• The Variscan Paleozoic chain (in light orange) occupies the middle part of Europe, between the Caledonian Paleozoic chain of Northern Europe and the Alpine Cenozoic chain of Southern Europe, whose structural continuity is partly destroyed by Neogene back-arc basins.

• The Neoproterozoic chain (Cadomian) is largely hidden by more recent deposits, or reworked in the Caledonian or Variscan chains.

• The Variscan basement fragments of the Alpine chain are not shown on this map.

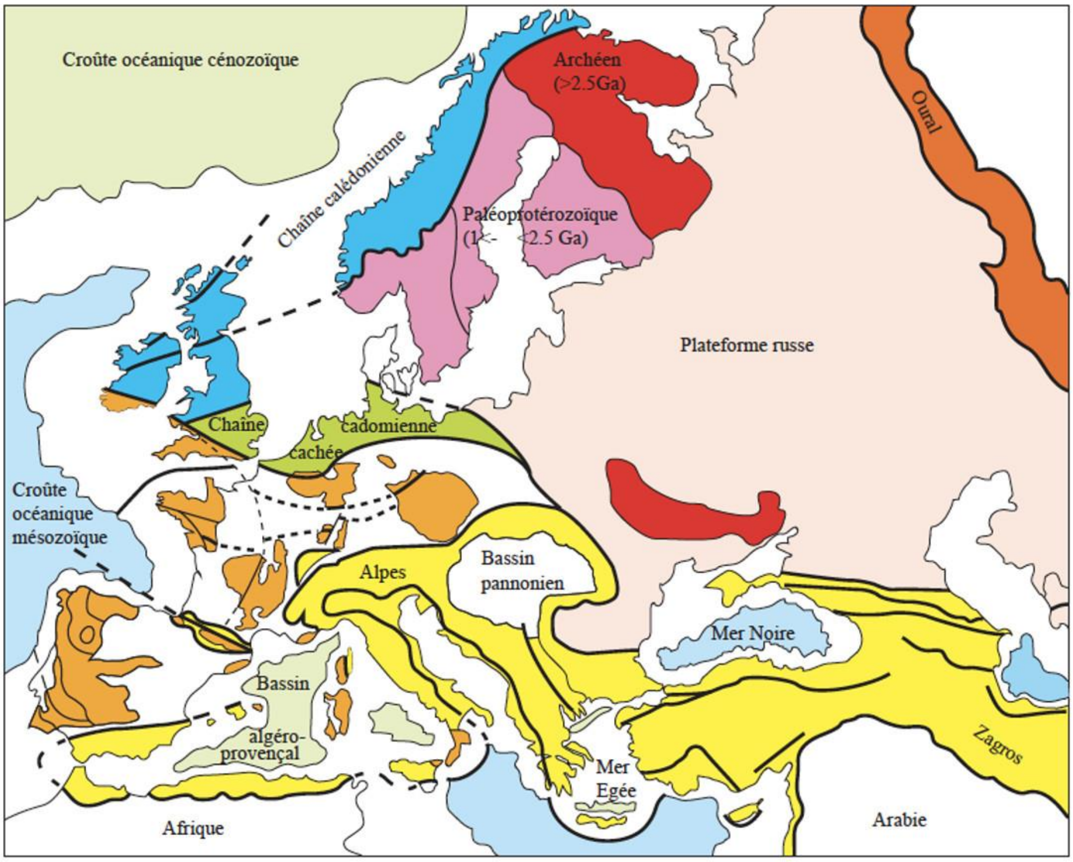
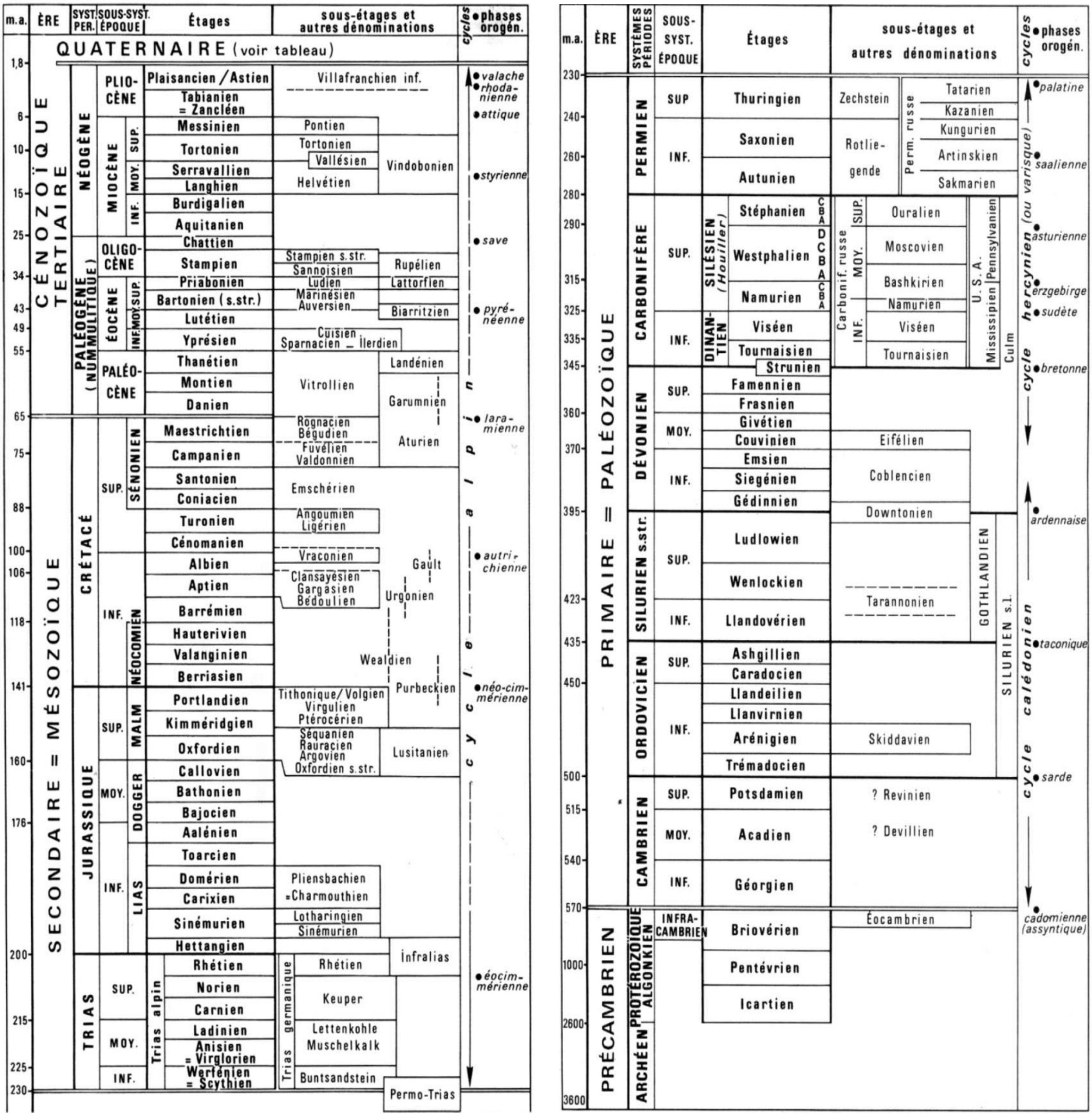


Fig. 21: Tectonic map of Europe [14]



Tab. 1: Orogenic cycles with their phases, associated to Geological time scale (Last colomn). [15]

ères	systèmes	âges absolus (Ma)	cycles orogéniques
Cénozoïque		1,65	cycle alpin
	Néogène	23,5	
	Paléogène ou Nummulitique	65	
Mésozoïque	Crétacé	135	
	Jurassique	205	
	Trias	245	
Paléozoïque	Permien	295	cycle hercynien ou varisque
	Carbonifère	360	
	Dévonien	410	
	Silurien	435	cycle calédonien
	Ordovicien	500	
	Cambrien	540	
Protérozoïque			cycle assyntique

Tab. 2: Simplified Orogenic cycles, associated to Geological time scale (Last colomn).

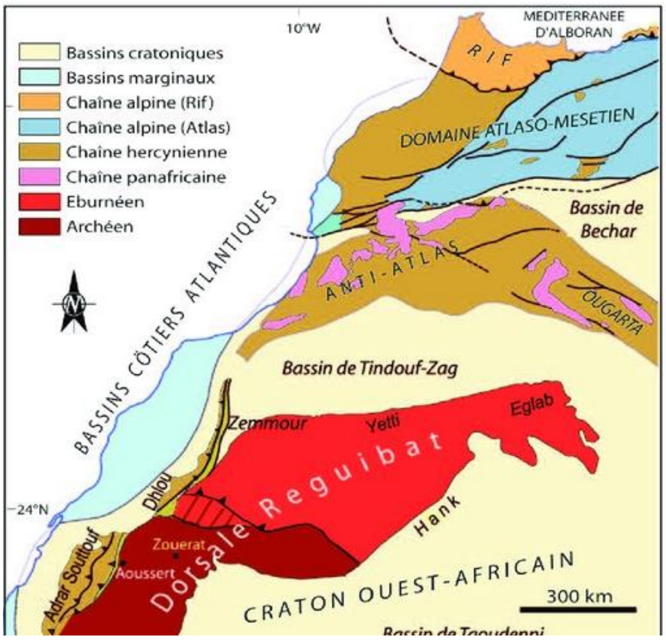


Fig. 22: The structural domains of Morocco. The range of terrains is extremely varied, with orogenic cycles ranging from the Archean (3 Ga) to the Alpine. [16]

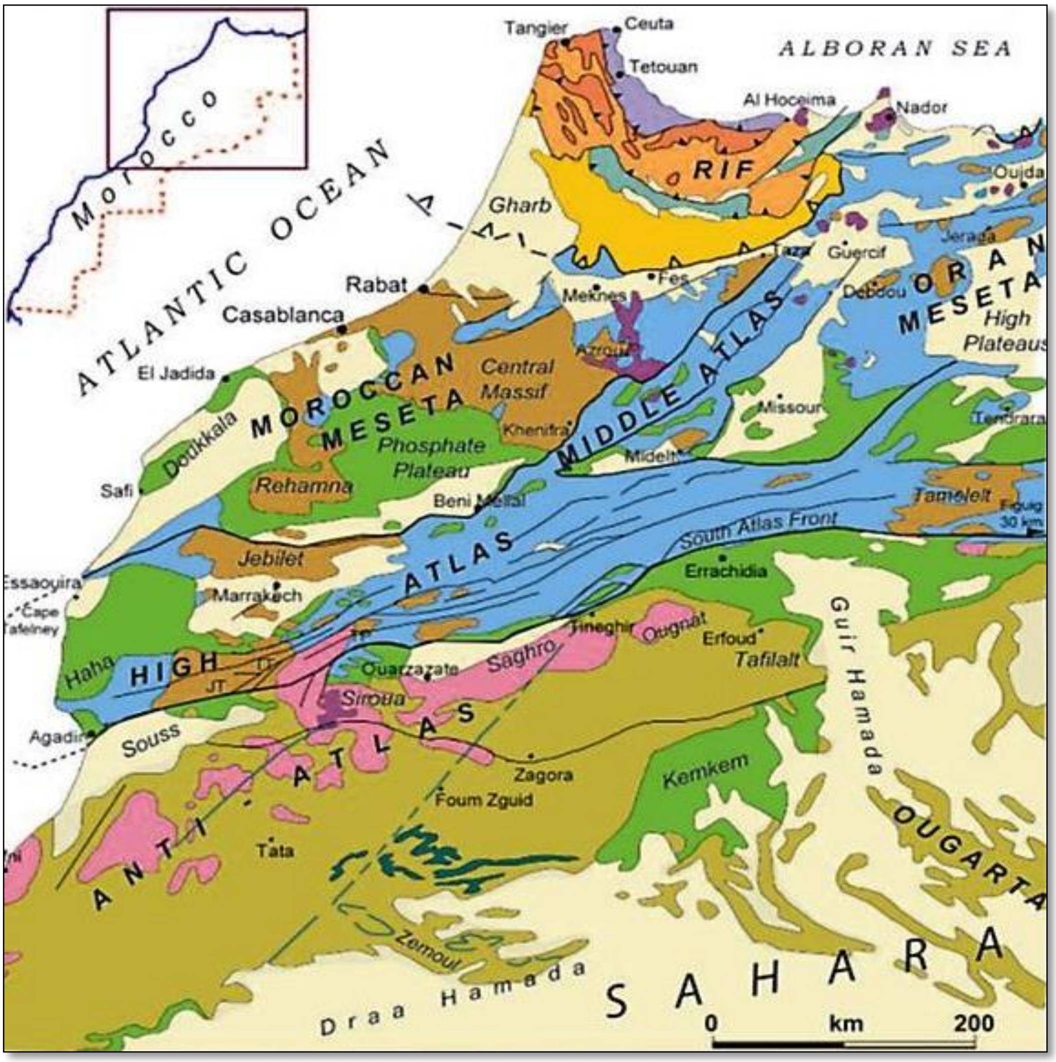


Fig. 23: The different structural domains of Morocco [17]

Some orogenic cycle's overview:

5. **Cadomian cycle (Assyntian):**

Precambrian orogenic cycle ending with the Cadomian phase (boundary of Precambrian and Cambrian, around 570 M.A., also called the Assyntian phase), marked by a well-visible unconformity in Brittany and Normandy (France).

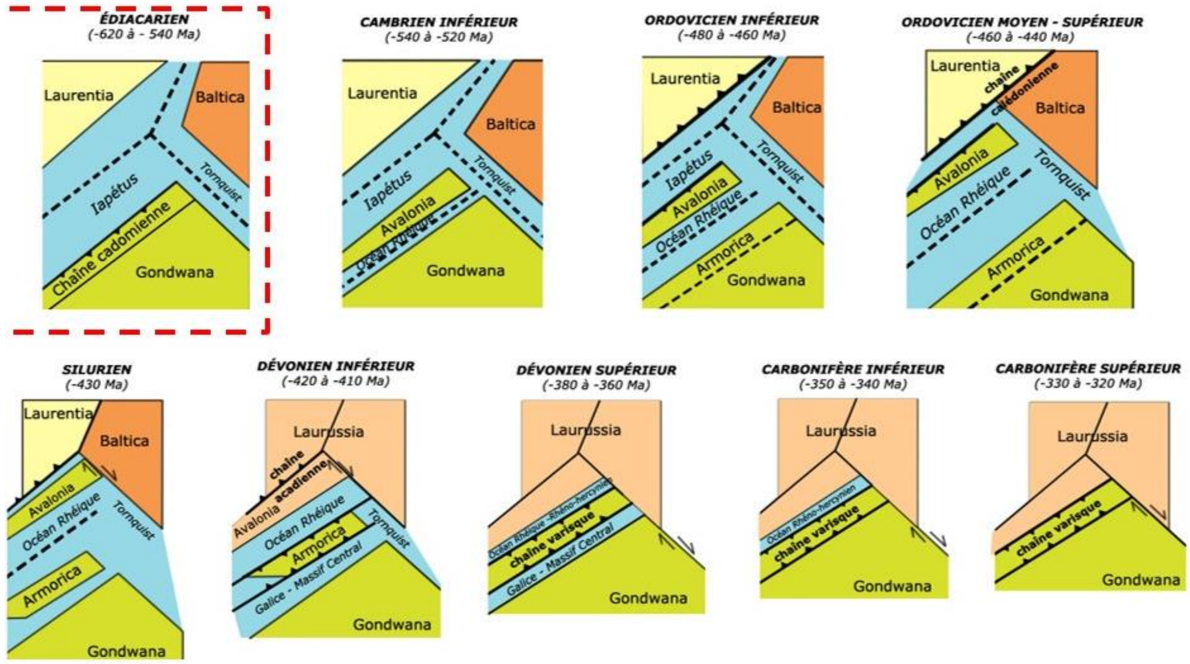


Fig. 24: Last phase of Cadomian cycle [18]

6. Caledonian cycle:

Orogenic cycle spanning from Cambrian to Silurian, responsible for building the Caledonian chains in Norway, Greenland, Scotland, Ireland, and partly the Appalachians.

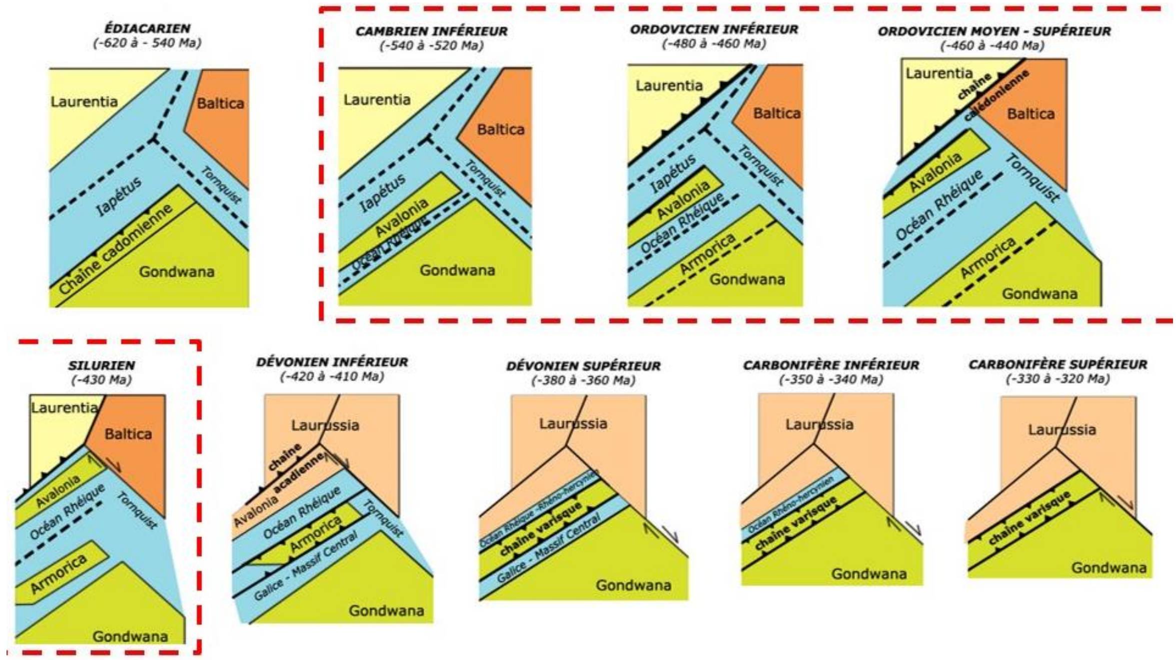


Fig. 25 : Caledonian cycle [18]

7. Hercynian (Variscan) Cycle:

Orogenic cycle whose construction began in the Devonian (385 Ma) with the confrontation of two large continental entities, in the south Gondwana, in the north Laurussia, and ended with the Permian.

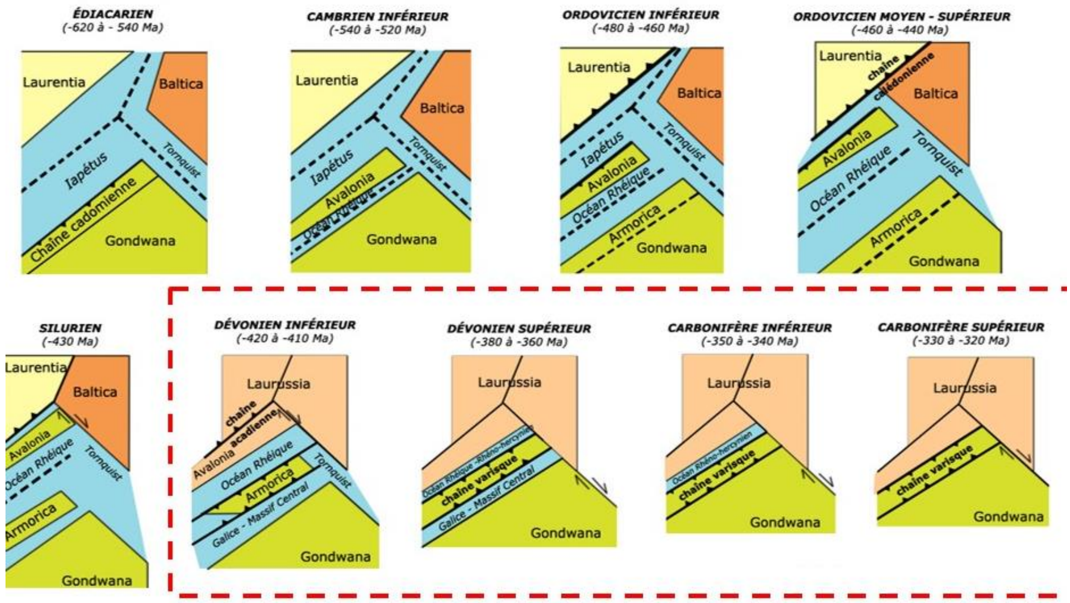


Fig. 26 : Hercynian cycle [18]

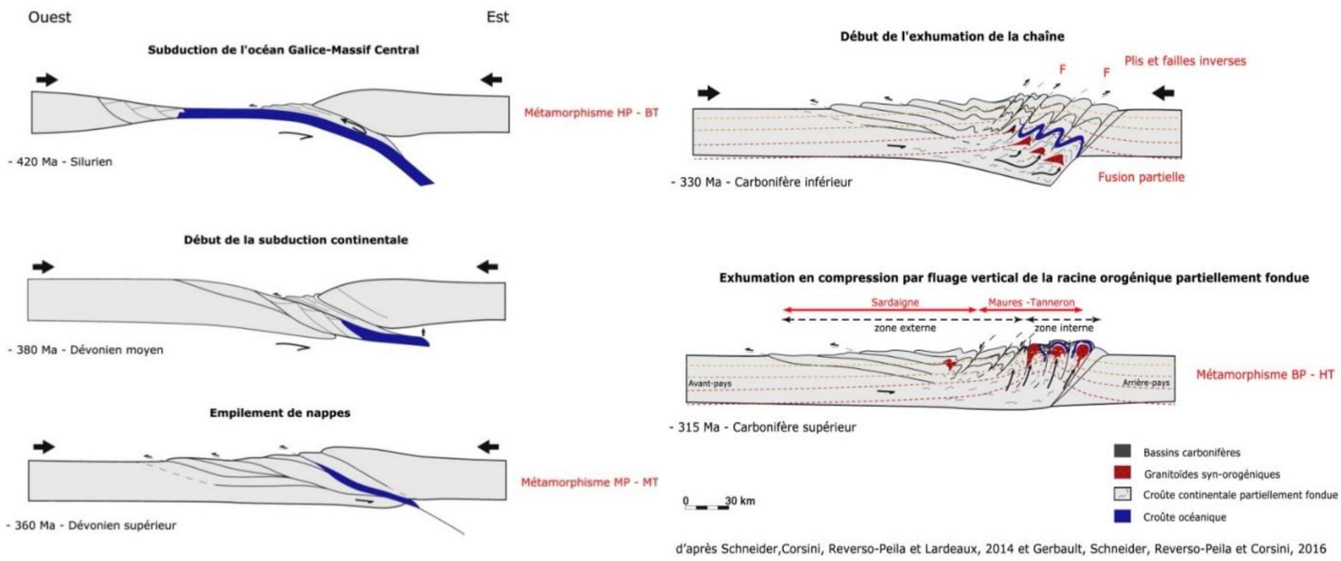


Fig. 27: Conceptual orogenic model of the southern branch of the Variscan orogeny [19]

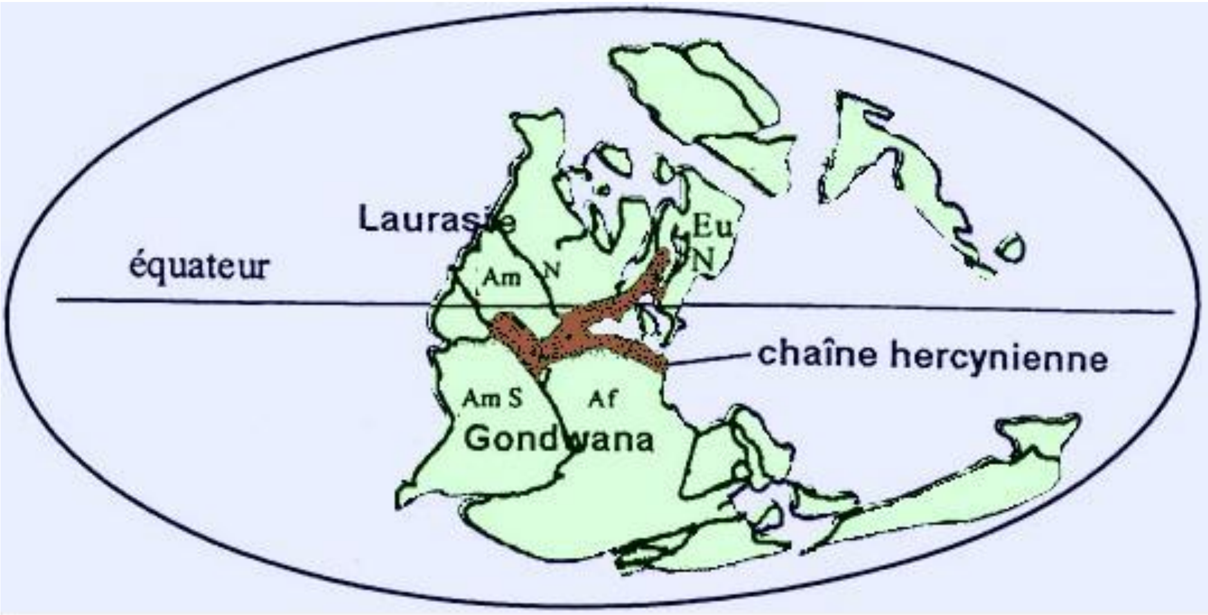


Fig. 28: Hercynian chain in the Upper Carboniferous

Fig. 29: Current distribution of varisican orogenies [20]

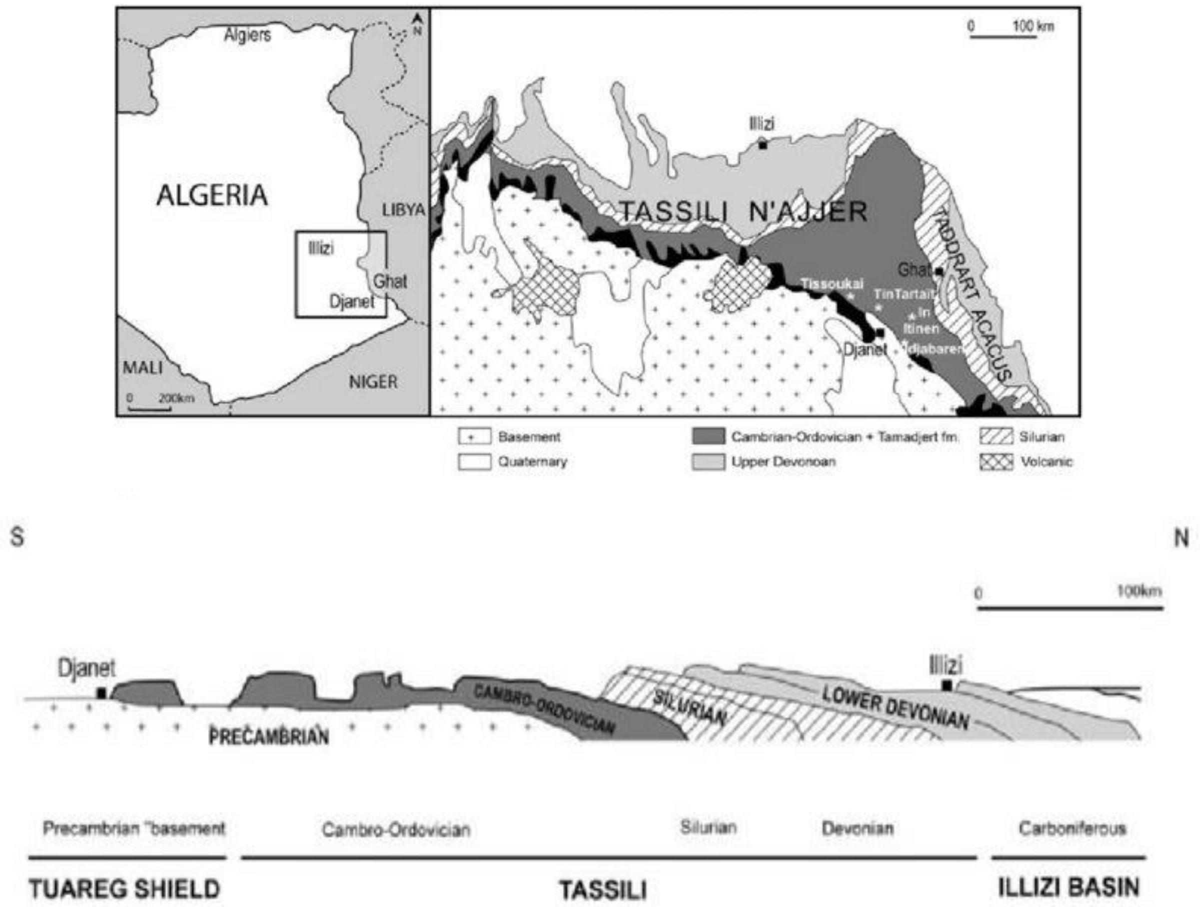


Fig. 30: Hercynian chain in Algeria (Illizi Basin)

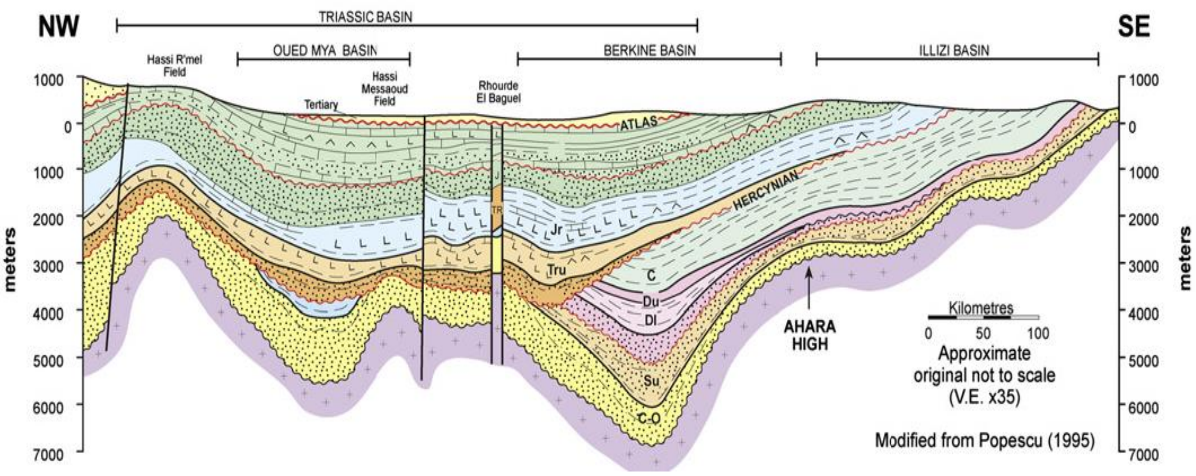


Fig. 31 : Hercynian chain in Algeria (Berkine Basin) [21]

8. Alpine Cycle

Orogenic cycle beginning in the Triassic and building, following the closure of Tethys, the alpine chains of southern Eurasia (from Gibraltar to Indonesia (Alps-Himalaya)).

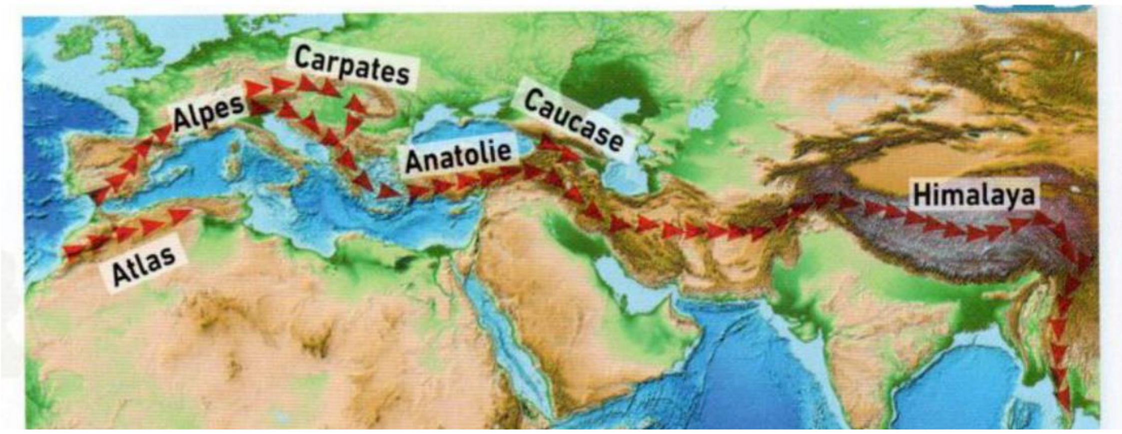


Fig. 32: Alpine ranges of southern Eurasia (Alps-Himalayas)

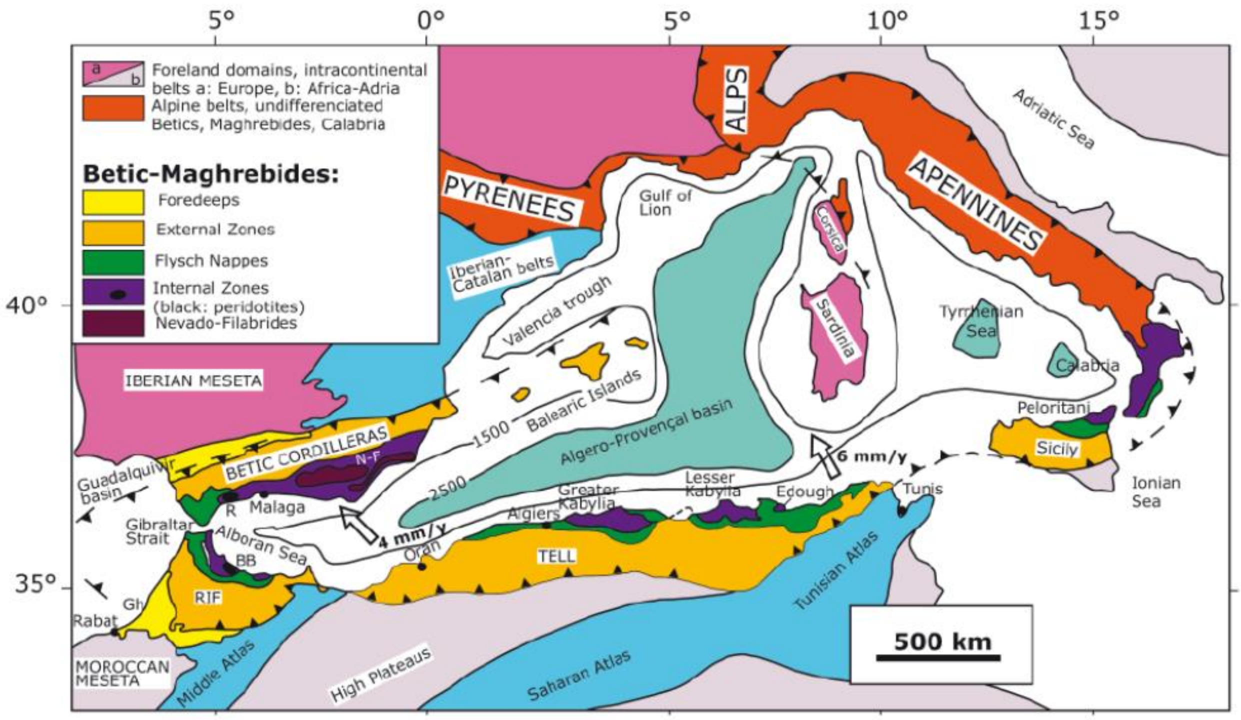


Fig. 33 : Chaînes alpines de la Méditerranée occidentale (d'après Durand-Delga, 1980). [22]
Flèches : convergence actuelle Afrique–Eurasie

ères	phases orogéniques	âges absolus (en millions d'années)
Quaternaire		
	pasadénienne (ou valaque)	– 1,6
Tertiaire	rhodanienne	– 5,3
	attique	– 23,7
	save	
	helvète	
	pyrénéenne	– 36,6
	laramienne	– 66,4
Secondaire	autrichienne	– 97,5
	néocimmérienne	– 144
	andine (ou névadienne)	
	cimmérienne	– 208
	discordance basale des terrains du cycle alpin	– 245

Tab. 3: Orogenic phases of the alpine cycle

Not to be confused: *Sedimentary cycle* ***VS*** *Tectonic cycles*

Sedimentary cycle refers to the period between a transgression and a regression. A sedimentary cycle does not necessarily indicate the existence of orogenic movements, and, as a result, the layers of two successive sedimentary cycles can be concordant.

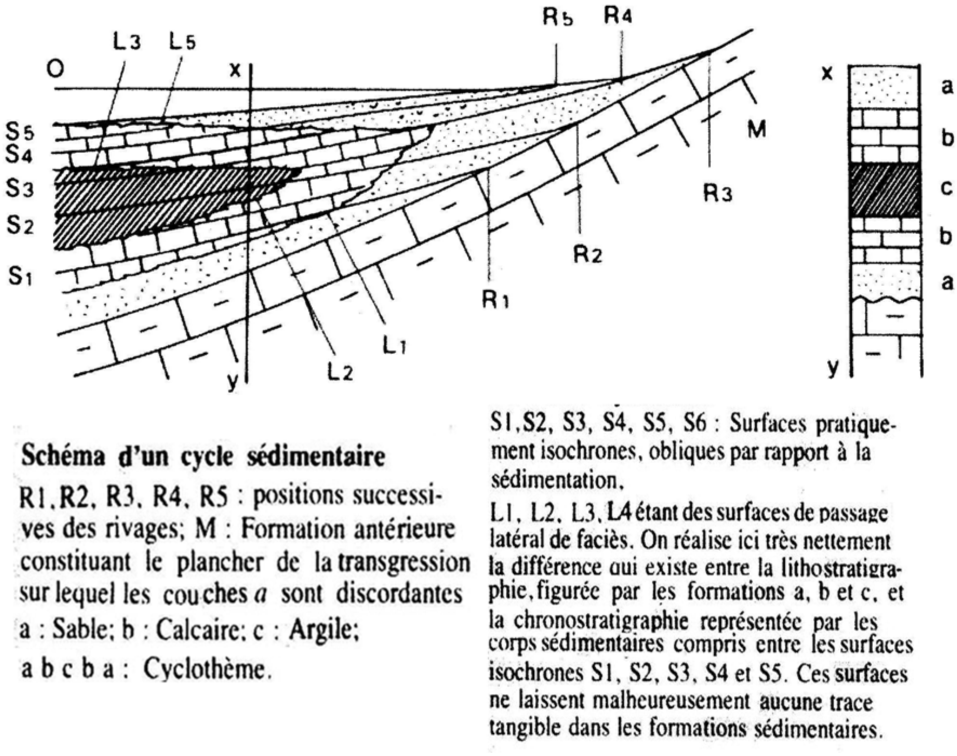


Fig. 34 : Sedimentary cycle

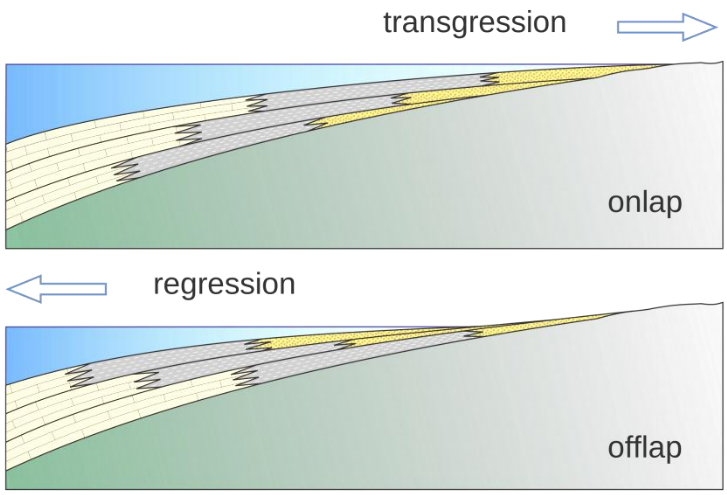


Fig. 35: Components of sedimentary cycle (transgression & regression)

Terminology associated with orogenic cycles:

6. **Molasse**

Thick detrital sedimentary formation, composed partly of turbiditic layers but also non-turbiditic terrigenous layers (sandstones, conglomerates), deposited in an orogenic zone at the end of tectonization, and typically discordant with the underlying layers. Molasses are most often tectonically autochthonous.

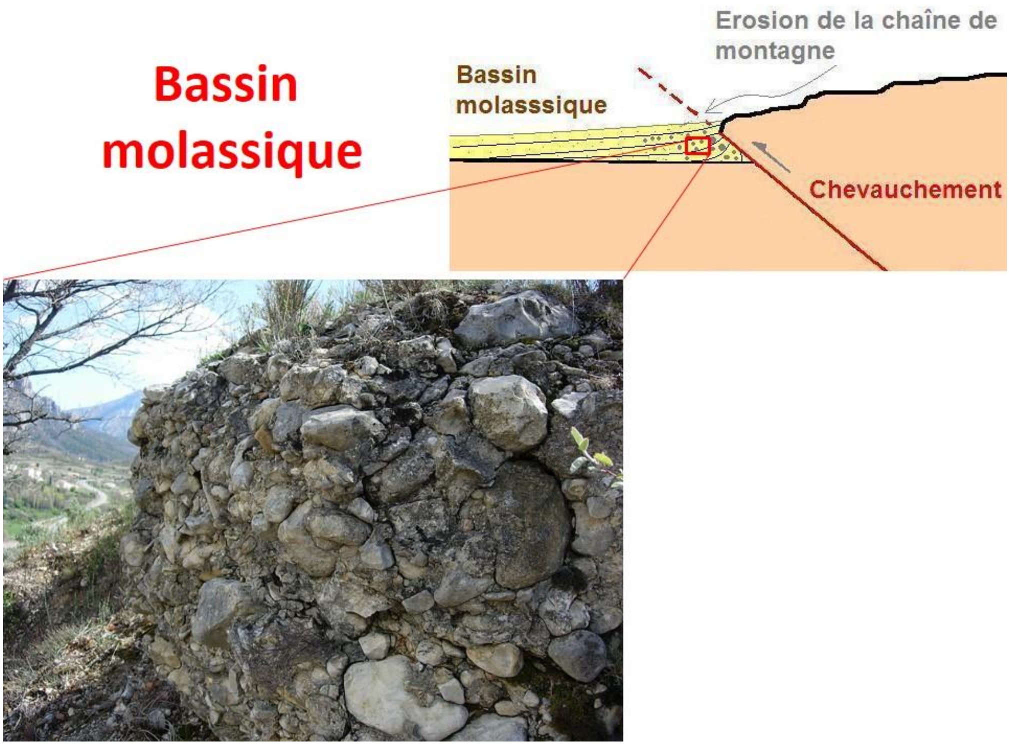


Fig. 36 : Mio-Pliocene conglomerate at Moustiers-Sainte-Marie, Valensole molasse basin [23]

Photo. 1: Northern Alps Molasse Basin (Switzerland)
Coarse conglomerate of the Lower Freshwater Molasse at Goldau (Switzerland).
The fluvial pebbles reach a diameter of approximately 15 cm. Image width: 80 cm [24]
© Jürg Meyer

7. Flysch

Detrital sedimentary formation, often thick, composed essentially of a stack of turbidites, typically in concordance with the underlying layers, and deposited in an orogenic zone that is now tectonized. Flyschs are often involved in significant thrust sheets. Their sedimentation mode is similar to that of current deep submarine deltas.

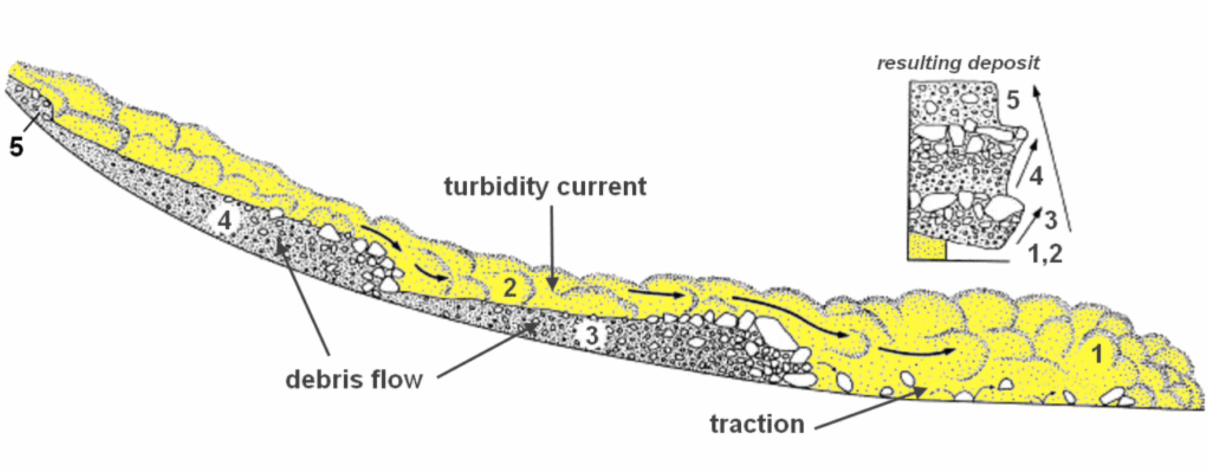


Fig. 37: Example of depositional architectures related to turbidity currents and debris flows. [25]

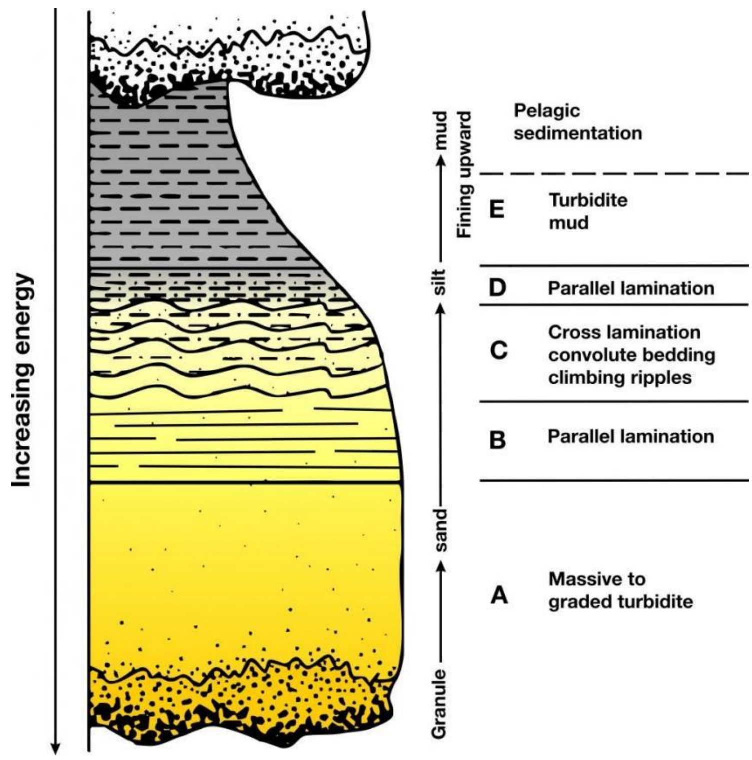


Fig. 38: Bouma sequence (Bouma, 1962). [26]

8. Anorogenic

Not related to orogenesis. Applies to a region that, for a given period, and contrary to neighboring areas, has not undergone orogenesis.

Also applies to intrusive granites that have emplaced independently of any orogenic period.

9. Late-orogenic

Occurring during the last period of an orogenic phase.

10. Orogenic belt

A set of folded chains forming a vast closed loop. Expression mainly used for the circum-Pacific orogenic belt.

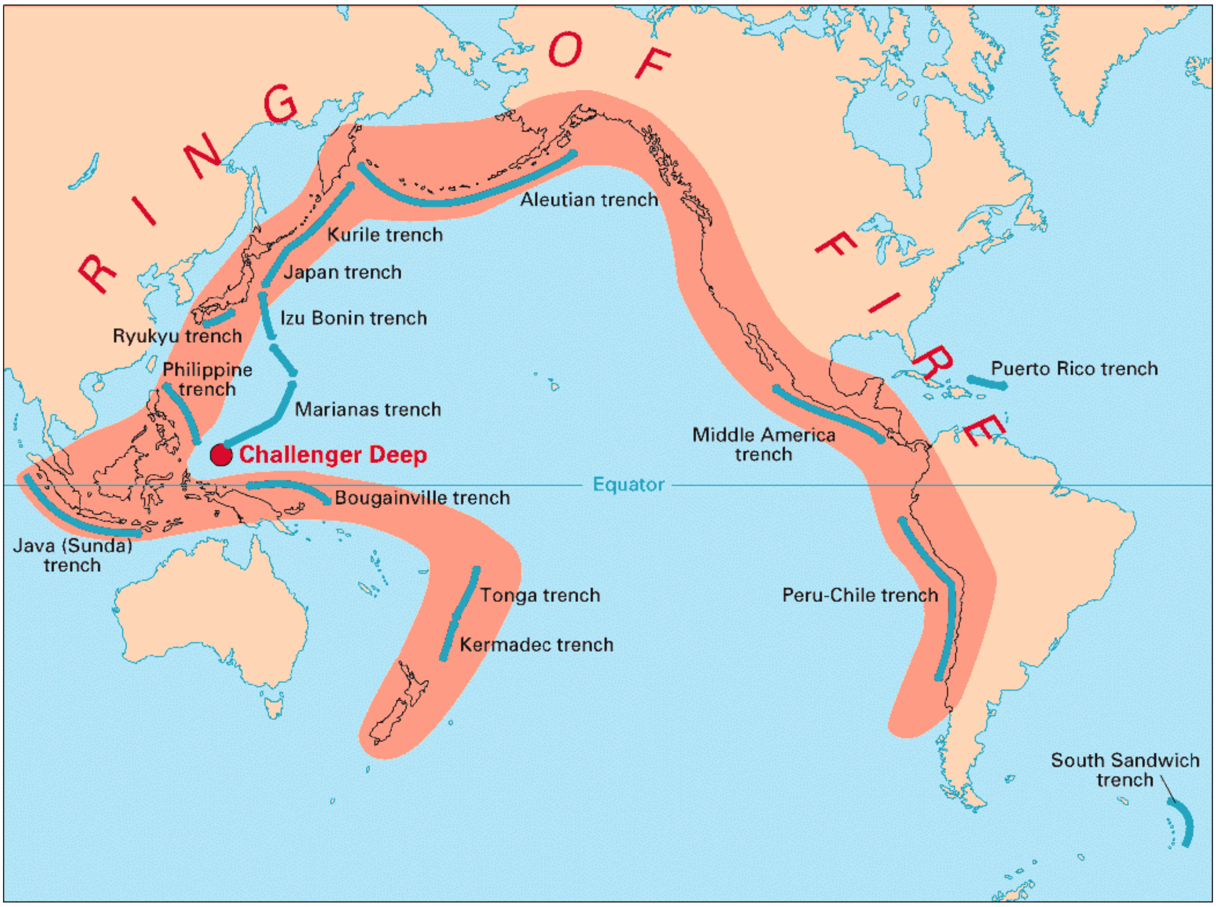


Fig. 39: Pacific orogenic belt [27]

The Precambrian

Precambrian = Pre (Prefix indicating anteriority in space or time; = before) + Cambrian (derived from Cambria (in French, Cambrie), Latin name of Wales, where numerous terrains of this period are visible).

Fig. 40: Wales, one of the four countries that make up the United Kingdom.

1. Why is the Precambrian poorly known?

Because:

1. Many Precambrian rocks have been eroded or metamorphosed.
2. Most Precambrian rocks are deeply buried under younger rocks.
3. Most Precambrian rocks outcrop in fairly inaccessible or almost uninhabited areas.
4. Fossils are rarely found in Precambrian rocks; the only way to correlate is radiometric dating. (But there are some exceptions.)

2. The latest discovery

Discover: Abderrazzak El Albani (Univ. Poitiers - France)

Subject: Multicellular macro-organisms would not have appeared 600 million years ago (Australia) as thought until 2008 but 2.1 billion years ago.

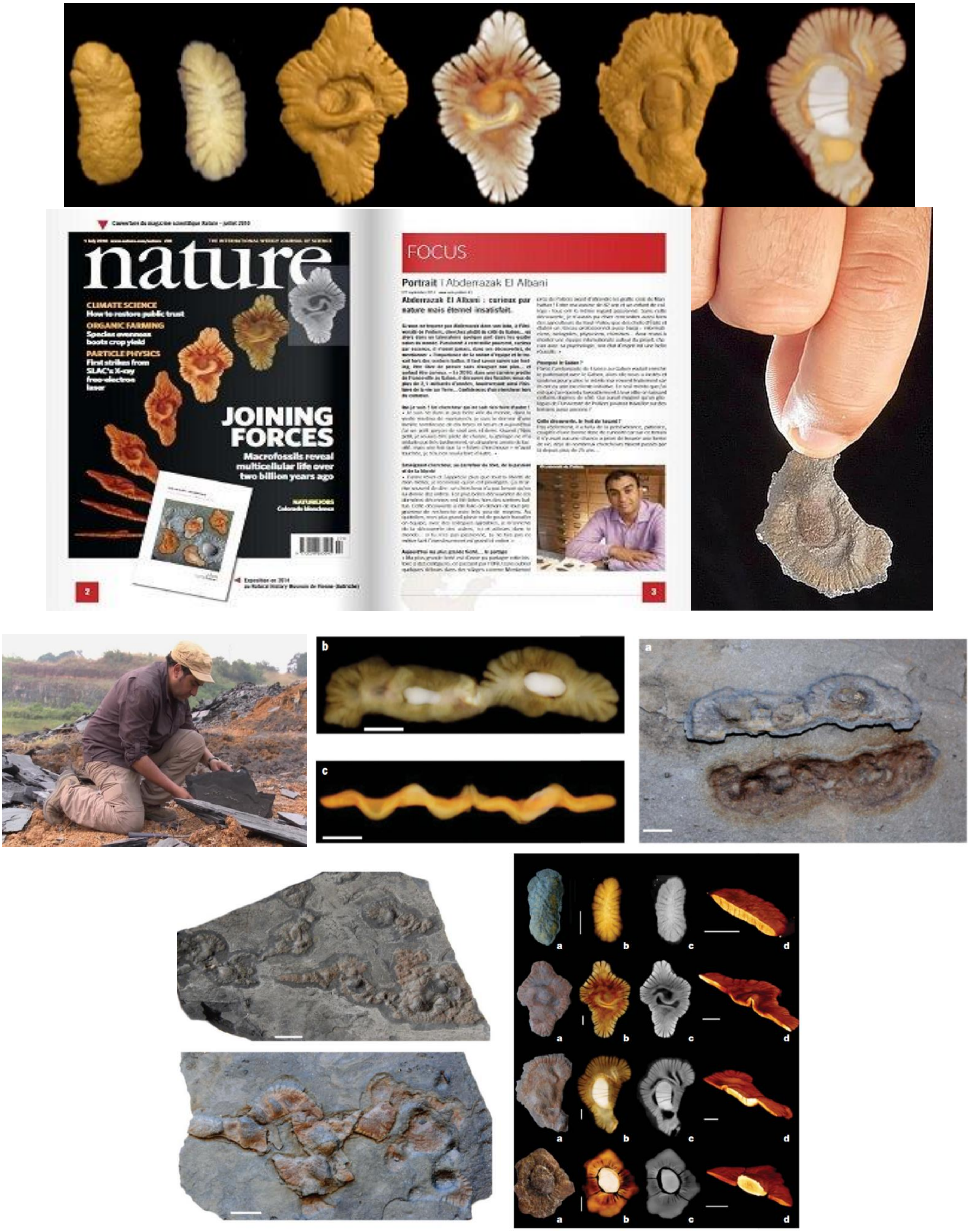
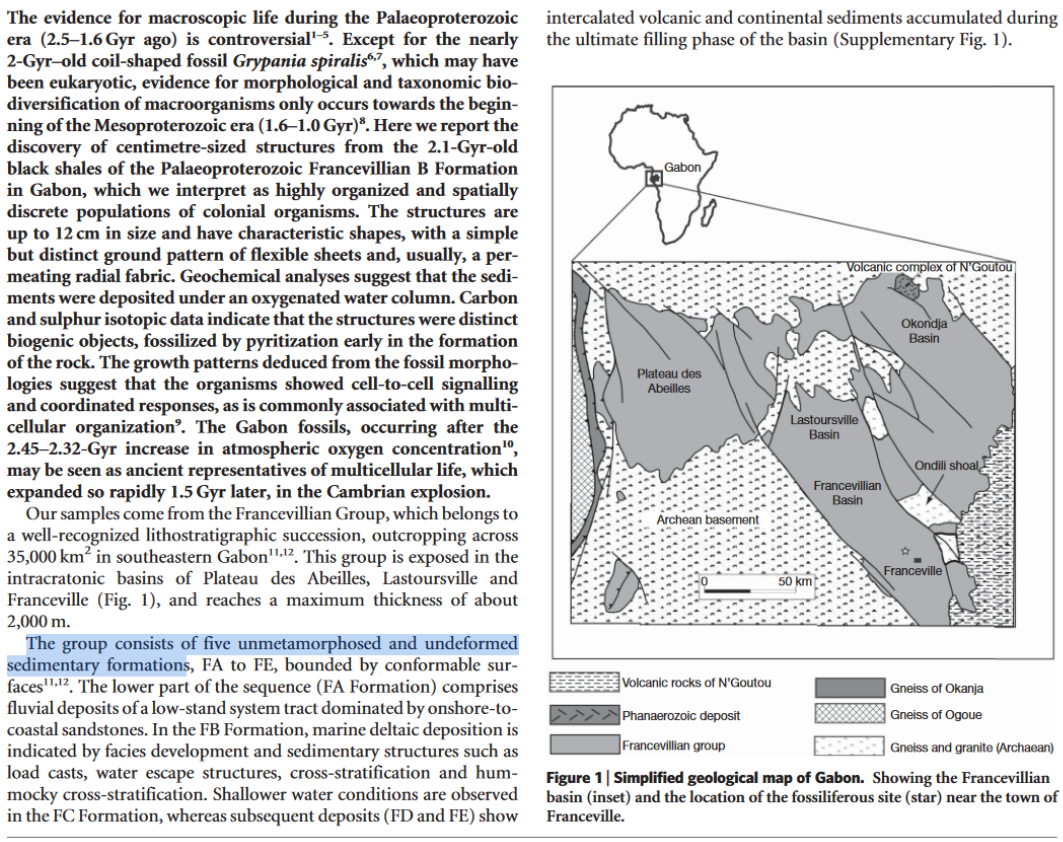


Photo. 2: The discovered macro-fossil Gabonionta [28]



The evidence for macroscopic life during the Palaeoproterozoic era (2.5–1.6 Gyr ago) is controversial[1–5]. Except for the nearly 2-Gyr–old coil-shaped fossil *Grypania spiralis*[6,7], which may have been eukaryotic, evidence for morphological and taxonomic biodiversification of macroorganisms only occurs towards the beginning of the Mesoproterozoic era (1.6–1.0 Gyr)[8]. Here we report the discovery of centimetre-sized structures from the 2.1-Gyr-old black shales of the Palaeoproterozoic Francevillian B Formation in Gabon, which we interpret as highly organized and spatially discrete populations of colonial organisms. The structures are up to 12 cm in size and have characteristic shapes, with a simple but distinct ground pattern of flexible sheets and, usually, a permeating radial fabric. Geochemical analyses suggest that the sediments were deposited under an oxygenated water column. Carbon and sulphur isotopic data indicate that the structures were distinct biogenic objects, fossilized by pyritization early in the formation of the rock. The growth patterns deduced from the fossil morphologies suggest that the organisms showed cell-to-cell signalling and coordinated responses, as is commonly associated with multicellular organization[9]. The Gabon fossils, occurring after the 2.45–2.32-Gyr increase in atmospheric oxygen concentration[10], may be seen as ancient representatives of multicellular life, which expanded so rapidly 1.5 Gyr later, in the Cambrian explosion.

Our samples come from the Francevillian Group, which belongs to a well-recognized lithostratigraphic succession, outcropping across 35,000 km^2 in southeastern Gabon[11,12]. This group is exposed in the intracratonic basins of Plateau des Abeilles, Lastoursville and Franceville (Fig. 1), and reaches a maximum thickness of about 2,000 m.

The group consists of five unmetamorphosed and undeformed sedimentary formations, FA to FE, bounded by conformable surfaces[11,12]. The lower part of the sequence (FA Formation) comprises fluvial deposits of a low-stand system tract dominated by onshore-to-coastal sandstones. In the FB Formation, marine deltaic deposition is indicated by facies development and sedimentary structures such as load casts, water escape structures, cross-stratification and hummocky cross-stratification. Shallower water conditions are observed in the FC Formation, whereas subsequent deposits (FD and FE) show intercalated volcanic and continental sediments accumulated during the ultimate filling phase of the basin (Supplementary Fig. 1).

Figure 1 | Simplified geological map of Gabon. Showing the Francevillian basin (inset) and the location of the fossiliferous site (star) near the town of Franceville.

Fig. 41: Part of the published paper, the discovery was in Gabon.

The fossil was named Gabonionta. [29]

Fig. 42: Distribution of Precambrian rock outcrops worldwide. The areas of Precambrian rock outcrop are indicated in the legend. The dashed areas indicate orogenic belts. [30]

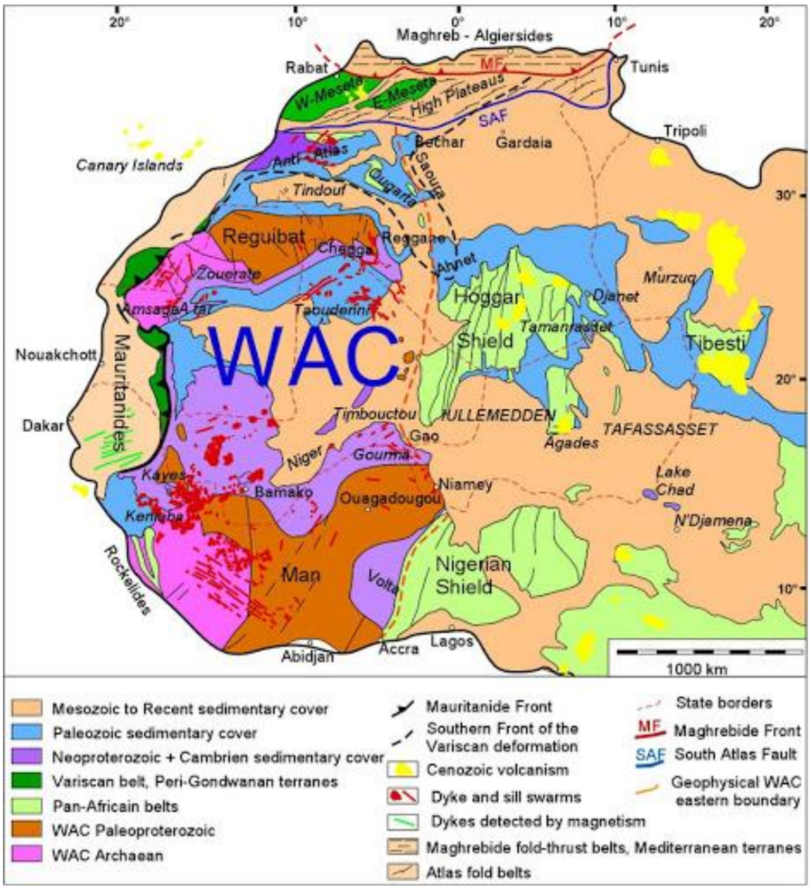


Fig. 43: The Precambrian in NW Africa [31]

Terminology

• Most information about the Precambrian comes from cratons (large portions of continents that have not been deformed since the Precambrian or early Paleozoic).

• The most extensive areas of Precambrian rocks are found in shields (portion of craton not covered by sedimentation).

• Precambrian rocks are often called basement rocks because they lie beneath a cover of sedimentary strata. In this case, the whole is called a Platform (e.g., the Saharan Platform)

The Precambrian is a chronological term that refers to a vast period of time preceding the Cambrian. This period remains relatively poorly understood.

It covers approximately 4 billion years (about 88%) of Earth's history. It is divided into three eons:

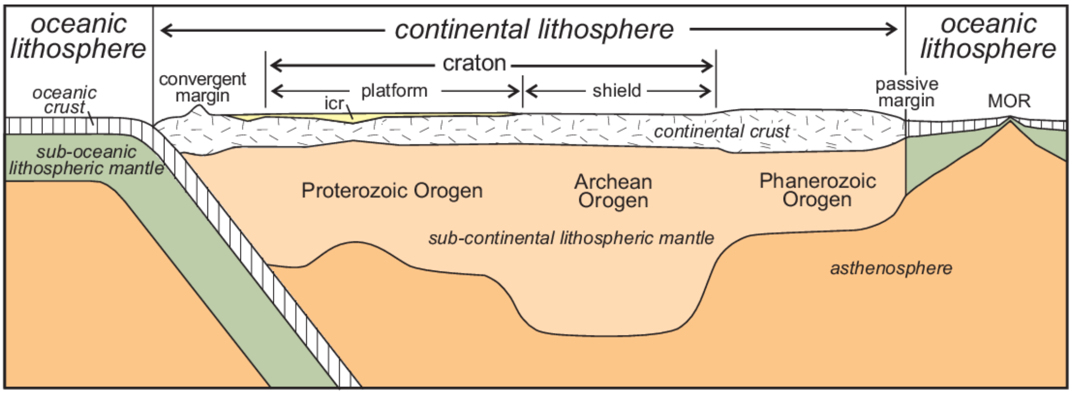


Fig. 44: Schematic cross section of types of continental lithosphere emphasizing the thick stable nature of Precambrian cratons. Thickness of lithosphere beneath Archean regions is of the order of 200-250 km and oceanic lithosphere is up to 100 km. [32]

Abbreviation: icr - intra cratonic rift; MOR-midocean ridge

3. The Precambrian divisions:

The Precambrian is a chronological term that refers to a vast period of time preceding the Cambrian. This period remains relatively poorly understood. It covers approximately 4 Ga (or ~88%) of Earth's history. It is divided into three eons:

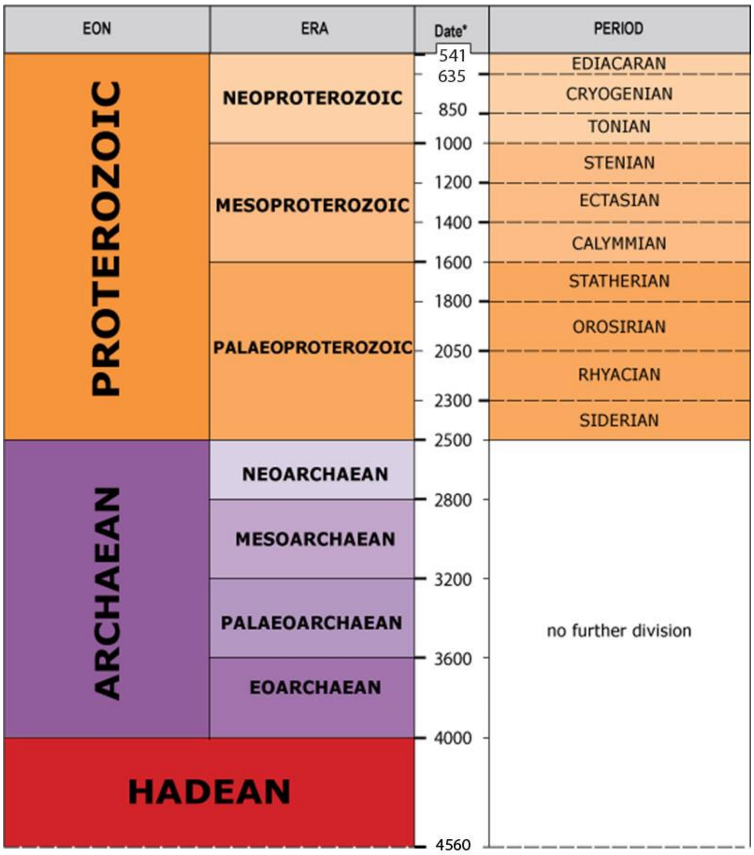


Fig. 45: The Precambrian divisions

a. The Hadean Eon

Its name comes from Hades, god of the Underworld in Greek mythology. It spans from ~-4.6 to ~-4 Ga. It extends from the formation of Earth to that of the oldest known rocks on the planet. Geological and paleobiological knowledge about the Hadean is very limited. It is supplemented by studying meteorites and lunar and Martian rocks of the same age. Life could only develop at the end of the Hadean after the cooling of the lithosphere and Earth's crust and when water had reached its liquid state.

The necessary conditions for the appearance of life were met around ~-4.0 Ga, when the great meteoritic bombardment was completed, thus closing the Hadean.

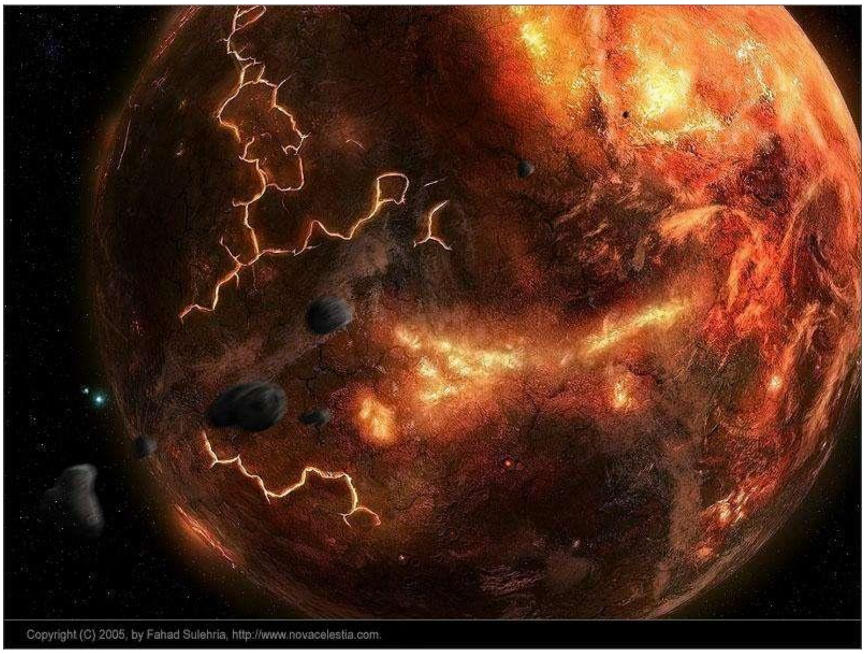


Fig. 46: The Earth imagined in the Hadean with continuous meteorite bombardment

The first 200 million years (Ma) after Earth's formation constitute a cooling phase, during which a solid Earth's crust of low thickness formed as well as a primitive atmosphere resulting from the degassing of internal fluid layers.

This atmosphere was mainly composed of nitrogen and carbon dioxide, plus small amounts of methane and ammonia. Enormous volumes of water were also present in the atmosphere, but this liquid was mobilized for the formation of oceans.

The Hadean is considered to be azoic, but traces of organic products in deposits dating from ~-4 Ga suggest that biological activity may have existed from this period.

This era is that of the creation of the globe and, by its age, there is practically no rock dating from the Hadean at present on the surface of the globe.