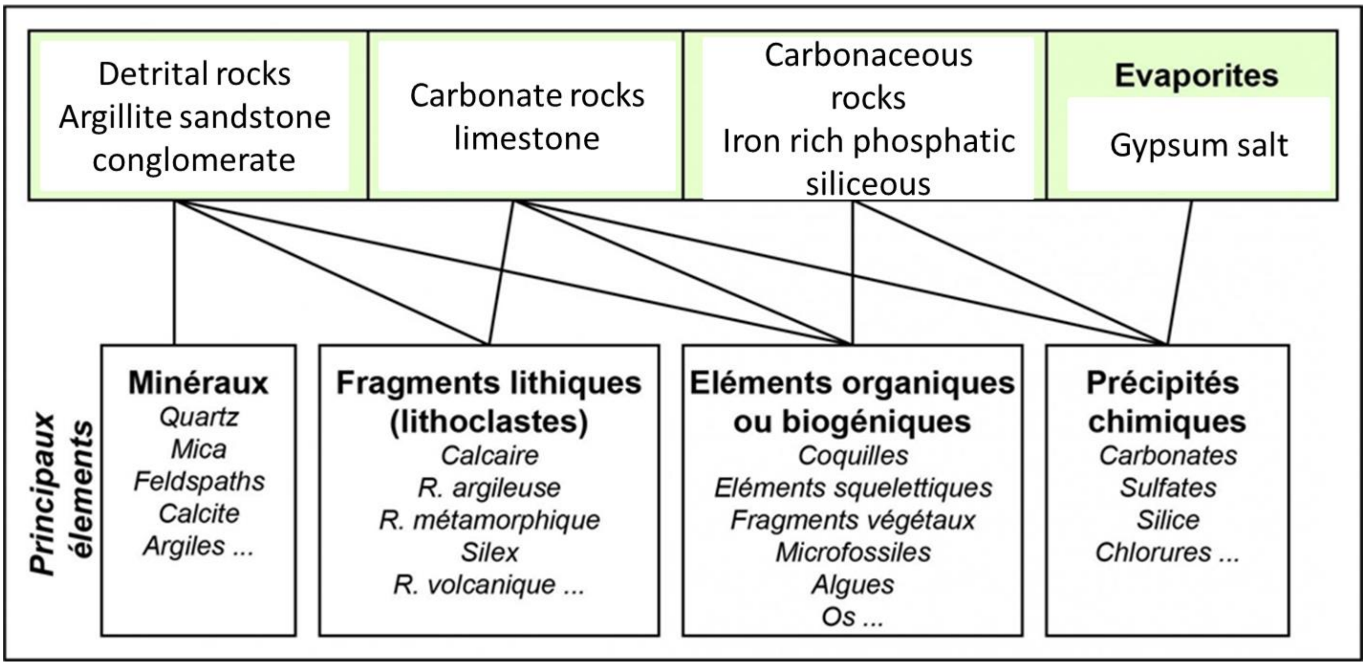
Classification of sedimentary rocks

There are many classifications of sedimentary rocks, based on different criteria like the origin of the elements, their size, arrangement, and chemical/mineralogical nature.

Which elements compose sedimentary rocks?

Among the elements found in sedimentary rocks, we have primarily detrital elements, minerals, or rock fragments (lithoclasts), which are predominantly silicate in nature and originate from the weathering of rocks in continental areas. There are also organic or biogenic elements, as well as chemical elements.



I_ The classification of detrital rocks

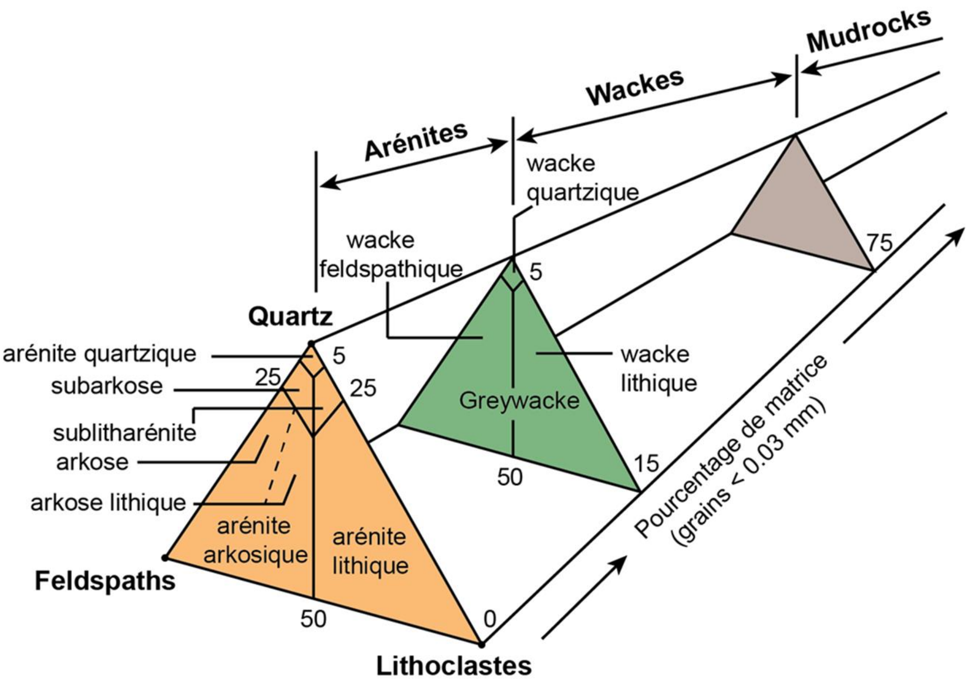
Detrital rocks, terrigenous detrital rocks, or siliciclastic rocks, are the most abundant sedimentary rocks (about 85% of rocks) and are composed of elements derived from weathering and erosion processes, predominantly silicate in nature.

- Terrigenous detrital rocks

  When characterizing terrigenous sedimentary rocks, it's generally done by observing several criteria:
- Grain size (granulometry)
- The nature of the elements making up the rock (including framework grains and the binding phase or matrix)
- The proportion of each element in the rock, and finally, the maturity.

Taille (mm)	Sédiments	Roche	Classe
	blocs *(boulders)*	Conglomérat *(conglomerate)*	Rudite
256			
128	cailloux / galets *(cobbles)*		
64			
32			
16	graviers *(pebbles)*		
8			
4			
	gravillons *(granules)*		
2,00	sable très grossier	Grès *(sandstone)*	Arénite
1,00	sable grossier		
1/2 0,50	sable moyen		
1/4 0,25	sable fin		
1/8 0,125	sable très fin		
1/16 0,0625	silt grossier	Siltite et Argilite *(mudrock)*	Lutite
1/32 0,031	silt moyen		
1/64 0,0156	silt fin		
1/128 0,0078	silt très fin		
1/256 0,0039	argile		

- This classification focuses on the mineral composition of sandstone and its content of fine matrix. It is represented in a triangular diagram with the three poles quartz-feldspar-lithoclasts (QFL). Three main groups of rocks are distinguished: arenites, wackes, and mudrocks. Only the first two types are sandstones (mudrocks are mudstones).



Conglomerates (Rudites class)

Conglomerates are cohesive detrital sedimentary rocks composed of elements larger than 2 mm and a binding phase. The shape of the cemented elements, whether rounded or angular, allows for the distinction between conglomerates (with rounded elements or pebbles) and breccias (mostly angular elements), along with their various intermediates.

Conglomerate classification:

According to Prothero and Schwab (1996), the classification of conglomerates is based on the following criteria:

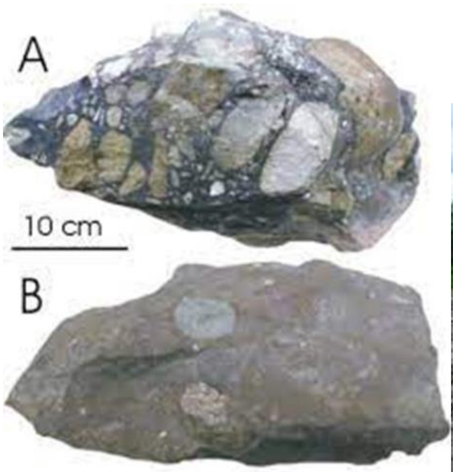
Based on the source of constituents, two categories are distinguished:

Conglomerates with elements from outside the sedimentation environment (extraformational)

Conglomerates with elements originating from the sedimentation area (intraformational)

Matrix content (15%): This criterion helps characterize:

orthoconglomerat and paraconglomerat



Orthoconglomerate (interlocking elements; higher element content than matrix) are deposited by rapid water flows where elements settle first, followed by matrix infiltration during transport agent deceleration phases (like rivers). Paraconglomerate (elements floating in the matrix) are deposited by ice or mass movements. Within orthoconglomerates, a distinction can be made:

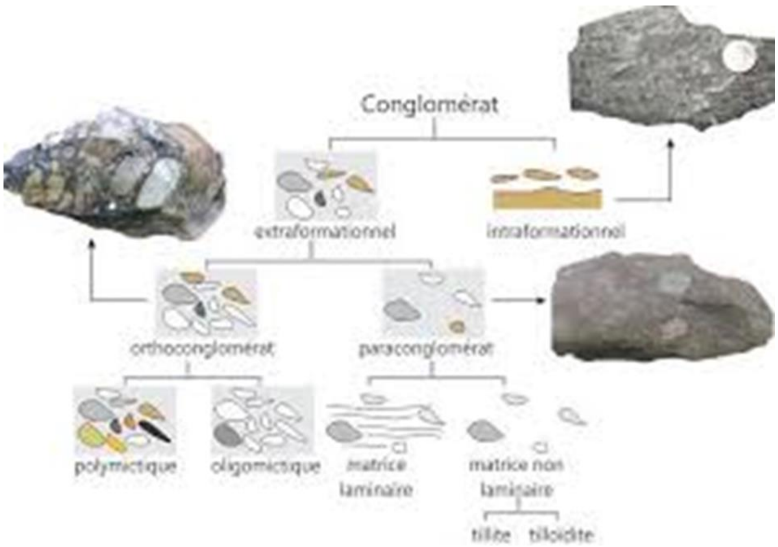
- Oligomictic conglomerates are almost exclusively formed of a few varieties of very resistant rocks. Polymictic conglomerates consist of elements of very diverse nature and origin.

Paraconglomerates are subdivided based on the nature of their matrix.

We can find paraconglomerates with laminar clay matrix where pebbles and blocks deform the laminations (like dropstones). Paraconglomerates with non-laminar matrix can be glacial tillites, varved deposits, or tilloïdites (formed by mass movements).

A: orthoconglomérat oligomictique;

B: paraconglomérat à matrice non laminaire:



Sandstone "Class of Arenites"

- Are conglomerated sands (where grains are cemented), with a grain size ranging from 0.063mm to 2mm. They have a diverse composition but are made up of 50% silica, hence they are also known as siliciclastics.

  Within a sandstone, three distinct components can be identified:
- A granular phase representing the elements (the clasts).
- A matrix or interstitial phase that binds the grains together (formed during sedimentation, or a cement formed later through chemical mineral precipitation).
- Fluids like water, hydrocarbons, or air.

According to the mineral composition, a sandstone contains the following constituents:

Quartz is the most common mineral constituent in sandstones due to its nature and resistance to weathering.

Feldspars, being fragile and prone to rapid weathering, rarely make up more than 10 to 15% of sandstones.

Micas are present in proportions not exceeding 20%.

Lithic fragments such as pieces of volcanic rocks, schists, and cherts.

The cement of sandstones varies in nature (siliceous, carbonate, or clayey).

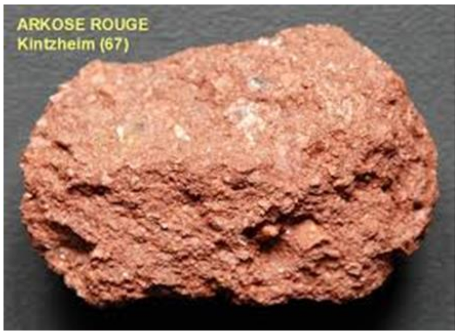
Classification of sandstones

Many classifications and nomenclatures have been proposed to classify sandstones. In the old classifications, authors like L.Cayeux.1929, used cement as a criterion for classifying sandstones:

- Sandstones defined by their cement: within this group, they are distinguished based on the mineralogical nature of the binder (cement) into several classes or types of sandstones:

    - Clayey cement sandstone.
    - Ferruginous cement sandstone: iron is in the oxide state (e.g., hematite).
    - Siliceous cement sandstone: with grains of opal, chalcedony, or quartz.
    - Limestone cement sandstone (grains are bound by calcite).
- Sandstones defined by their constituents: the terminology only considers the clasts (mineral constituents present in the rock).
    - Siliceous sandstone: predominantly composed of quartz.
    - Micaceous sandstone (Psammite): formed of quartz with a significant percentage of micas.
    - Feldspathic sandstone (Arkose): marked by the presence of quartz and feldspar.





<u>The classification of carbonate rocks:</u>

By definition, carbonate rocks are sedimentary rocks containing at least 50% carbonates. Carbonate rocks represent about 20%. They are generally of low hardness; when attacked by acids, they release CO_2. Apart from a few accessory minerals, often of terrigenous origin, sometimes newly formed, carbonate rocks are composed almost exclusively of calcite and dolomite. The two main carbonate rocks are:

limestone composed of $CaCO_3$ (calcite),

dolomite formed from $CaMg(CO_3)_2$ (dolomite).

The three main carbonate minerals are calcite and aragonite, which have the same chemical formula, and dolomite. There are numerous classification systems for these rocks.

Some focus on the mineralogical/chemical composition or physical properties of the rocks, while others emphasize the texture of the rocks.

The two modes of limestone fixation, organic skeletons and chemical precipitation, can coexist. These various actions result in a sediment chemically composed of $CaCO_3$, distributed in terms of grain size as follows:

Coarse grains (visible grains to the naked eye or under a magnifying glass), similar in size to arenites and rudites, of various origins.

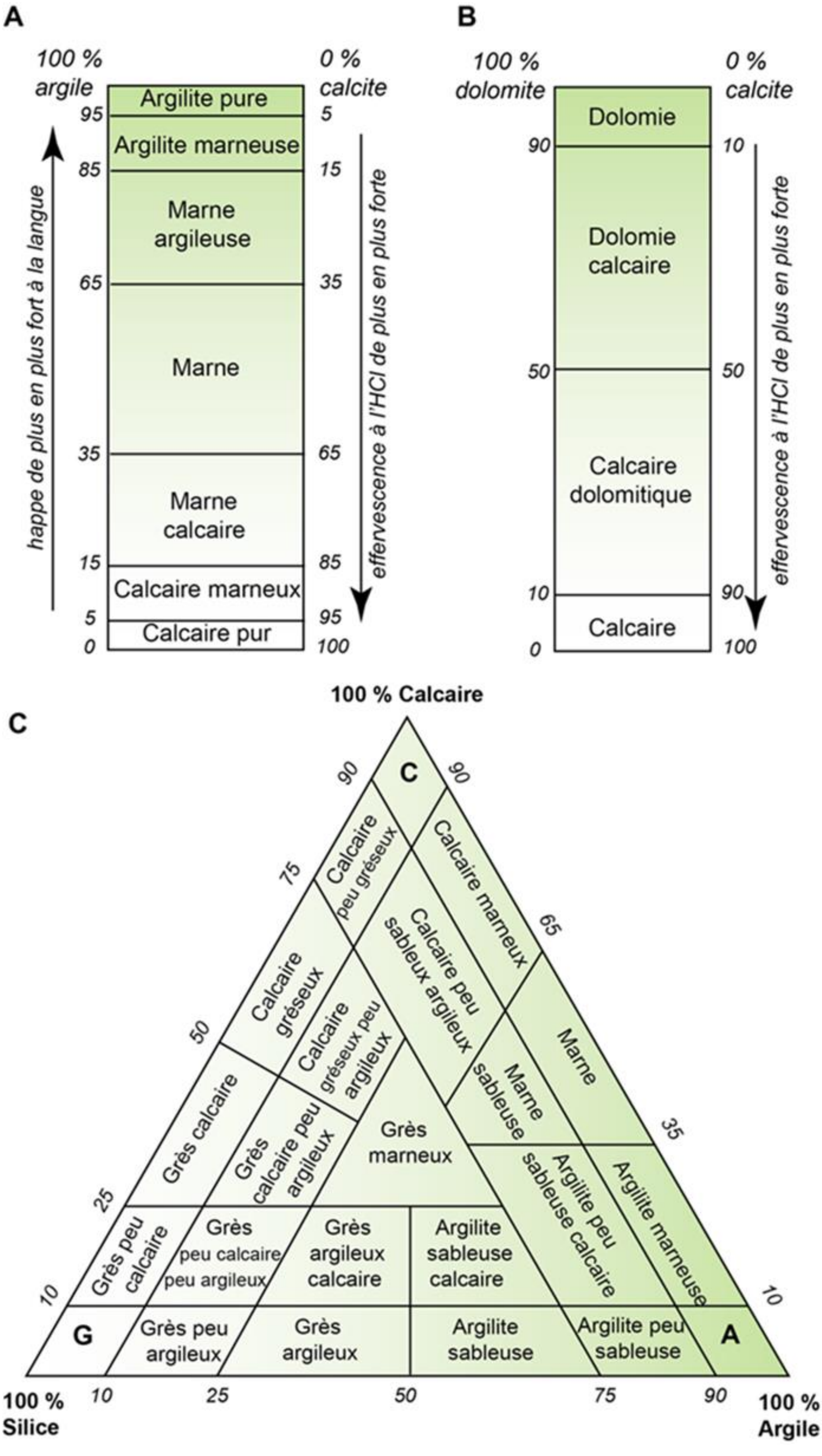
Finer particles the size of lutites; they result from the chemical precipitation of $CaCO_3$, intense grinding of coarse grains, and the deposition of micrometer-sized particles from nannoplankton skeletons. They form the matrix and represent calcareous mud or mudstones that settle saturated with water.

We can classify carbonate rocks based on their carbonate mineral content (Figure A) or clay mineral content (Figure B). Figure C is a ternary diagram showing the naming of mixed rocks, composed of a mixture of limestone, clay, and silica (figure adapted from Vatan, 1967). Chemical and mineralogical classifications:

A. Based on the dolomite/calcite ratio.

B. Based on the clay/calcite ratio.

C. Ternary diagram showing the different types of rocks based on the proportion of clay, silica, and limestone.



A
100 % argile
0 % calcite
Argilite pure
Argilite marneuse
Marne argileuse
Marne
Marne calcaire
Calcaire marneux
Calcaire pur
95
85
65
35
15
5
0
5
15
35
65
85
95
100
happe de plus en plus fort à la langue
effervescence à l'HCl de plus en plus forte
B
100 % dolomite
0 % calcite
Dolomie
Dolomie calcaire
Calcaire dolomitique
Calcaire
90
50
10
0
10
50
90
100
effervescence à l'HCl de plus en plus forte
C
100 % Calcaire
C
Calcaire peu gréseux
Calcaire marneux
Calcaire gréseux
Calcaire peu sableux argileux
Calcaire gréseux peu argileux
Marne
Grès calcaire
Marne sableuse
Grès calcaire peu argileux
Grès marneux
Argilite peu sableuse calcaire
Argilite marneuse
Grès peu calcaire
Grès peu calcaire peu argileux
Grès argileux calcaire
Argilite sableuse calcaire
G
Grès peu argileux
Grès argileux
Argilite sableuse
Argilite peu sableuse
A
100 % Silice
100 % Argile
10
25
50
75
90

Common Terminology of Limestones:

Alongside the nomenclatures that aim to fit limestones into a logical system, a number of terms often appear in geological literature (such as geological map descriptions). They refer to types of rocks that are generally well represented in sedimentary formations.

Lithographic and sublithographic limestone: This is a fine micro to cryptocrystalline limestone, falling into the category of mudstones. It is slightly clayey limestone (5%), with a slab-like appearance and sharp fracture, of detrital origin, and deposited near coral reefs.

Gravelly limestone: This is a calcarenite, of unspecified origin and nature, typically belonging to packstone and grainstone types.

- Oolitic limestone: They could be classified as detrital limestones, as oolitic sands are transported and sorted by waves and currents.
- Nodular limestone: Colored limestones formed of calcareous concretions encased in red or green cement (e.g., Italian "ammonitico rosso," Pyrenean "griotte marbles").
- Clayey limestone (not marly): Bluish-gray rocks colored by cryptocrystalline pyrite and hydrocarbonaceous materials. If the limestone contains 23 to 28% clays, it forms a natural cement. Marls bridge the gap between clayey limestones and calcareous mudstones.
- Organism-bearing limestones: Depending on the predominant organism, we distinguish:

- Shell limestone, Lumachelles: Fossil tests are identifiable and cemented by calcite. They could also be referred to as bioclastic limestones. In the case of Lumachelle (mollusks, brachiopods), the tests are oriented parallel to stratification.
- Crinoidal limestone: Bioclastic limestones formed almost exclusively from echinoderm debris. Each bioclast is a fragment of broken calcite crystal following cleavage planes, giving the rock a glittering appearance of crystalline limestone, often enhanced by epitaxial cementation.

Reef limestone: Limestone built by the accumulation of reef-building polyps (thick and massive banks).

This formation requires strict conditions: warm water at 18°C, no suspended mineral matter, and sufficient illumination as corals live in symbiosis with algae (shallow bathymetry < 60 m).

Bioherm: Biolithite (fossil reef or reef complex) built by constructing organisms (corals) often preserved in their living position. It has a thick, non-bedded lens shape independent of the stratification of adjacent layers.

Biostrome: Represents the same as bioherm but strictly stratiform.

Chalk: A bioclastic limestone, always very fine-grained, mainly composed of planktonic foraminifera and nannofossils (coccoliths: calcareous pieces of coccolithophores = unicellular plants = phytoflagellates). Due to its fine grain size, chalk has escaped diagenesis. It is a white, soft, crumbly, traceable, porous, yet low permeable rock. These rocks are only known in the Mesozoic series of shallow basins (≤ 300 m).

Travertines (Calcareous tufas): These are friable, vacuolar rocks, white or yellowish, with well-preserved plant debris. They are deposits that form at the emergence of limestone springs. The precipitation of CaCO3 is favored by the absorption of CO2 by plants.

Marble: Any limestone fine and compact enough to be polished. It is often also a metamorphic limestone (general metamorphism or contact metamorphism).

Limestones can contain significant proportions of terrigenous detrital elements. This is the case with sandy limestone (containing quartz) or clayey limestone. In limestone regions, one often encounters slope breccias and conglomerates with pebbles and limestone cement.

The textural classifications

Caractéristiques étudiées	Exemples de textures
Taille des éléments	Grossière, moyenne, fine, sublithographique, lithographique (= cryptocristalline)
Taille et morphologie des éléments	Conglomérée, poudinguiforme, bréchoïde, noduleuse, grumeleuse, graveleuse
Morphologie et microstructure	Oolithique, pisolithique
Arrangement des éléments	Schisteuse, feuilletée, rubanée, zonée, concrétionnée, varvée
Porosité	Spongieuse, vacuolaire, poreuse
Dureté	Pulvérulente, terreuse

In Folk's classification, four types of elements (allochems) and two types of bonding phases (orthochem) are distinguished. The rock's name is constructed by combining a prefix (dominant allochem) with a root (orthochem):

Eléments (= allochems)	***Préfixe***	***Phase de liaison (= orthochem)***			
		Ciment (calcite spathique)	Matrice (calcite à grains fins)		
			Allochem > 10 %	Allochem < 10 %	Allochem < 1 %
bioclastes	BIO-	Biosparite	Biomicrite	Micrite fossilifère	
intraclastes	INTRA-	Intrasparite	Intramicrite	Micrite à intraclastes	Micrite
ooïdes	OO-	Oosparite	Oomicrite	Micrite à ooïdes	
péloïdes	PEL-	Pelsparite	Pelmicrite	Micrite à péloïdes	

In carbonate rocks, the four types of elements present are:

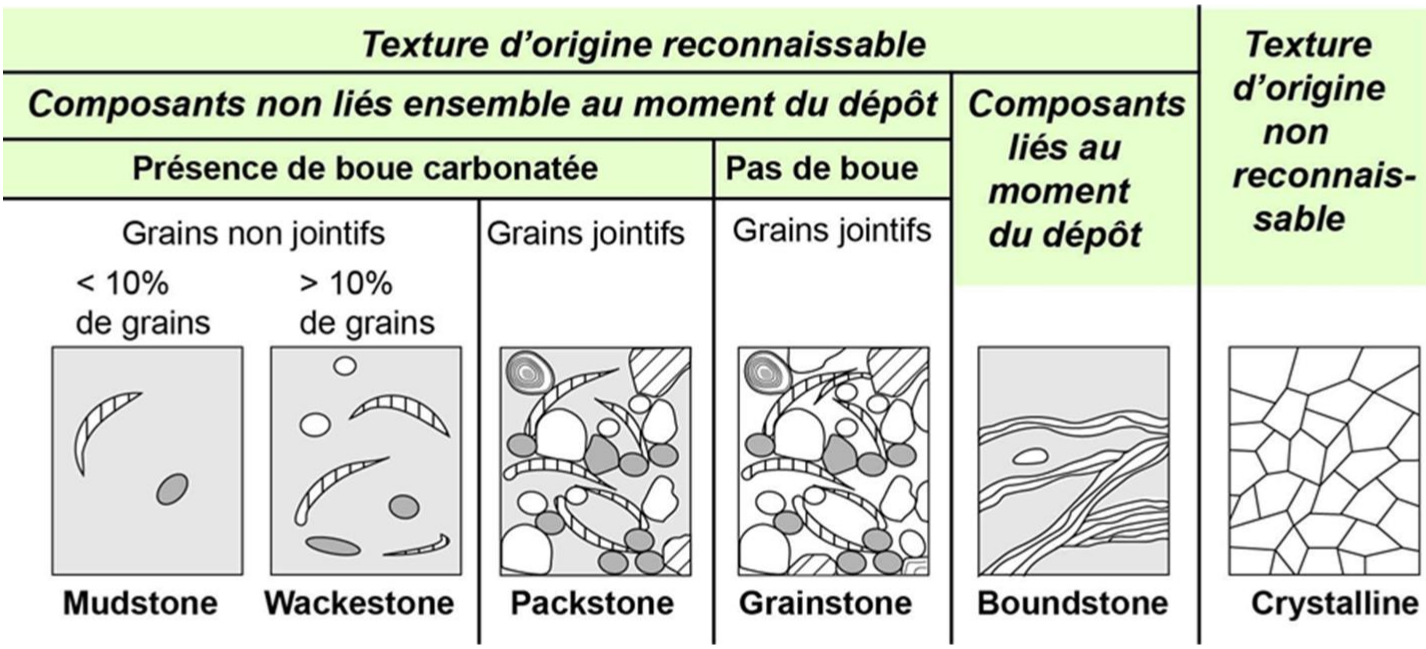
Ooids (or ooliths) are chemically formed elements with a round shape and concentric internal structure. They are smaller than 2mm.

Bioclasts are organic elements, often fossils or fossil fragments.

Intraclasts are fragments of rocks.

Peloids, pellets, or fecal pellets are organic elements rich in organic matter (hence the dark color) and lack internal organization. They typically measure between 0.1 and 0.5mm.

In Dunham's classification, the focus is on studying the type of bonding phase (matrix or cement), the abundance of elements, and their arrangement (continuous or dispersed elements). The names given to the rocks are English words.



<u>Evaporites,</u>

Also known as evaporitic rocks, saline rocks, or chemical saline rocks, are chemically derived rocks formed from the deposition of salt that precipitates from salty or brackish water. They typically form in closed environments such as inland seas, lagoon or coastal areas (through the evaporation of seawater), salt lakes (evaporation of continental waters), salt pans (concentration of seasonal rainwater in chotts, playas...).

Secondary Minerals

Secondary evaporitic minerals refer to evaporites reworked by diagenesis, early or late. The most common diagenetic transformations include:

Conversion of gypsum into anhydrite: through heat input, resulting in the loss of water from gypsum. Total dehydration is observed at 90 °C.

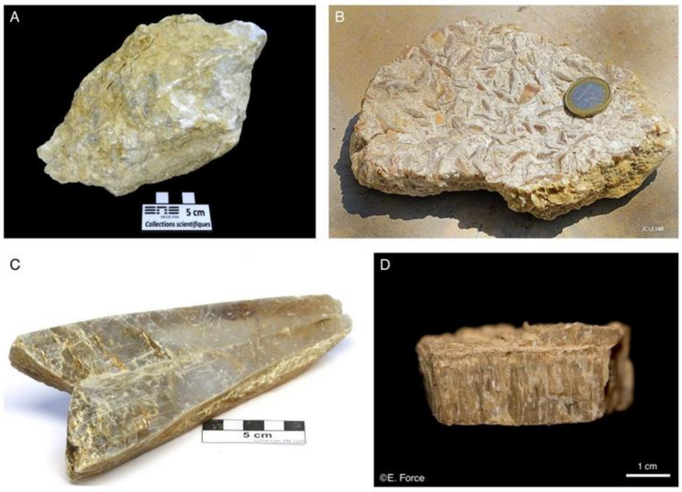
Conversion of anhydrite into gypsum: the reverse reaction of the previous one, through hydration.

Conversion of carbonates into sulfates.

Conversion of sulfates into carbonates.

Conversion of sulfates into silica.

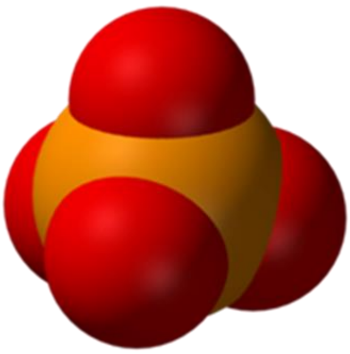
Metamorphic transformations are also observed.



Gypsum and salt   Samples of evaporites

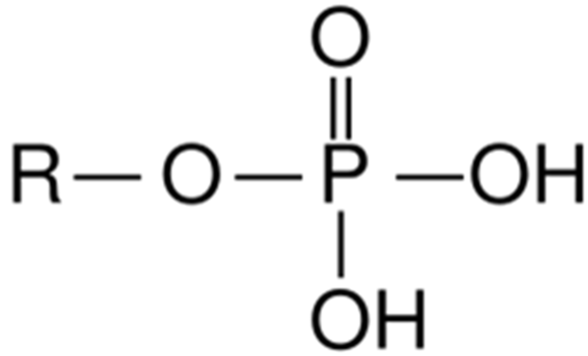
<u>Phosphate rock (a rock enriched in phosphate salts)</u>

Is a type of sedimentary rock classified as an exogenous rock: its formation involves the concentration of phosphate ions precipitating within a rock during diagenesis. Biogenic varieties, such as bird and bat guanos, have been harvested for centuries.



phosphate is a chemical compound containing the element phosphorus, naturally occurring in the environment and notably in water. A phosphate is a compound derived from phosphoric acid H_3PO_4 by the loss or substitution of one or more hydrogen atoms with other atoms or functional groups.

Structure tridimensionnelle d'un ion phosphate



Structure d'un groupe phosphate lié à un radical R

The phosphate ion (or orthophosphate) is a polyatomic anion with a chemical formula of PO43− and a molecular mass of 94.97 daltons. It appears as a tetrahedron with its vertices formed by four oxygen atoms surrounding a phosphorus atom.

Elemental phosphorus appears in various forms, ranging in colors from violet-black, red, white-yellow to white. Highly pure white phosphorus is transparent. Typically, white phosphorus is amber-white, slightly malleable with a faint garlic-like smell. Red and black forms can be in powder or crystallized.

In the field of mineral chemistry, it represents a salt formed through the reaction of an acid with a base, or the anion component within this salt. The orthophosphate ions are the predominant chemical forms of phosphate in the environment (H2PO4−, HPO42−, PO43−), all originating from phosphoric acid through the removal of one to three hydrogen atoms. These ions find application in certain fertilizers and detergents.

In organic chemistry, a phosphate is a type of organophosphorus compound; the substituent groups replacing the hydrogens of phosphoric acid can be carbon chains, sometimes referred to as organic phosphate.

Phosphate exists in four forms depending on the acidity level. Going from most basic to most acidic:

The first predominant form is the phosphate ion (PO43−) (strongly basic);

The second form is the hydrogen phosphate ion (HPO42−) (weakly basic);

The third form is the dihydrogen phosphate ion (H2PO4−) (weakly basic);

The fourth is the trihydrogen phosphate form (in non-ionized crystalline state) or phosphoric acid (H_3PO_4) (strongly acidic in solution).

Minerals of Phosphate Rocks

The valence of phosphorus is a stable valence. Therefore, the formation of $(PO_4)^{3-}$ is observed.

Apatite: (calcium, magnesium, nitrogen)$_{10}(PO_4)_{6-x}(CO_3)_xF_y(F, OH)_2$

Pristine: fluorapatite

Francolite: by substituting PO_4 with CO_3

Dallite: by substituting F with OH

Thuyaminite: contains a yellow uranium phase

Vivianite: iron phosphate

Pyromorphite: lead phosphate

Turquoise: copper and aluminum phosphate

Substitutions of calcium are also possible with potassium, strontium, uranium, and thorium. PO_4 can be substituted by SiO_4, AsO_4, VO_4. The uranium contained in substitution can be used for absolute dating with radioactive isotopes. The solubility of phosphates increases with the presence of carbonates. The presence of magnesium inhibits the growth of apatite.

As per the 1974 International Mineralogical Classification, phosphate rocks are categorized into two primary groups:

Rocks falling within the apatite family. These phosphatites harbor significant crystals and may not necessarily exhibit chlorine and fluorine-based lattice structures akin to apatite.

The remaining rocks, termed as phosphorites, represent calcium phosphates, occasionally displaying whitish, grayish, or pale hues, yet often adorned in yellow or red tones. Phosphorites are designated by mineral type, texture, structure, exogenous composition, and notably their phosphorus pentoxide (P_2O_5) content, which must surpass 17%.

The origins of phosphate contributions are subject to various theories.

In continental settings: Minerals are brought in through soil leaching, movements, and the accumulation of organic debris (like coprolites and bones). Deposits nestled in karsts often stem from bone accumulations (such as the phosphorites of Quercy).

In island environments, the abundant guano production by birds and the substantial fish quantities are believed to give rise to concentrated yet localized deposits (like the Chincha Islands in Peru). The alteration of deposits may occur during marine transgressions, potentially leading to apatite formation.

Within marine realms, oceans serve as significant phosphate reservoirs.

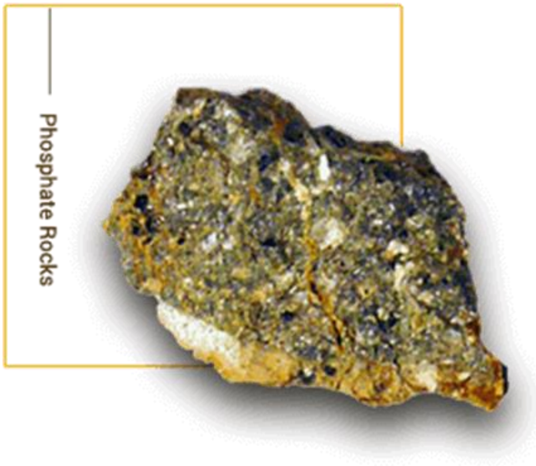
Continental phosphate deposits encompass karsts and soils. While their volume is considerable, their concentrations are modest. Epicontinental deposits found in lagoons and shallow basins are lucrative and exploitable.

The Phosphorus Cycle

The phosphorus tends to be leached towards the seas through the action of rainfall leaching, from the upper watershed towards the sea. Wind erosion can carry significant amounts of phosphorus to very distant areas, including the Sahara.
Phosphorus in soils is abundantly wasted by intensive agriculture and certain wastewater treatment units, and is heavily present in detergents.

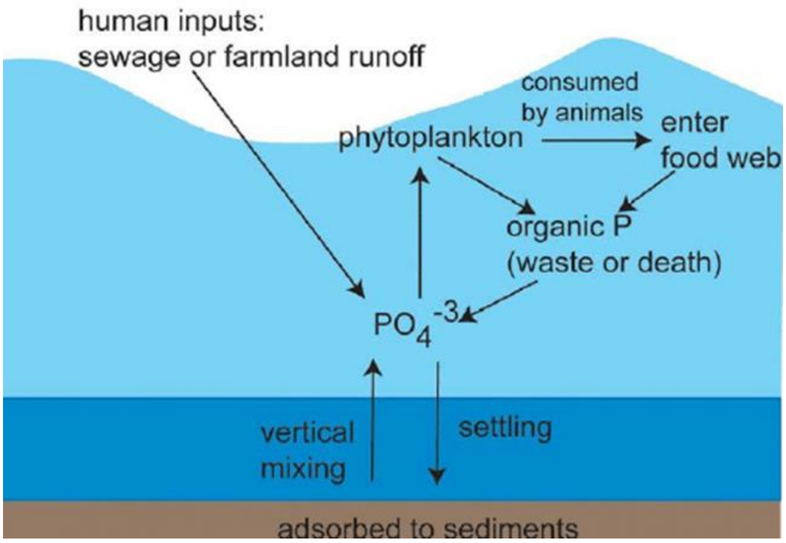
 

Phosphorite (raw material used to make phosphate fertilizers) from Morocco.



Continental deposits, found in karsts and soils, boast significant volume but low concentrations. On the other hand, epicontinental deposits in lagoons and shallow basins are rich and commercially exploitable.

Phosphate is a sedimentary rock formed millions of years ago by the accumulation of organic matter at the bottom of the oceans.



A siliceous rock, or silicite,

Is a sedimentary rock primarily composed of silicon dioxide (SiO_2) in the form of quartz, chalcedony, or opal. These silica-rich rocks (> 50%) have the property of scratching glass and steel. They can originate from three sources:

Detrital origin rocks (such as siliceous sands, sandstones, conglomerates, and gaizes).

Organic origin rocks: layered silicites that may result from bioprecipitation. The three main silica biomineralizing organisms are:

Radiolarians (forming rocks known as radiolarites),

Diatoms (diatomites),

Sponges (spiculites and spongolites).

Chemical origin rocks: nodular silicites (like flint, cherts, and meulières) resulting from the reprecipitation of biogenic silica.

Rocks rich in silica form a subset of sedimentary rocks. Their common feature is the high silica content, SiO_2.

Red arkose is a siliceous rock that is a poorly rounded quartz sandstone. These sandstones are made up of quartz and feldspar grains with a predominantly calcareous cement. Sometimes called feldspathic arenite or feldsparénite, red arkose is a terrigenous detrital sedimentary rock.

Like all sandstones, arkose is a detrital rock rich in quartz (up to about 60%), but defined by a feldspar content of at least 25%, possibly accompanied by some micas and a clay-based cement (about 15%). It is a coarse, feldspathic sandstone. Additionally, its binder is clayey, not calcareous, which enhances its resistance over time to rain.

opall

quartz

The minerals of siliceous rocks

The flint is a chemical siliceous rock, very hard, formed by chemical precipitation and composed of nearly pure chalcedony and impurities such as water or oxides, which influence its color. Flints are black, gray, or brown in color, occurring in nodules with a conchoidal fracture.

The formation of flint is a complex phenomenon. It is generally accepted that this rock forms from seawater or a lake saturated in hydrated silica, known as opal, which, through epigenesis, chemically evolves into microporous chalcedony, then into compact chalcedony, and finally into quartz.


A chaille (known as chert in English) is a sedimentary rock containing partially silicified concretions. Under certain conditions, silica present in limestone mud can migrate and gather in nodules (ovoid masses), lenses, or centimeter to decimeter-sized beds within marine carbonate rocks (limestone, dolomite, chalk...).

A rock (chert) primarily composed of silica, containing traces of organic matter dating back 3.5 billion years, originates from the "Barberton Greenstone Belt" site in South Africa. The oldest rocks on Earth (Archean) preserving traces of organic matter are siliceous (cherts). The study of this organic matter helps determine whether it is of biological origin or not, thus aiding in dating the appearance of life on Earth.

Brown to reddish rock, ovoid, with diffuse contours (gradual transition from silica to limestone)

Radiolarite is a fine-grained sedimentary rock with barely visible grains to the naked eye, showing an alternation of dark layers and light layers. The red color is attributed to the presence of ferric iron Fe^{3+}. At times, iron is in the ferrous form Fe^{2+}, resulting in a green hue in the rock. To form radiolarite, the radiolarian shells must be preserved.

The sedimentation rate depends on the ratio of Primary Production to Dissolution. Adequate primary productivity is essential for sedimentation to occur.

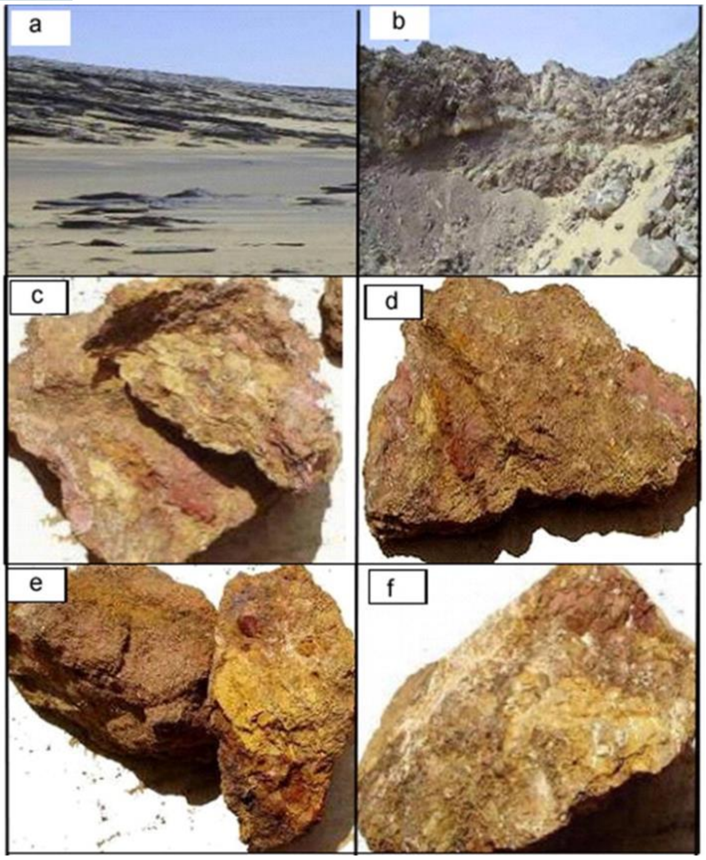
Diatomites

Through diagenesis,

the opal in the frustules generally transforms into chalcedony, but it can also undergo epigenetic processes to become calcite, phosphate, pyrite, and so on.

The ferruginous and aluminous rocks:

Sedimentary iron ores (minette) and aluminum ores (bauxite). Pyroclastic rocks result from the assembly of debris ejected by volcanoes: ashes, lapilli, volcanic tuffs. The material of the ammonite has gradually been replaced by pyrite.



Carbonaceous Rocks

Biogenic rock resulting from the accumulation, burial, and transformation of sediments rich in organic matter of plant or animal origin

Coals	Petroleum
solid	viscous liquid and gaz
	

Organic matter (CH_4, $C_nH_{2n}O_n$) is a ubiquitous component of sedimentary rocks.

S Raw material or natural energy source to meet the needs of living organisms

Minerals Organics

Detrital	Carbonate	Evaporites	Carbonaceous
SiO_4^{2-}	CO_3^{2-}	SO_4^{2-}	CH_4, $C_nH_{2n}O_n$
Construction aggregate	cements	Plaster	Gas Coal Petroleumome

Figures on the abundance of organic matter are as follows:

Clayey sediments of continental shelves: 2%

Deep oceanic sediments: 0.4%

Coals, peat, source rocks: 90%

There are three categories of carbonaceous rocks:

Continental: peat, lignite, coal, gas

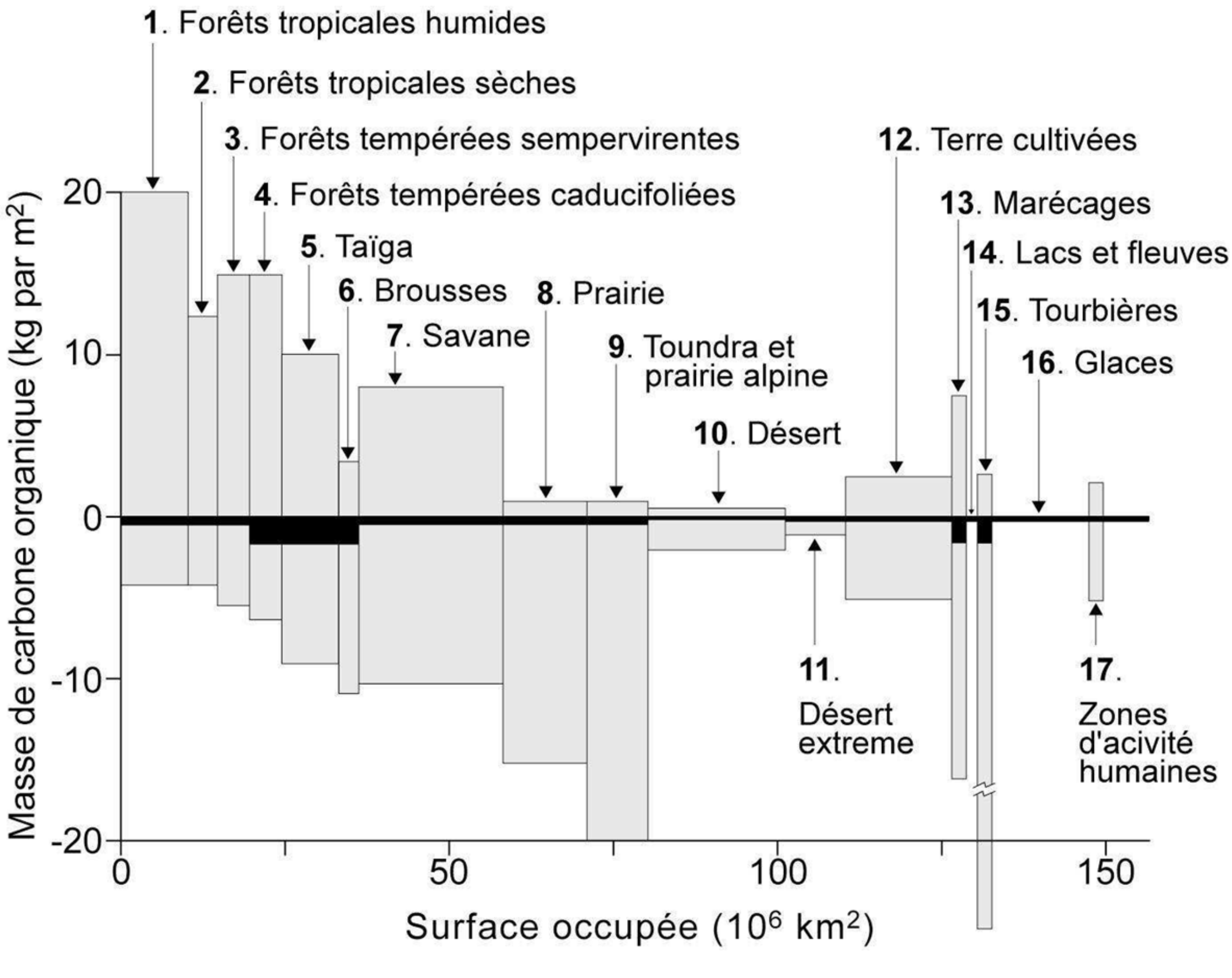
Marine: gas, oil, bitumen

Lacustrine: oil

The organic carbon cycle involves both a fast biological cycle and a slow sedimentary cycle. In the fast biological cycle, organic matter produced through photosynthesis is recycled in food chains and degraded by various physical and biochemical processes. On the other hand, the slow sedimentary cycle involves the evolution of organic matter based on burial conditions (pressure, temperature).

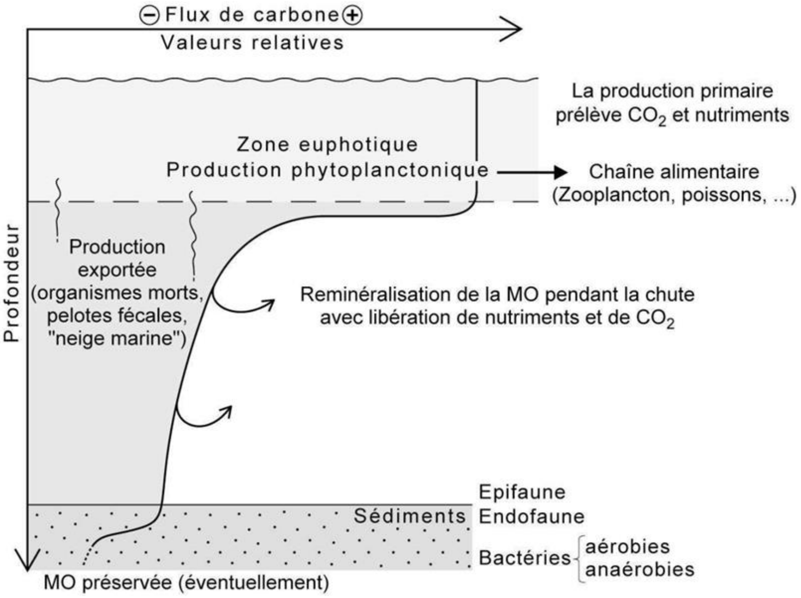
It's fascinating to observe how nature intricately manages the transformation and utilization of organic carbon through these cycles.

Organic matter in continental areas is primarily produced by higher plants, and to a lesser extent by lichens and mosses. The recycling of organic matter is crucial in forests, resulting in minimal incorporation into the soil. However, organic matter tends to accumulate significantly in grasslands, tundra, and peatlands.



Organic matter in the marine environment is primarily produced in proximal settings, such as continental shelves, in shallow waters (>100m deep).

The production of organic matter depends on climatic factors (temperature, light intensity) and environmental conditions (nutrients, CO2 levels). It is mainly produced and recycled in the photic zone. Organic matter undergoes decomposition through biological and physicochemical processes in the water column and eventually in the sediment.

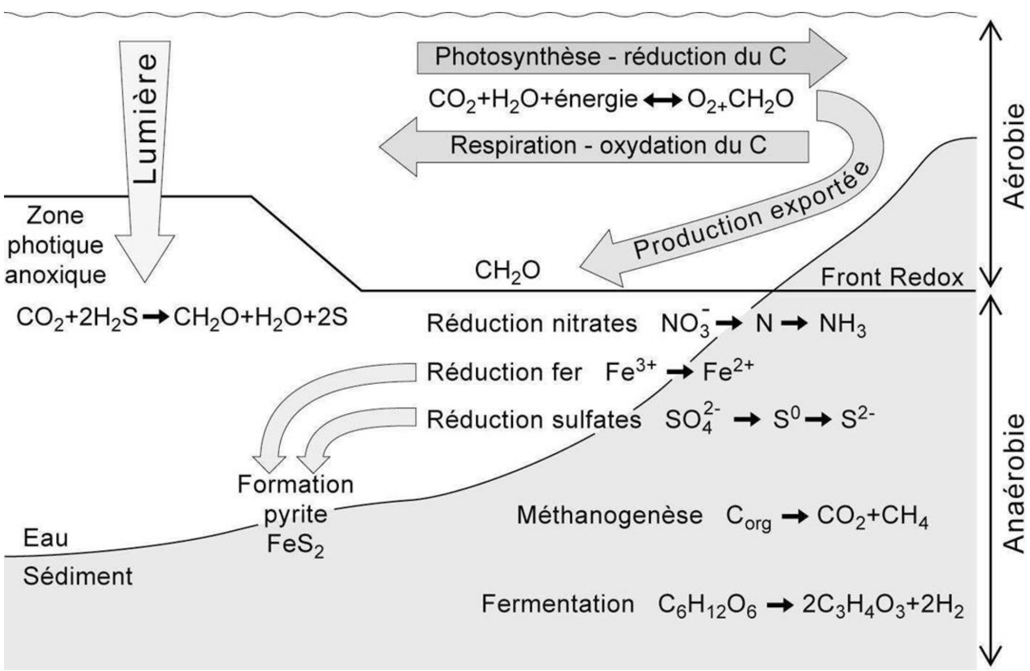


Degradation of Organic Matter in Marine Environments

In the presence of O2:

Organic matter is degraded directly or by microorganisms.

In the absence of O2:



Organic matter is degraded by anaerobic bacterial fermentations (using NO−3 and SO4).

Organic Matter Storage in Marine Environments

Controlled by 3 processes:

Burial

Production

↓Sedimentation Rate

↓

Preservation

Organic Matter

↓

Oxygen Level

Storage of Organic Matter Over Time

Periods conducive to organic matter storage

Formation of carbonaceous rocks

Sapropel: Pelagic sediments rich in algal organic matter

Black Shale: Sedimentary deposit (argillite) rich in dark, laminated organic matter

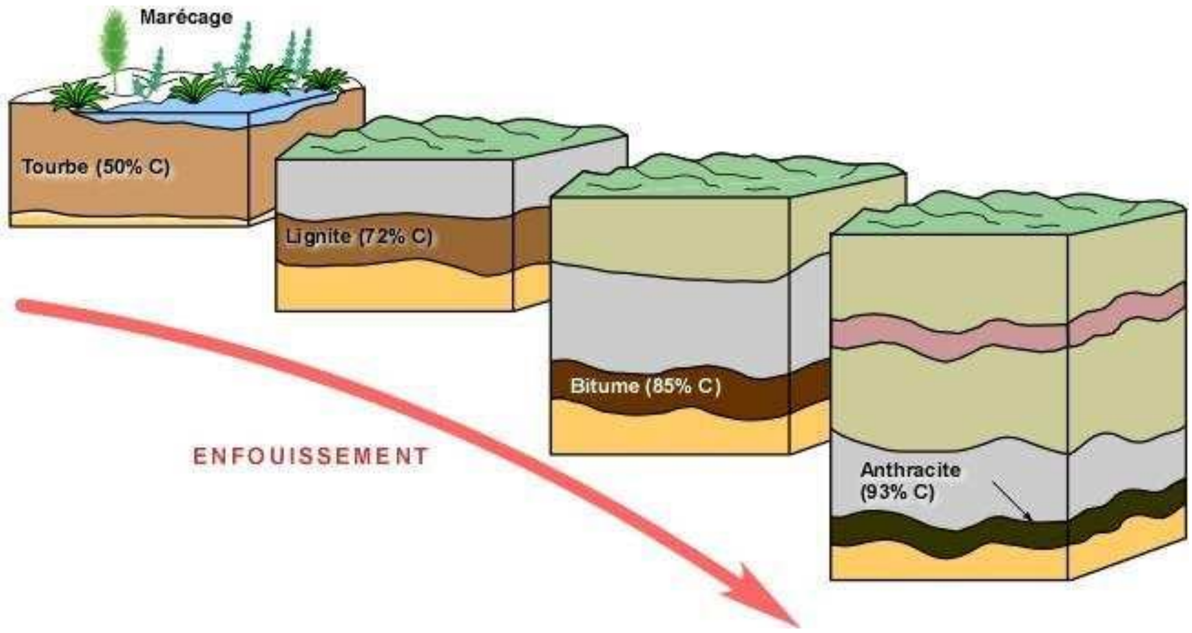
<u>Coals</u>

Carbonaceous sedimentary rock containing at least 50% combustible carbon and resulting from the carbonization of organic matter (higher plants or algae)

Humic coal	Sapropelic coal
Higher plants 90%	Algae <10%

Coal is a fossil fuel of organic origin, formed from the transformation of buried biomass over geological time. The oldest and most sought-after coals date back to nearly 300 million years ago, during the Carboniferous era.

Residues of the physico-chemical evolution of plant debris during burial and diagenesis



Successive ranks of coals (peat ⇒ anthracite) obtained by degradation and carbonization (coalification) of organic matter

Coals - Formation

Deposits and exploitation

Degradation: a set of complex chemical and biochemical reactions that occur in the early stages of evolution (peat⇒ lignite).

Humification: transformation of organic compounds into acids

(accompanied by a loss of 70 to 90% water)

Lignite → humic acid Cellulose → fulvic acid

Gelification: colloidal transformation of humic acids

Carbonization: a series of complex chemical and biochemical reactions that occur deep underground, away from air, leading to an enrichment in carbon and a depletion of volatile elements (H, O, N) through gas formation.

Coal activated, also known as activated charcoal or activated carbon, is a material primarily composed of carbonaceous matter with a porous structure.

Activated charcoal refers to any coal that has undergone a specific preparation process, giving it a high degree of ability to adsorb and retain certain molecules upon contact. It is an amorphous structure mainly consisting of carbon atoms, typically obtained after a precursor is carbonized at high temperatures.

Coal, like oil and natural gas, is a fossil fuel. Its formation began over 350 million years ago through the deep transformation of plant organic matter.

It all starts in a swamp, on the edge of a lagoon or lake. Tectonic movements cause the sea level to rise: the vegetation, submerged, dies. Trees and plant debris accumulate and are covered by masses of mud and sand due to sedimentation. This burial protects them from air and prevents them from rotting quickly. Vegetation regrows above... until the next submergence. 95%: that's the pure carbon content in anthracite.

As the sedimentary basin gradually sinks under the weight of the earth's crust, the layers of dead vegetation are subjected to an increase in temperature, causing their gradual transformation. Cellulose, the main component of wood, goes through various stages.

After peat, the first sedimentation stage, come lignite, then bituminous coal, and finally anthracite. The latter has the highest carbon content.

<u>Oil, a natural mineral oil,</u>

Is composed of numerous organic compounds, primarily hydrocarbons, trapped in specific geological formations.

A complex mixture of hydrocarbons present in three forms:

Bitumen: viscous

Oil: liquid

Gas: dry or wet

Once refined, it can be used to produce various fuels such as gasoline, diesel, gases like butane and propane, and other combustibles. It is categorized as a fossil energy resource.

Crude oil primarily composed of H and C:

%C: 80-90

%H: 10-14

%O: 0-2

%N: 0-1

%S: 0-3

Dry gases (CH_4 or C_2H_6) are usually associated with coals, while wet gases (C_3H_8 or C_4H_{10}) are associated with oils.

Products resulting from the transformation of organic matter (plankton) through biochemical (microbial) degradation followed by thermal processes.

Oil is a product of the geological history of a region, particularly influenced by the interplay of three conditions: the accumulation of organic matter derived from the decomposition of marine organisms (primarily plankton) in sedimentary basins at the bottom of oceans, lakes, and deltas; its transformation into hydrocarbons; and its entrapment.

Large quantities of oil formed between 20 to 350 million years ago. Subsequently, as an oil reservoir is affected by plate tectonics, it undergoes various geological processes.

Petroleum - Formation

Source rock: Initial kerogen

Deposits and exploitation

Biogenic CH4

Early diagenesis

CO2, H2O

Burial diagenesis

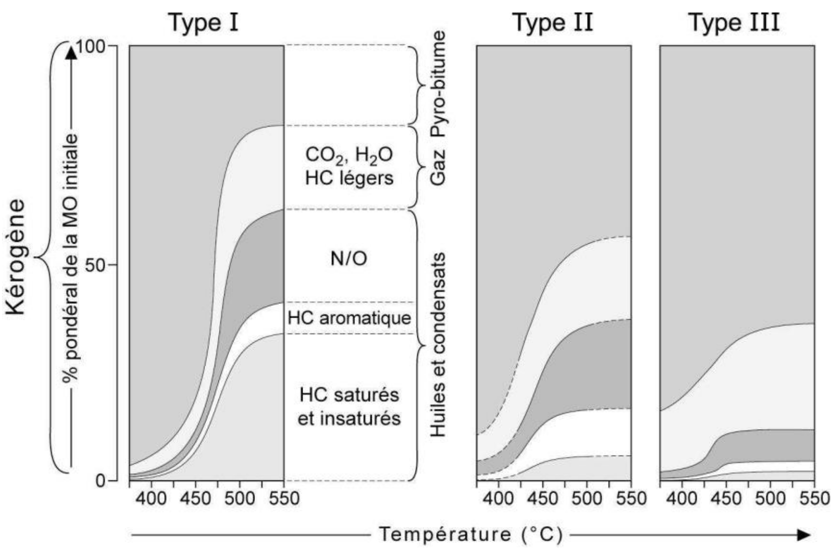
Catagenesis

Oils and light hydrocarbons

Metagenesis

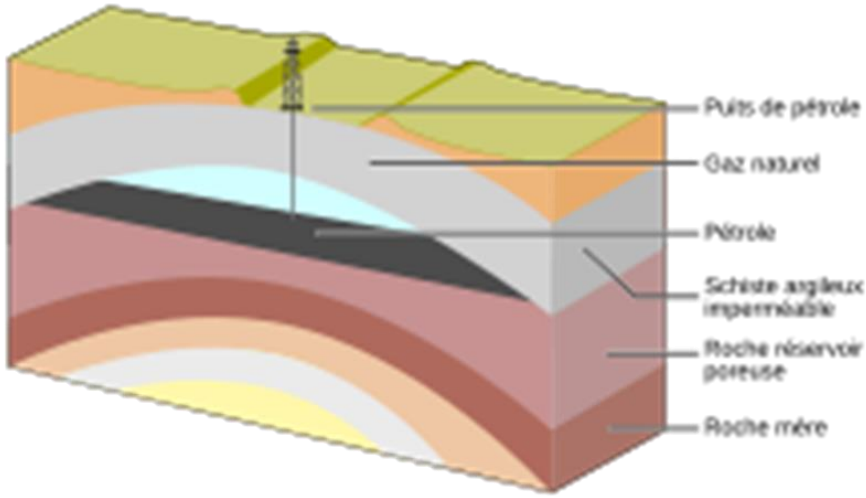
Thermogenic gas

During thermal maturation, each type of organic matter is characterized by different proportions of released products (hydrocarbons and gas).



As for the expelled hydrocarbons, lighter than water, they generally escape to the Earth's surface where they are oxidized or biodegraded (the latter case results in oil sands), but a minimal amount is trapped:

it ends up in a reservoir rock, a permeable zone (usually sand, carbonates, or dolomites) from which it cannot escape due to a covering rock layer, an impermeable barrier (composed of clay, shale, and evaporites), the "trap rock" forming a trap structure.



Petroleum reservoirs

Source rock: Fine-grained sedimentary rock (typically clay-rich) abundant in organic matter, which will generate hydrocarbons.

Migration 3 stages

expulsion from the source rock through compaction

migration to the reservoir by gravity

escape from the reservoir (leakage)

Accumulation   Secondary migration ⇒ Leakage

Concentration: Petroleum stored and concentrated in the reservoir due to the presence of:

A seal rock: impermeable sedimentary rock (clays, evaporites) capable of halting oil migration

A petroleum trap: closed sedimentary or tectonic structure where hydrocarbons will accumulate