Chapter II. Stratigraphic units

1. Stratigraphic units

Stratigraphic units are proposed to define depositional sequences. Through a detailed description of the slices of land that make up the sections and profiles, the aim is to propose a sequence for each section or profile, as well as to define correlations between them. It is the convergence of criteria that enables correlations to be proposed. Each criterion provides information on the modes of emplacement and/or post-depositional transformations.

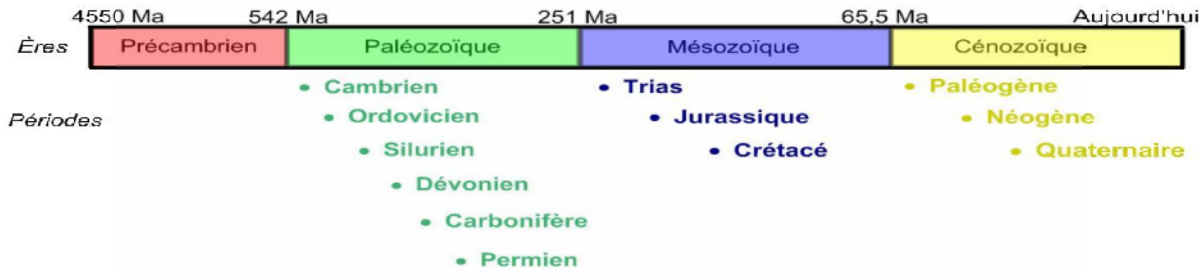
2. The great geological periods

The geological time scale divides the Earth's history into shorter units, based on the appearance and disappearance of different life forms. It begins 4.55 billion years ago (4550 million years) and continues to the present day.

Eras are the four main divisions of the geological time scale: Precambrian, Paleozoic, Mesozoic and Cenozoic.

Periods are subdivisions of the eras.

The following timeline provides an overview of the four eras and their respective periods. However, the divisions of this scale are not representative of their actual duration.



2.1. The Precambrian (4550 - 542 Ma)

The beginning of the Precambrian era corresponds to the formation of planet Earth and the other planets in the solar system, i.e. 4550 million years ago.

The Earth was formed by the agglomeration of dust and rock particles, which were drawn together by gravity. Eventually, the planet heated up until it became a huge sphere of magma. As it cooled, the Earth's crust formed and a volcanic episode began. A series of volcanic eruptions led to a major release of water vapor, which condensed and created the oceans. A billion years later, life appeared in these oceans.

The first life forms were bacteria and single-celled organisms without nuclei (prokaryotes). Among these are cyanobacteria, which use solar energy to produce oxygen, a gas that was absent from the planet's surface at the time. As a new substance appears, it has a negative impact on living organisms already present, leading them to adapt and diversify.

Generally speaking, living organisms in the Precambrian period were very simple. Single-celled organisms with nuclei (eukaryotes) appeared 2000 Ma ago, while multi-celled organisms appeared 1000 Ma ago.

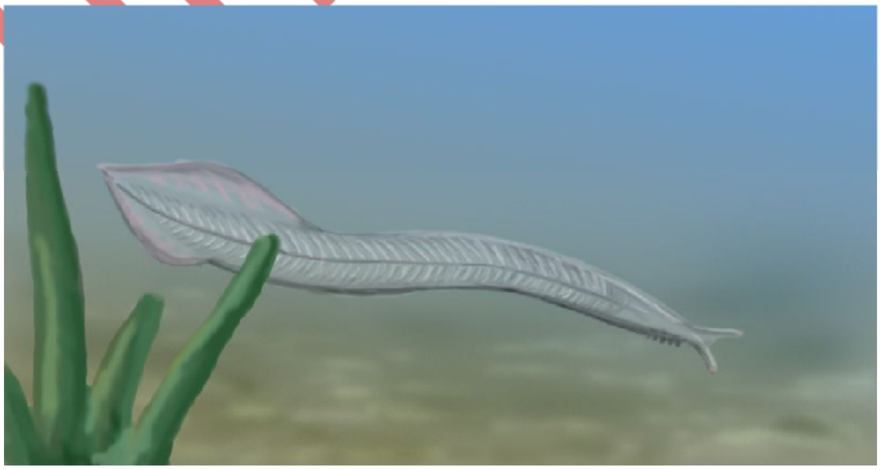
Fossil of Dickinsonia costata, a multicellular eukaryotic organism that lived in the Precambrian.

2.2. Paleozoic (542 - 251 Ma)

This era began with the appearance of invertebrates with shells. It is divided into six periods: Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian. The Paleozoic era includes three mass extinctions, as well as the appearance of the first vertebrates, the first plants and the first terrestrial organisms.

2.2.1. Cambrian (542 - 488 Ma)

This period is marked by the appearance of several hard-bodied invertebrate species, such as sponges, arthropods and molluscs. The first animal with a vertebral column also appeared. In fact, the Pikaia is the ancestor of reptiles, dinosaurs, birds and mammals.



The Pikaia lived at this time. It is considered one of the ancestors of vertebrates.

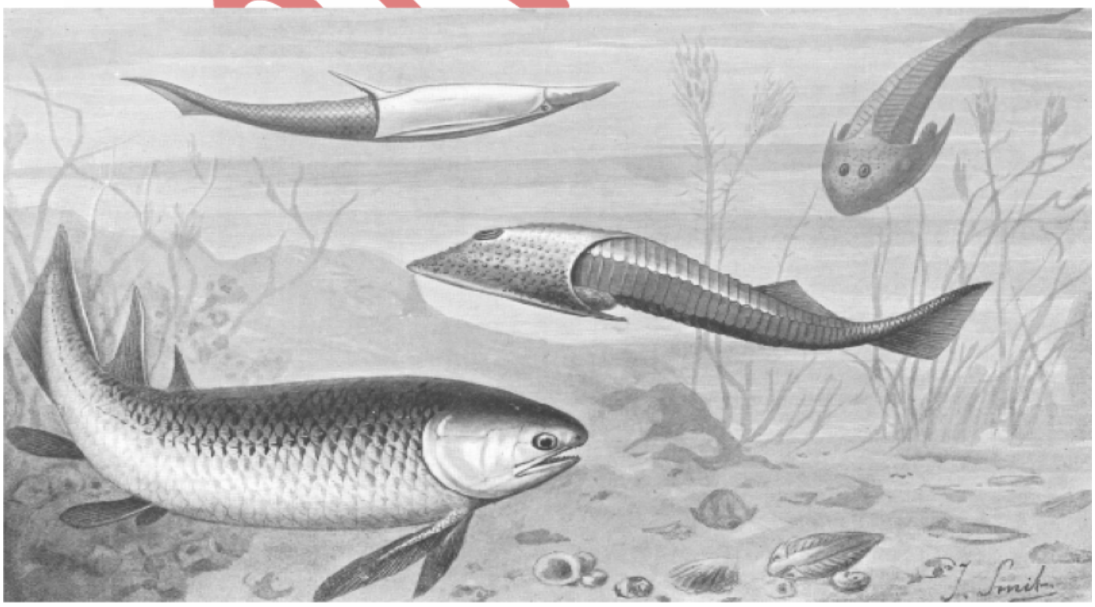
2.2.2. Ordovician (488 - 443 Ma)

It was during this period that the first marine vertebrates appeared, as well as the first plants such as mosses, fungi and lichens. Thus, life began to colonize dry land. However, at the end of this period came the first mass extinction, when more than half of all animal species disappeared.

Orthoceras was one of the cephalopod mollusks living at that time.

2.2.3. The Silurian (443 - 416 Ma)

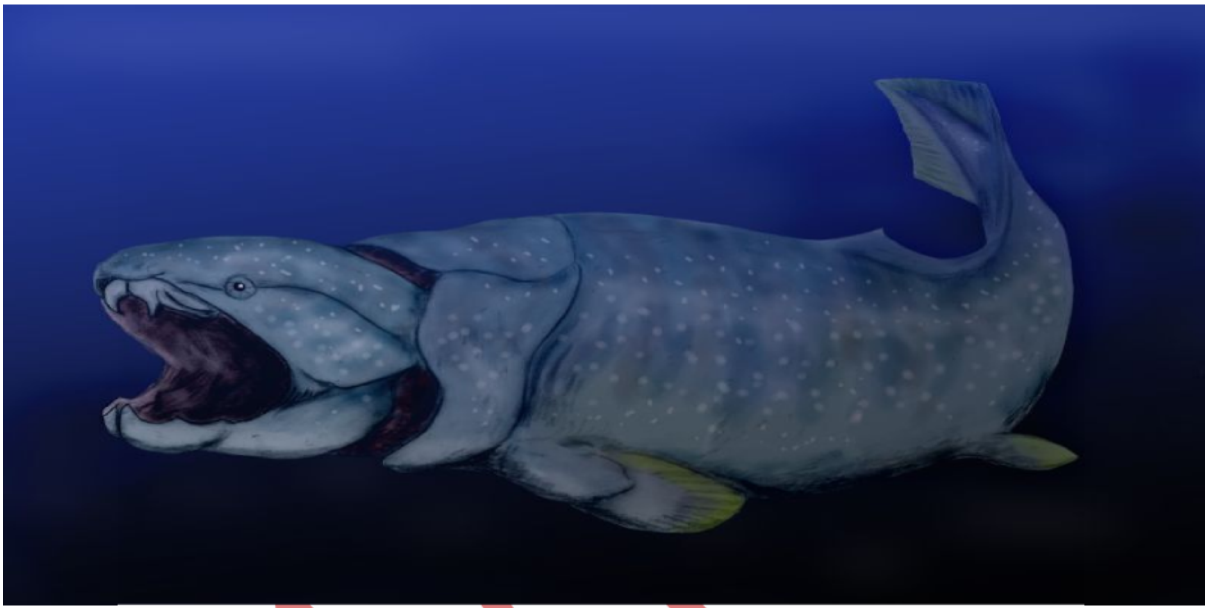
The Silurian saw the appearance and diversification of fish species: jawless fish (like the lamprey), cartilaginous fish (like rays and sharks) and bony fish (like modern fish).



Some examples of Silurian fish.

2.2.4. The Devonian (416 - 359 Ma)

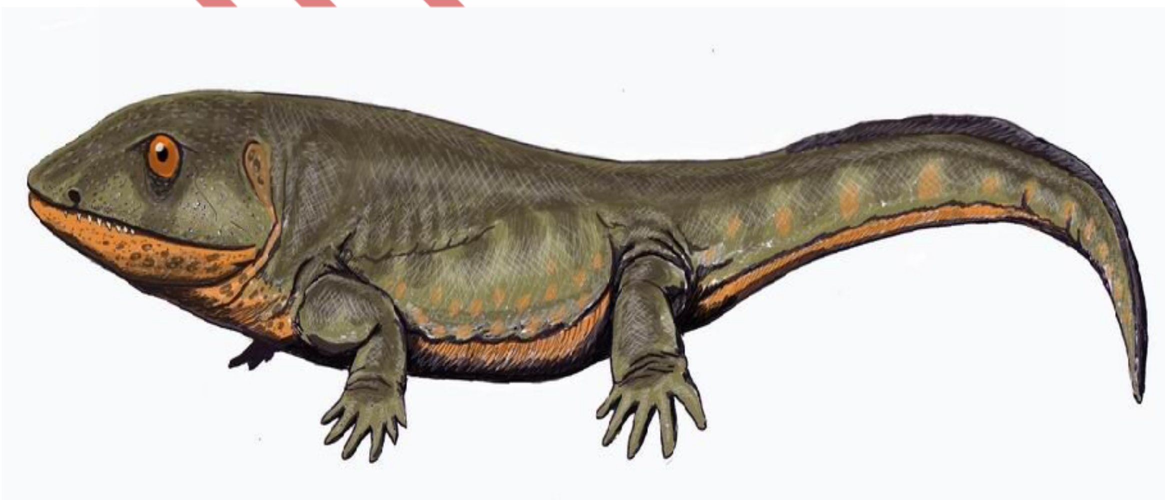
During the Devonian, land plants diversified and now reach tree size. They reproduce mainly by spores, as do ferns and lichens. Several species of arthropods and amphibians are also colonizing dry land. Unfortunately, more than 70% of marine species disappeared at the end of this period as a result of successive climate changes, making it the second mass extinction.



Dunkleosteus is a Devonian placoderm fish.

2.2.5. The Carboniferous (359 - 299 Ma)

In the Carboniferous, vast coniferous rainforests covered the surface of Pangea, the only continent present at this time. Many giant insects were also present. Numerous reptile species such as turtles, snakes, lizards and iguanas also appeared.



Pederpes is a tetrapod species that lived in the Carboniferous period.

2.2.6. Permian (299 - 251 Ma)

This period, the last of the Paleozoic, is marked by the development of animal life both on land and in the marine environment. Plants, reptiles (including the Dimetrodon, a fearsome carnivore) and amphibians populated the continents, while molluscs and echinoderms occupied marine environments. The most important mass extinction occurred during this period. Over 95% of marine species and 75% of terrestrial species disappeared as a result of a series of meteorological events (glaciation, volcanic activity, acid rain, destruction of the ozone layer).

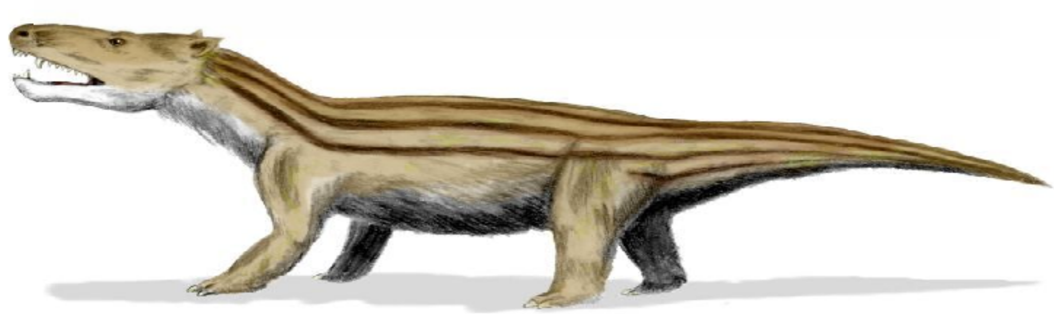
Dimetrodon and Eryops, both Permian.

2.3. The Mesozoic (251 - 65.5 Ma)

This era is commonly referred to as the "age of the dinosaurs", since they dominated the planet at this time. It is divided into three periods: the Triassic, the Jurassic and the Cretaceous.

2.3.1 The Triassic (251 - 200 Ma)

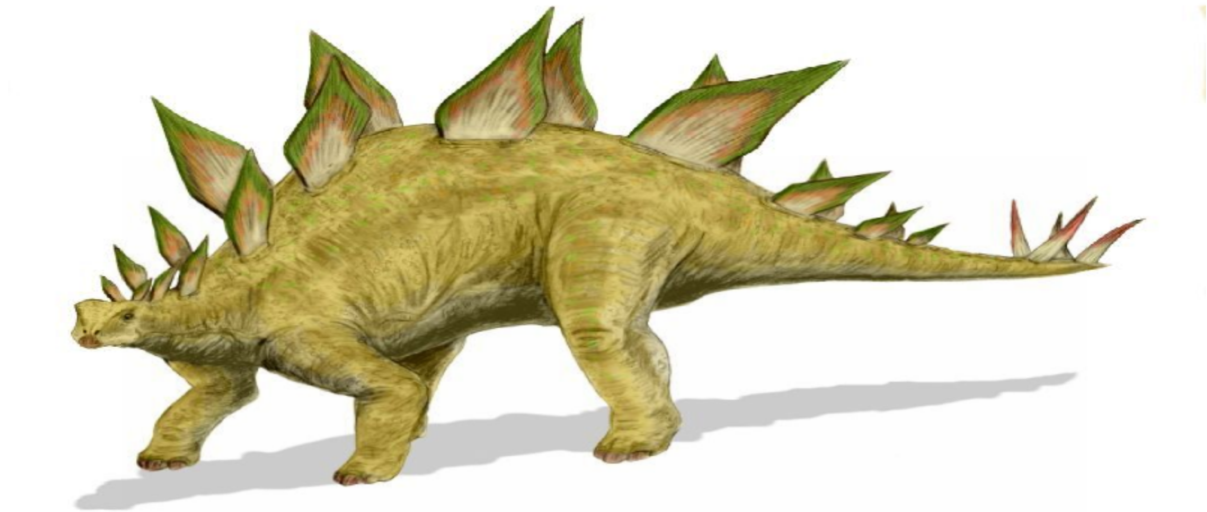
This period is associated with the appearance of the first dinosaurs and mammals. Species diversification continued in the Jurassic and Cretaceous. These imposing reptiles were present in all environments (land, sea and air). At the end of this period, the fourth mass extinction occurred, when over 50% of fish, sponge and coral species disappeared, possibly due to meteorite impacts or volcanic eruptions.



Cynognathus is a mammal-like reptile that lived in the Triassic period.

2.3.2. The Jurassic (200 - 145 Ma)

In the Jurassic, climatic stability favored the multiplication of marine and terrestrial animal species, including the first birds. Flowering plants also flourished. It was also at the end of this period that Pangea began to break up.



The genus Stegosaurus groups together several species of Jurassic dinosaurs.

2.3.3. The Cretaceous (145 - 65.5 Ma)

During the Cretaceous, Pangea broke up and the continents drifted to their present locations. During this period, flowering plants proliferated, bees became increasingly common and mammals were also present, albeit on a relatively small scale. At the end of the Cretaceous, a fifth and final mass extinction occurred, associated with the disappearance of the dinosaurs. This event is thought to have been caused by the fall of a meteorite in northern Yucatán, Mexico.

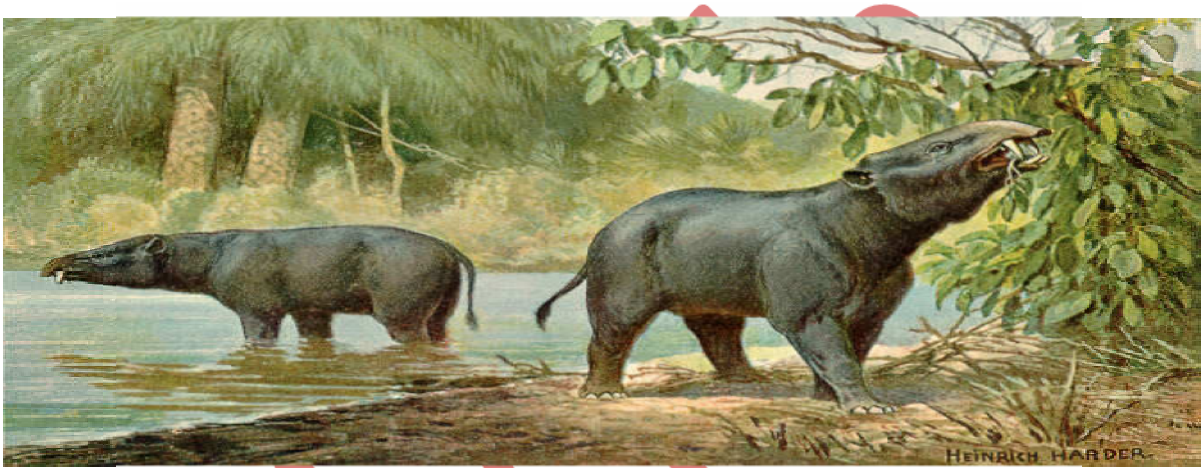
Tyranonosaurus is one of the Cretaceous species.

2.4. The Cenozoic (65.5 Ma - present)

This is the era we are currently living in. It was during this era that most of the species of birds, mammals and flowering plants we know today appeared. It is divided into three periods: the Palaeogene, Neogene and Quaternary.

2.4.1. Paleogene (65.5 - 23 Ma)

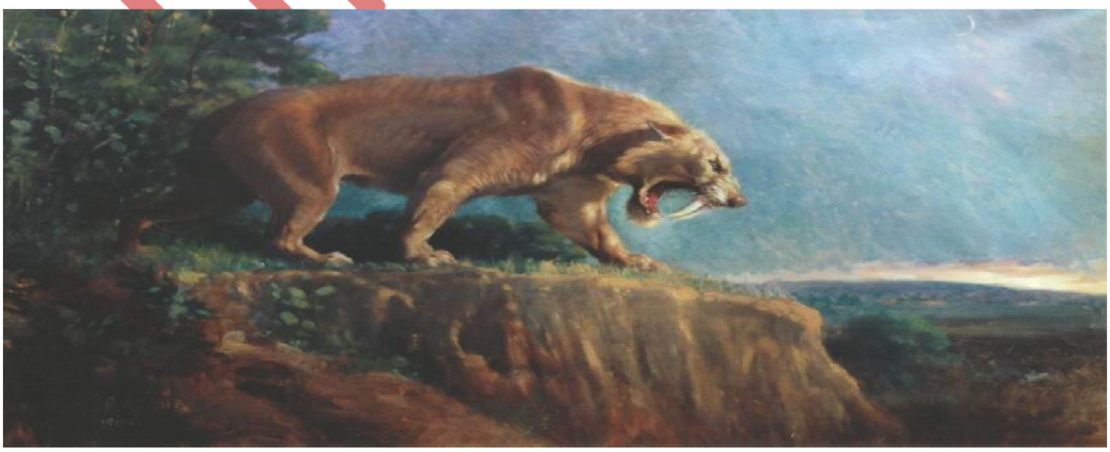
During this period, all the animals and plants that appeared resembled the species currently living on the planet. Insects, birds, fish, amphibians and mammals are all represented in the Paleogene.



The genus Moeritherium groups together several species of mammals that lived during the Paleogene.

2.4.2. Neogene (23 - 1.8 Ma)

During the Neogene, grassy plants such as wheat, rice and bamboo multiplied. These served as food for large herbivores, encouraging their development. It should be noted that a greater or lesser proportion of the species present in this era will disappear in the Quaternary, but this is not considered a mass extinction.



Smilodon, also known as the saber-toothed tiger, lived in the Neogene.

2.4.3. The Quaternary (1.8 Ma - present)

This is the period we are currently in. The beginning of this period was characterized by alternating periods of glaciation, which favored the development of mammals. The mammoth and woolly rhinoceros appeared during cold periods, while warm periods favored the development of the hippopotamus and elephant.

3. Stratotypes

A stratotype is a type stratum, an outcrop designated as the type of a geological stage (or geological era), the standard for a layer of rock (usually soil). This type profile is a geological term that names the location of a particular reference exposure of a stratigraphic sequence or stratigraphic boundary. Stratotypes are represented and grouped together in a stratigraphic scale.

A unit stratotype is the agreed reference location for a particular stratigraphic unit, and a boundary stratotype is the reference for a specific boundary between stratigraphic units (geological formations or chronostratigraphic units).

Each lithostratigraphic unit has a stratotype which, by definition, has the lithology and fossil content of the unit. Usually, the stratotype is easily accessible, so it can be easily studied and visualized.

A geological stage is the fundamental chronostratigraphic unit in geology. It represents a time interval of variable duration, but generally corresponding to a few million years.

There are two types of stratotype: unit stratotypes and boundary stratotypes.

The unit stratotype corresponds to an outcrop recognized by specialists as the “type” of a geological stage.

The boundary stratotype corresponds to a continuous set of layers at which the boundary between two stages is identified. This boundary is marked by a Golden Spike attached directly to the rock.

Barremian Stratotype at Angles (Alpes-de-Haute-Provence).

4. Lithostratigraphy

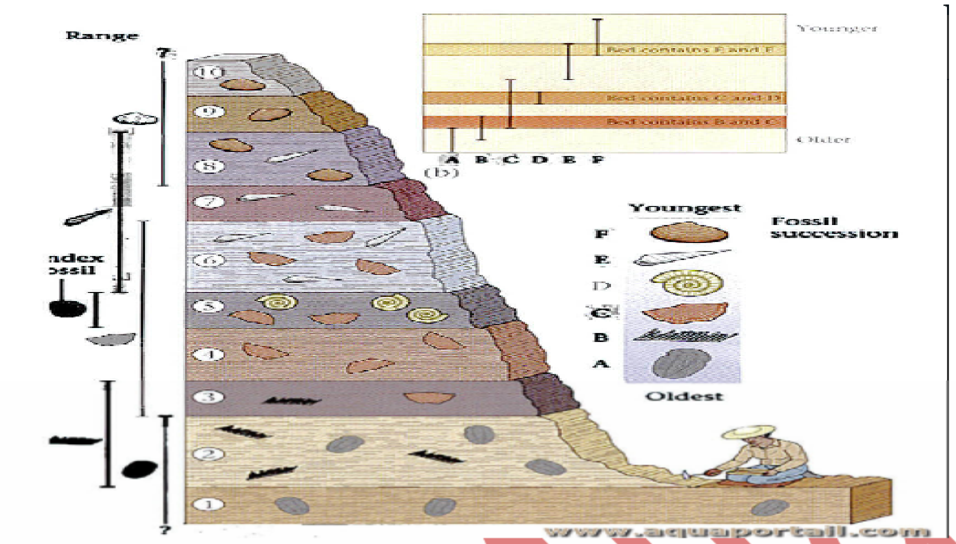
Lithostratigraphy is a correlation based on lithology, with the description and systematic organization of rocks into distinctive named units based on the lithological character of the rocks and their stratigraphic relationships. It does not include direct age dating like chronostratigraphy. Lithostratigraphy is the basis for most geological mapping and description of stratigraphic sections, both in outcrop and in boreholes.

A lithostratigraphic layer is a stratum used to describe a geological facies.

Lithostratigraphy is a stratigraphic approach involving the study of sedimentary piles from a geometric, lithological and petrographic point of view.

5. Biostratigraphy

Biostratigraphy is the study of terrain layers, enabling us to establish a stratigraphic chronology based on the fossils associated with a layer. The study of these fossils can be used to establish stratigraphic correlations between distant terrains.



Assuming that the sequence of fossil content is laterally equal, lateral correlations between rocks or sediments can be established. This is important, as sediments of the same age can differ considerably over large distances due to the principle of sedimentary facies (e.g. clay may be deposited in one place, sand in another at the same time). If rocks with the same guiding fossil are found in two places, this shows that the layers have the same age.

Because biostratigraphy doesn't give an absolute age to a rock, it's a way of relative dating. Stratigraphic paleontology is included in magnetostratigraphy.

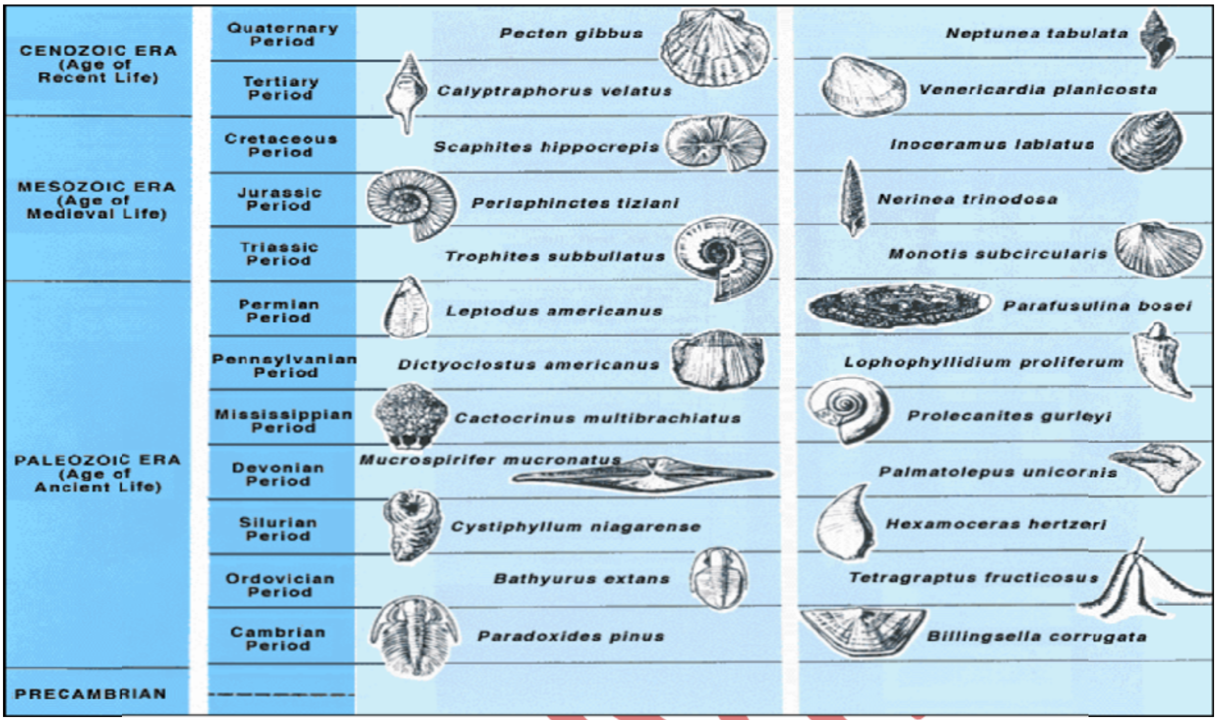
A biozone is an interval characterized by the presence of a certain species. Biozones can also be defined as the interval of overlap between two species, or intervals in which a given species is clearly more or less defined than in the upper and lower layers. A sequence of a number of biozones is called a biozonation. These biozonations may differ regionally for rocks of the same age.

Biozones can be defined by the appearance and disappearance of certain fossils, but also by the quantities of a particular fossil found there. Other biozones are identified by a combination of certain fossils.

6. Chronostratigraphy

Chronostratigraphy is a branch of stratigraphy concerned with the organization and division of rock strata according to their age relationships.

The aim of chronostratigraphy is to organize the different sequences and depositional epochs of all rocks, according to their geological region, into chronostratigraphic units, ultimately establishing a complete geological record of the Earth (geological time scale). This organization is based on the principles of geochronology.



Fossil chronostratigraphy

Chronostratigraphy relies on the principles of relative and absolute dating to date geological units. A stratotype is defined on the basis of specific fossil assemblages found in the rocks to estimate the period of deposition of the sediments in the layer. The fossils used come from species that have evolved rapidly over time, and have a fairly high geographical extension. The end of a stratotype is marked by the disappearance of a fossil group. Isotope geochemical dating improves the precision of the dating performed. In practice, however, it is very difficult to date most fossils and sedimentary rocks directly by isotopes, so adjustments have to be made to obtain an age for the beginning and end of depositional intervals.

As the appearance of magmatic rocks occurs at precise moments in time, and can be considered instantaneous on the geological time scale, they can be used to date geological stages. Their mineral assemblages are also better candidates for isotope dating than sediments. They can be accurately dated by isotopic methods, so the construction of a stratigraphic column will be based essentially on volcanic and plutonic rocks.

Metamorphism, often associated with faulting, can also be used to frame the different intervals of a chronostratigraphic column. Metamorphic rocks can sometimes be dated to delimit the period when the layer began to form. But this is a complex and laborious process. For example, several million years may have elapsed between the time the layer began to form and the time a plutonic rock was deposited there, so the age estimate must necessarily be between the oldest and the most recent plutonic rock included in the fossil assemblage.

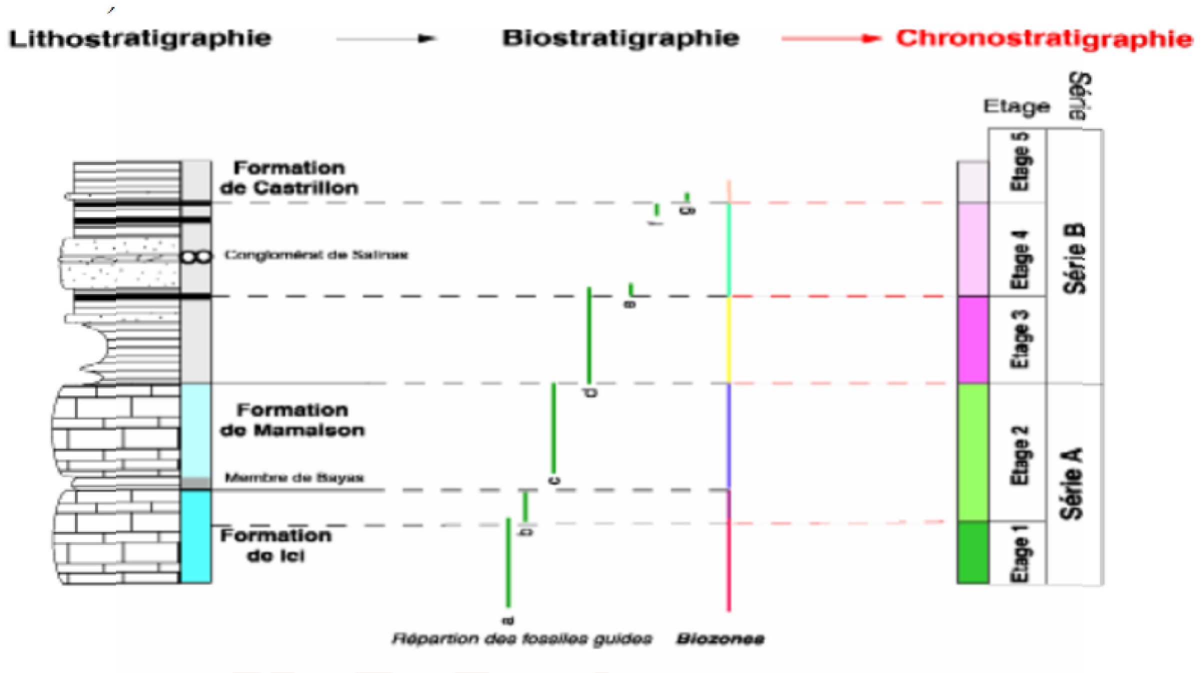
7. Relationship between litho-, bio- and chronostratigraphy

The relationship between litho-, bio- and chronostratigraphy is a complementary and successive one, and has enabled us to :

- Identify the lithology and stratification of a geological section.

- Identification and determination of the fossil group (biozonation) presenting the biostratigraphy.

- Determination of the age of each formation using information from lithostratigraphy and biostratigraphy to give chronostratigraphy (as shown below).



Litho-, bio- and chronostratigraphic correlations

The study of the Earth's history as recorded in sedimentary strata (stratigraphy) is based on two methodological approaches: one that establishes a chronological breakdown that is as detailed as possible, and one that links contemporary deposits or deposits of different ages between sites that are more or less distant.

The means of correlation (geochronological, lithological, paleontological) are not all equally precise, nor are they all equally applicable. This is why we have tended to rank them in order of importance, until we realize that their value depends primarily on the conditions in which they are used: local or long-distance correlations, precise or approximate correlations, across continents or oceans.

Geochronological correlations, using the isotopic age method, are often considered the only valid ones. It's true that, for metamorphosed sediments, the absence of preserved fossils and the complexity of deformations make them the last resort. But this is to overlook the limitations of the method and, in particular, the uncertainty surrounding the significance of the age obtained. In the case of submarine flows, the use of paleo-magnetic anomalies provides completely corresponding sequences from one side of an oceanic ridge to the other; their geochronological calibration enables us to accurately reconstruct the successive stages of ocean expansion.

Lithostratigraphic correlations

Assume that the same deposits have been deposited uniformly over a fairly wide area, which is very rarely the case. The obliquity of facies and the diversity of contemporary environmental conditions are obstacles to the use of lithology as a rigorous correlating agent; however, within a quarry, the nature of a particular layer often constitutes a reliable means of correlation, the accuracy of which is very satisfactory on the scale considered. On the other hand, the limited extent of deposition of this layer means that it cannot be used on a basin-wide scale.

Biostratigraphic correlations:

The use of fossils (plants and fauna) as a good indicator of time and space enables local/regional or provincial correlation.