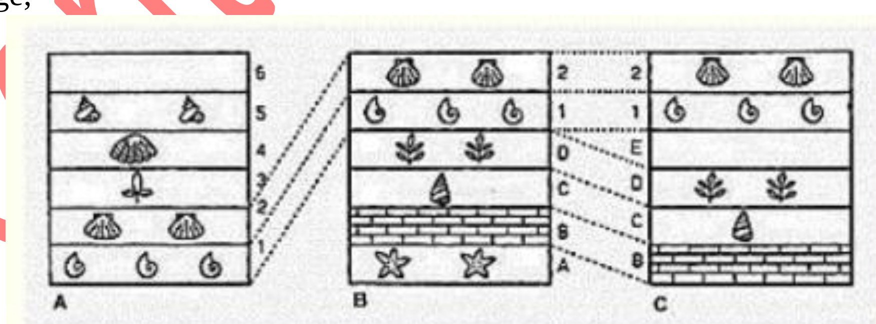


b) Principle of Continuity: the same layer has the same age over its entire extent and at all its points regardless of its facies;



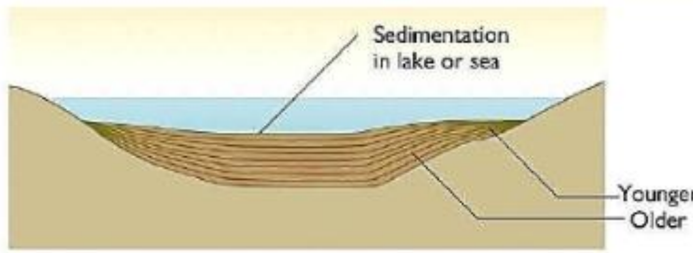
* The facies provides information on the conditions and environment of deposition
* The thickness is not necessarily proportional to the duration it represents

c) Principle of paleontological identity: two layers having the same fossils are considered to be of the same age;

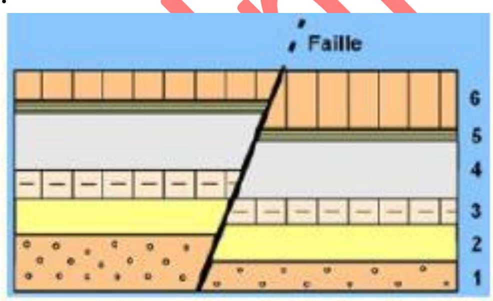


d) Principle of Actualism: past geological structures were formed by phenomena (tectonic, magmatic, sedimentary or others) acting as in our time. Moreover, to recognize a fossil organism, it is often necessary to look for its identical in current nature.

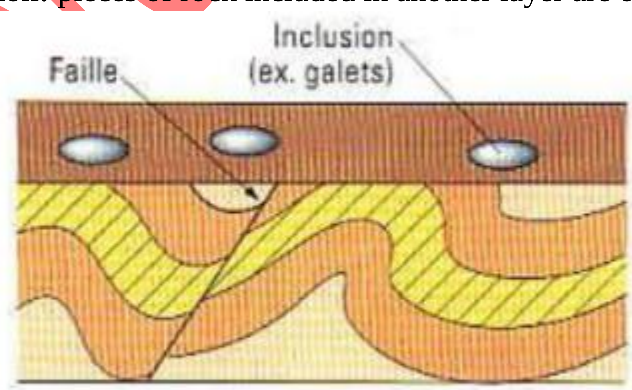
e) Principle of Horizontality: sedimentary layers are deposited horizontally; a sedimentary sequence which is not in a horizontal position has undergone deformations subsequent to its deposition;



f) Principle of Intersection: the sedimentary layers are older than the faults (or other phenomena, bodies) which intersect them.

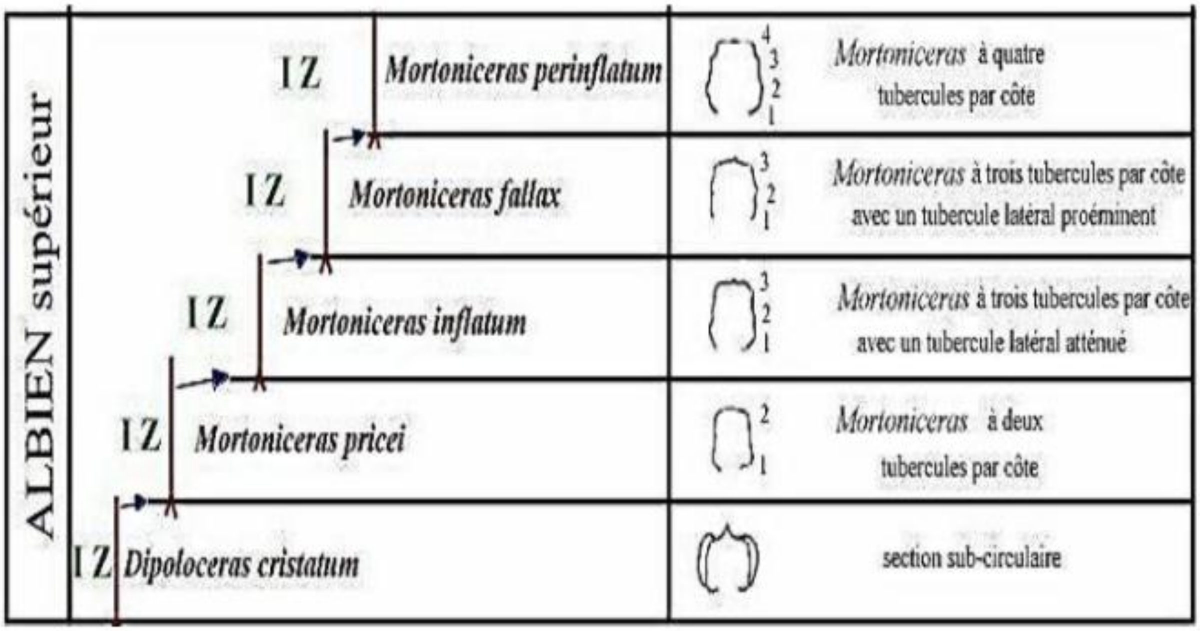


g) Principle of Inclusion: pieces of rock included in another layer are older than their container.



III. Biostratigraphic Zonations:

This is the subdivision of a stage or a geological period into several subunits according to the vertical (stratigraphic) distribution of a taxon, generally, it is a dater species (time marker, good stratigraphic fossil). This zonation is used for fine dating of geological layers or regions


ALBIEN supérieur
I Z Mortoniceras perinflatum
Mortoniceras à quatre tubercules par côte
I Z Mortoniceras fallax
Mortoniceras à trois tubercules par côte avec un tubercule latéral proéminent
I Z Mortoniceras inflatum
Mortoniceras à trois tubercules par côte avec un tubercule latéral atténué
I Z Mortoniceras pricei
Mortoniceras à deux tubercules par côte
I Z Dipoloceras cristatum
section sub-circulaire