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NATURAL STONE

2 - PETROLOGY

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THE THREE CLASSES OF ROCKS

- Igneous (magmatic) rocks
- Sedimentary rocks
- Metamorphic rocks

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Cours de pétrologie magmatique en ligne

http://www.botanic06.com/site/geol/magma1.htm - 17.09.2015

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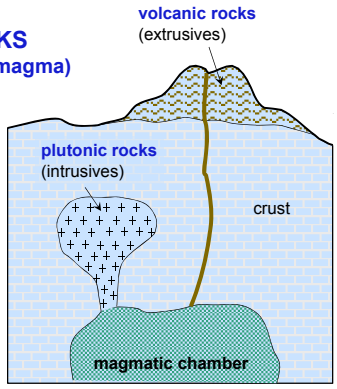
IGNEOUS ROCKS
(= formed from a magma)

Magma : molten rocks (silicate solutions) located in the Earth crust or in the mantel

T ≈ 1200 – 1500° C



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	plutonic rocks	volcanic rocks
magma	granitic	basaltic
origin of the material	crust (metamorphic rocks)	mantel (peridotites)
[SiO_2]	high	low
viscosity	high	low
rocks	intrusives	extrusives
solidification	slow	fast
cristallization	complete	incomplete or non-existent

"Schematic" characterization of the igneous rocks

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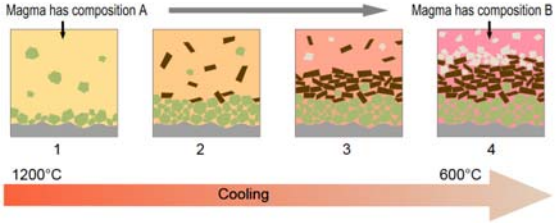
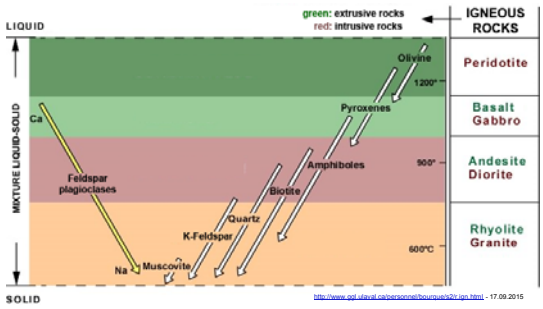
Concept of fractional crystallization

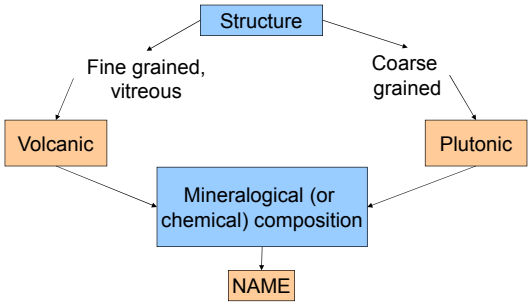


https://fr.wikipedia.org/wiki/Cristallisation_fractionn%C3%A9e_%28g%C3%A9ologie%29 – 17.09.2015

Concept of fractional crystallization



Classification of magmatic rocks



Classification of magmatic rocks

Cardinal minerals (light colours):
- quartz
- Na,K feldspars
- plagioclases (Ca,Na feldspars)
- feldspathoids

Essential minerals (dark colours):
- micas
- amphiboles
- pyroxenes
- olivine

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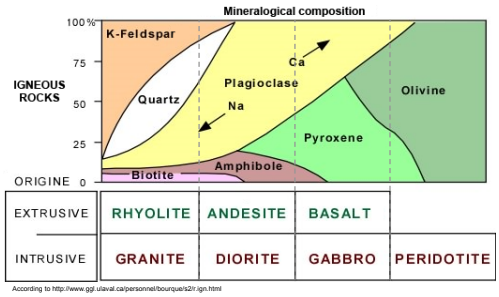
Classification of magmatic rocks (simplified)

----------Light to dark coloured----------→



According to http://www.ggl.ulaval.ca/personnel/bourque/s2/ir.ign.html

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PLUTONIC ROCKS (intrusives)

Some characteristics:

- all the cristals are visible with the unaided eye
- the cristals have no particular orientation
- the porosity is very little or non-existent
- cristals are often well formed (automorphes)

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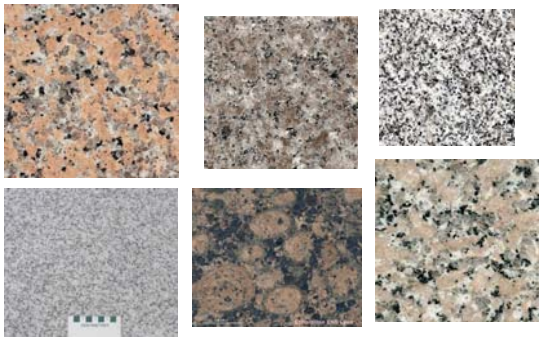
Plutonic rock: granite (≈95% vol.)



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Plutonic rock: diorite




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Plutonic rock: gabbro






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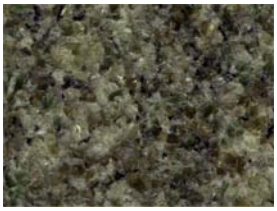
Plutonic rock: peridotite



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VOLCANIC ROCKS
(extrusives)
Effusives and pyroclastics rocks

Some characteristics:

- the matrix is always amorphous, glassy or fine grained
- the porosity can be very high
(vacuoles in pyroclastic rocks => trapped porosity)
- If cristals exist, they can be orientated (=> lava flow)

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Effusive volcanic rocks come from effusive volcanos:



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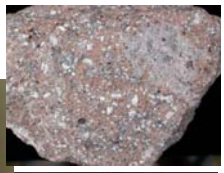
Effusive volcanic rock: rhyolite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Effusive volcanic rock: obsidian (rhyolite)

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Effusive volcanic rock: andesite

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Effusive volcanic rock: basalt (≈90% vol.)

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Basalt columns

Stony materials and conservation of the built heritage – Petrology – BR 22

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Pyroclastic volcanic rocks come from explosive volcanos:

Stony materials and conservation of the built heritage – Petrology – BR 23

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Pyroclastic volcanic rock: bombs, blocs

Stony materials and conservation of the built heritage – Petrology – BR 24

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Pyroclastic volcanic rock: **pumice** *(pierre ponce)*




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THE THREE CLASSES OF ROCKS

- **Igneous (magmatic) rocks**
- **Sedimentary rocks**
- **Metamorphic rocks**

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Cours de sédimentologie et pétrologie sédimentaire:
Prof. Frédéric Boulvain, Uni. Liège Belgique
Cours en ligne:
http://www2.ulg.ac.be/geolsed/sedim/sedimentologie.htm - 17.09.2015

Eléments de Sédimentologie
et de Pétrologie sédimentaire

Stony materials and conservation of the built heritage – Petrology – BR 27

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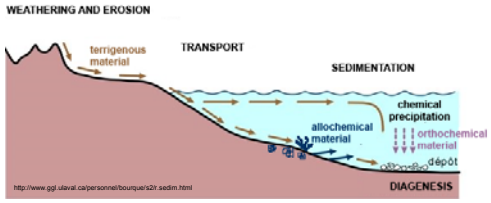
Genesis of the sedimentary rocks

Processes: weathering, transport, sedimentation, diagenesis



Material: terrigenous, allochemical (shells, skeleton,... from the sedimentary basin) orthochemical (chemical precipitation within the sed. basin)

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Weathering and erosion

mechanical: mechanical disintegration (freez/thaw, roots of plants)

chemical: the minerals in imbalance with the atmospheric conditions are easily attacked (high temperature minerals or minerals with high solubility)

biochemical: plants take the elements they need from the minerals of the rocks

These 3 mechanisms => erode the preexisting rocks and produce debris of all dimensions

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Sediment transport

Transporting mediums: rivers, glaciers, wind, ocean currents and tides (*marées*).

During transportation, edges are smoothed.

Depending on the medium and the energy, transport can last a few hours to several days/weeks/months/years

Deposition occurs when the speed of the transporting medium becomes insufficient to maintain the particles in suspension

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Sedimentation

The transported material accumulates in a **sedimentary basin** in the form of successive layers whose composition, size of the particles, colour, etc, vary in time => **stratifications** (cf Gd Canyon, Jura,)

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Sedimentation

Vosgien sandstone
(Vosges Mountains, France)

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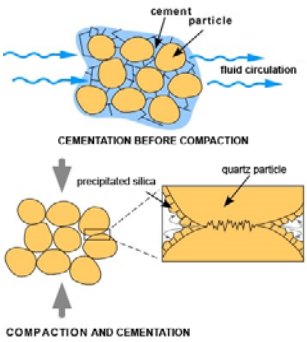
Diagenesis: transformation of a sediment into a hard rock

Chemical and mechanical processes which modify a sedimentary deposit after its deposition (dehydration, burying, compaction, dissolutions, recrystallizations, neo-formations, cementation)



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Identification criteria of the sedimentary rocks

Stratification:

sedimentary rocks are mostly laminated

(except reef limestone, tuf limestone, glacial moraines)

Fossil content:

presence of substances or objects related to the living world (the hard parts of animals, plants footprints, holes, signs of grazing *(pacage)* or locomotion)

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Classification of sedimentary rocks

The classification is based on the formation process.

The subdivisions are based on the chemical composition, the mineralogy or again on the formation process.

(Several classifications exist)

- **Clastic sedimentary rocks** *(roches détritiques)*
- **Biogenic/organic sedimentary rocks** *(roches biogéniques ou biochimiques)*
- **Chemical sedimentary rocks** *(évaporites)*

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CLASTIC SEDIMENTARY ROCKS

Composed of fragments of materials derived from other rocks (original rock can be **easily identified**). Largely composed of **quartz** with other common minerals (feldspars, amphiboles, clay minerals,…)

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Clastic sedim. rocks / *roches sédim. détritiques*

Coarse grains (>2mm)	Rounded clasts (of any rock type)	CONGLOMERATS S.L.	**Conglomerate** *(poudingue)*
	Angular clasts (of any rock type)		**Breccia** *(brèche)*
Fine grains (63µm to 2mm – can be seen / naked eye)	Quartz +/- feldspars, micas, clay minerals – Sandpapery feel and scratches glass	GRÈS	**Sandstone** *(grès)*
Very fine grains (<63µm – cannot be seen / naked eye)	Quartz + clay minerals	PÉLITES S.L.	**Siltsone** *(pélite)*
	Clay minerals – non laminated		**Mudstone** *(argilite)*
	Clay minerals –laminated		**Shale** *(shale)*

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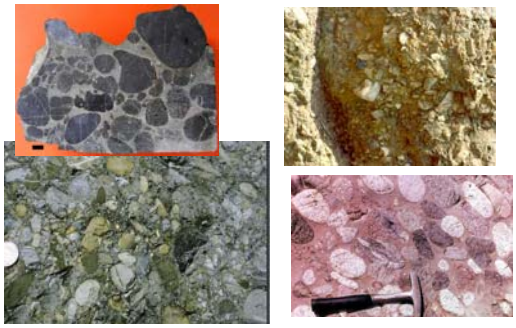
Clastic sedim. rocks / **conglomerate** *(poudingue)*



Ex. near Lausanne: the poudingue from the Mont Pelerin

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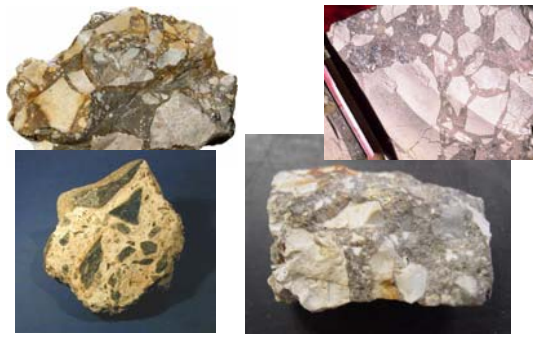
Clastic sedim. rocks / **breccia** *(brèche)*



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Clastic sedim. rocks / sandstone *(grès)*

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Clastic sedim. rocks / a kind of sandstone: the molasse sandstone *(molasse = grès molassique)*

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Clastic sedim. rocks / siltstone *(pélite)*

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Clastic sedim. rocks / mudstone *(argilite)*

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Clastic sedim. rocks / shale *(shale)*

Stony materials and conservation of the built heritage – Petrology – BR /44

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Biogenic sedim. rocks
= organic or biochemical origin rocks

Carbonate rocks: biogenic sedimentary rocks that contain carbonate minerals generated by living organisms (corals, molluscs, foraminifera,…):
limestones *(calcaires)*, **dolostones** *(dolomies)*

Other organic rocks:
- **Siliceous** biogenic rocks : **diatomite**, **flint** *(silex), …*
- **Carbonaceaous** rocks : **coal**, **oil, petroleum**…
- **Phosphates** rocks

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Biogenic sedim. rocks / biological

CARBONATE STONES (roches carbonatées)			
Mostly calcite ($CaCO_3$) Fizzes with cold dilute HCl (10%)	Muddy matrix with fossils	CALCAIRES s.l.	**Fossiliferous limestone** *(calcaire fossilifère)*
	Shells or shell fragments (>2mm) poorly cemented => porous rock		**Coquina** *(calcaire coquiller/ lumachelle)*
	Shells or shell fragments (<63µm) poorly cemented => porous rock		**Chalk** *(craie)*
	Shells or shell fragments (<4µm) well cemented => dense rock		**Micrite** *(calcaire micritique)*
Mostly dolomite $CaMg(CO_3)_2$ Fizzes with hot dilute HCl (10%)	Muddy matrix with or without fossils	DOLOMIES s.l.	**Fossiliferous (or not) dolostone** *(dolomie fossilifère ou non)*

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Biogenic sedim. rocks / **limestone** *(calcaire)*

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Biogenic sedim. rocks / **dolostone** *(dolomie)*

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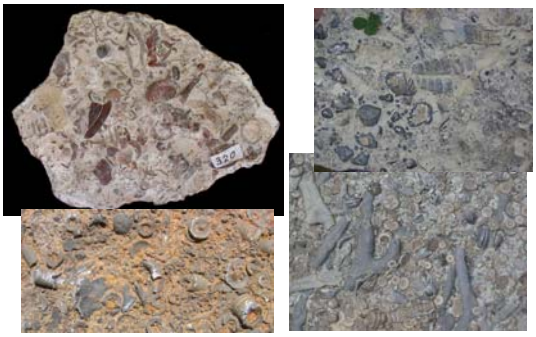
Biogenic sedim. rocks / fossiliferous limestone



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Biogenic sedim. rocks / coquina *(calcaire coquiller ou lumachelle)*

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Biogenic sedim. rocks / chalk (made of coccolithophore)

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Biogenic sedim. rocks / Coccolithophore (plankton)

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Biogenic sedim. rocks / micrite

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Biogenic sedim. rocks / biological

SILICEOUS STONES		
Mostly quartz (SiO_2) scratches glass	Made of radiolarians, red or green coloured, dense, alternation of dark and bright layers	**Radiolarite**
Mostly quartz (SiO_2) scratches glass	Made of diatoms, light coloured, extremely light weight, friable	**Diatomite**

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Biogenic sedim. rocks / radiolarite
(made of radiolarians)

http://www.praehistorische-lithothek.de / 18.09.2014

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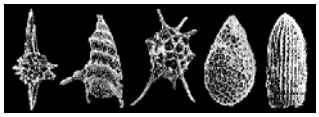
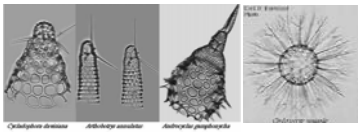
Biogenic sedim. rocks / radiolarians (plankton)



Fossilized radiolarians
x 150

Today's radiolarians
x 150



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Biogenic sedim. rocks / diatomite
(made of diatoms)

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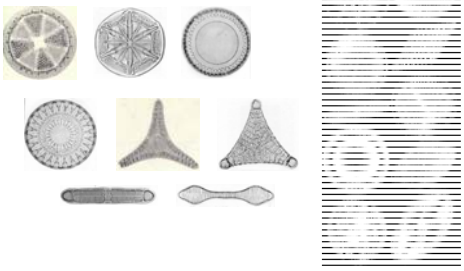
Biogenic sedim. rocks / diatoms (plankton)



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Biogenic sedim. rocks / biological

CARBONACEOUS STONES (roches carbonées)		
Dull brown and plant-like	Porous and easy to break apart in plant fragments	**Peat** *(tourbe)*
	Woody appearance, light weight	**Lignite**
Highly altered plant remains (carbon)	Black, dense and brittle or porous and sooty	**Bituminous coal** *(charbon bitumineux)*

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Biogenic sedim. rocks / peat *(tourbe)*

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Biogenic sedim. rocks / lignite

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Biogenic sedim. rocks / bituminous coal

(charbon bitumineux)

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Chemical sedimentary rocks *(évaporites)*

Chemical rocks are mineral sediments
- that result from the evaporation of surficial oversaturated water or
- that precipitated from mineralized oversaturated solutions.

This usually happens in an arid environment with a small sedimentary basin fed by a limited input of water (evaporites: **halite, gypsum**,…) or in an environment where water undergoes drastic modifications of pressure/temperature conditions (**stalactite, stalagmite, travertine,…**).

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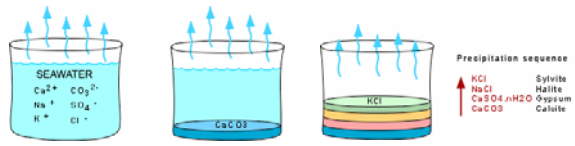
Evaporites

Minerals precipitate out of solution in the reverse order of their solubilities. For ex., the order of precipitation from sea water is:

1. Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$)
2. Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$).
3. Halite (NaCl)
4. Potassium and magnesium salts



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Chemical sedimentary rocks

Mostly calcite ($CaCO_3$) Fizzes with cold dilute HCl	Spherical grains like tiny beads with concentric laminations	**Oolitic limestone** *(calcaire oolitique)*
	Banded	**Travertine**
	Highly porous, recognizable plant debris (mosses, twigs, leaves) and / or angular gravel	**Tuf limestone**
Very fine grained Chalcedony (SiO_2)	Light coloured, scratches glass	**Chert** *(chaille)*
	Dark coloured, scratches glass	**Flint** *(silex)*
Fine to coarse cristalline gypsum ($CaSO_4.2H_2O$)	Can be scratched with fingernail	**Rock Gypsum** *(pierre à plâtre)*
Fine to coarse cristalline halite (NaCl)	Salty taste	**Rock Salt** *(roche saline)*

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Chemical sedim. rocks / oolitic limestone

(calcaire oolitique)

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Chemical sedim. rocks / **travertine** *(travertin)*

Roman travertine (Italy)

Travertin Gerdoo'i (Iran)

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Chemical sedim rocks / **travertine** *(travertin)*

Hot Springs at Pamukkale, Turkey

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Chemical sedim rocks / **tuf limestone** *(tuf calcaire)*

Tuf from Corpataux, Escaliers du court chemin, Fribourg

Chemical sedim. rocks / tuf limestone
(tuf calcaire)

Beaume-les-Messieurs, France, Jura

Chemical sedim rocks / chert *(chaille)*

Chemical sedim. rocks / flint *(silex)*

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Chemical sedim. rocks / rock gypsum

(pierre à plâtre)

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Chemical sedim. rocks / rock salt

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THE THREE CLASSES OF ROCKS

- Igneous (magmatic) rocks
- Sedimentary rocks
- Metamorphic rocks

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Metamorphic rocks

A metamorphic rock is the result of the **transformation of a pre-existing rock** type (protolith), in a process called metamorphism. The protolith is subjected to **heat, extreme pressure and tectonic movements** causing profound physical and/or chemical change. Protolith = sedimentary rock, igneous rock or another older metamorphic rock.

Metamorphims ("change in form") = **solid state** recrystallisation of pre-existing rocks due to changes in heat and/or pressure and/or introduction of fluids **without melting**. There will be mineralogical, chemical and crystallographic changes

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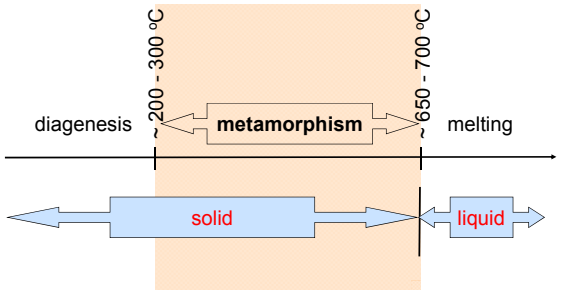
Limits of the metamorphism



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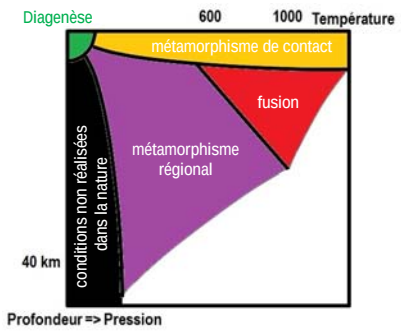
Conditions of the metamorphism



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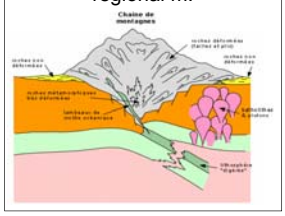
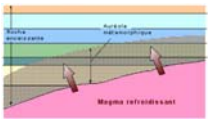
Types of metamorphism

regional m.



contact m.



shock m.

Meteor Crater in Arizona

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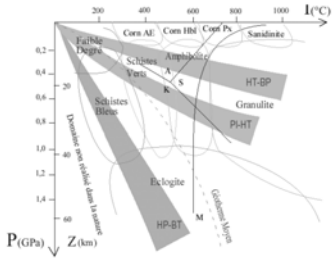
Cours métamorphisme en ligne :
http://christian.nicollet.free.fr/page/enseignement/licencemetam.html - 17.09.2015

Cours métamorphisme en pdf:
http://christian.nicollet.free.fr/page/Publications/encycl.pdf - 17.09.2015



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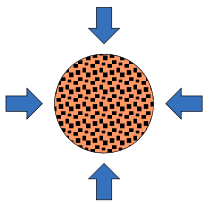
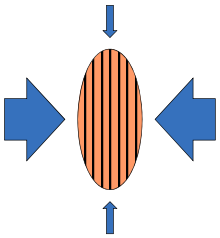
Orientated or not orientated structures?



Deep in the crust
=> isotropic strain
=> no orientated structures



Near the surface
=> anisotropic strain
=> orientated structures

but always very low porosity

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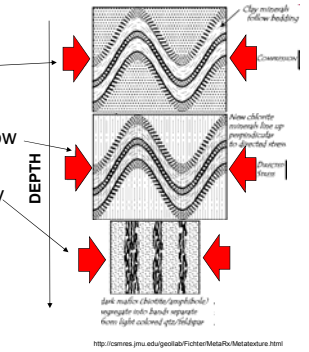
Orientated or not orientated structures?

In the compression zones:

- **at a shallow depth:** only **fold deformation**
- **at a medium depth:** fold deformation + mechanical flow = **schistosity** *(schistosité)*
- **at a high depth:** schistosity + alternations of distinct mineral beds = **gneisocity** *(foliation)*
- **at a very high depth:** no orientated structure



http://csmres.jmu.edu/geollab/Fichter/MetaRx/Metatexture.html

Classification of metamorphic rocks (simplified)

Schistosity *(schistosité)*	Clay minerals, micas	Dense, easy to split into thin sheets	**Slate** *(ardoise)*
	Micas, chlorite, talc, garnet, kyanite, staurolite, feldspars, quartz, tourmaline,…		**Schist** *(schiste)*
Gneisocity *(foliation)*	Feldspars, quartz, micas, ferromagnesian minerals – Color banded		**Gneiss**
Non foliated, non orientated grains	Calcite ($CaCO_3$)	Fizzes with dilute HCl	**Marble**
	Dolomite $(Ca,Mg)(CO_3)_2$	Fizzes with dilute HCl only when powdered	**Dolomitic marble**
	Quartz (SiO_2)	Scratches glass	**Quartzite**
	Amphiboles	Generaly black prismatic crystals (2 cleavages 60°/120°)	**Amphibolite**

Metamorphic sequences

Séquences	Roches initiales	Roches métamorphiques (métamorphisme croissant)
pélitique	pélites, argilites	schistes -> micaschistes -> gneiss -> leptynites
arénacée	grès, arkoses	quartzite -> gneiss -> leptynites
calcaropélitique	marnes	micaschistes à mnx -> amphibolites -> pyroxénites
carbonatée	calcaires et dolomites	calcschistes -> marbres -> cipolins
granitique	granitoïdes et laves analogues	(protogine) -> gneiss -> leptynites
basique	diorite, gabbros, basaltes	schistes -> prasinites -> amphibolites -> pyroxénites

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Metamorphic rocks / Slate *(ardoise)*

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Metamorphic rocks / schists

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Metamorphic rocks / schists: serpentinite

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Metamorphic rocks / Gneiss

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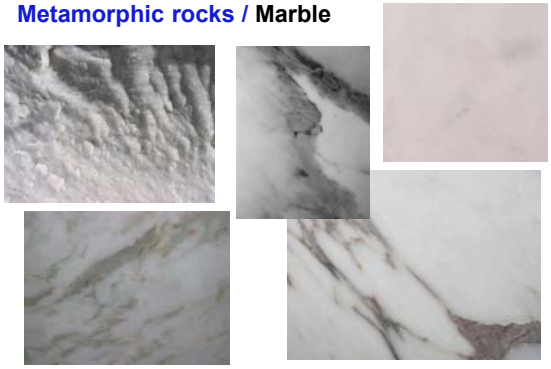
Metamorphic rocks / Marble



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Metamorphic rocks / Quartzite

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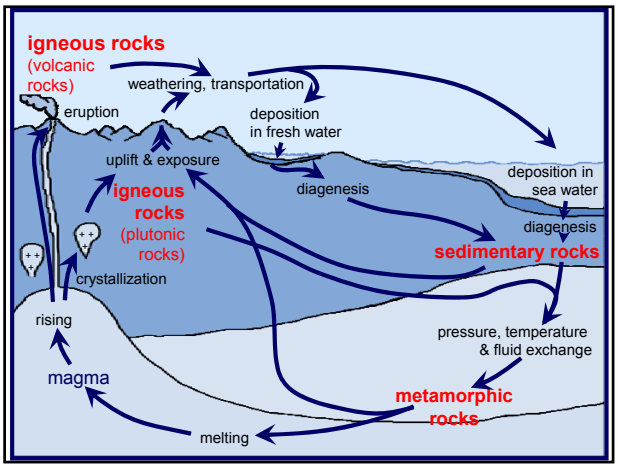
igneous rocks
(volcanic
rocks)
weathering, transportation
eruption
deposition
in fresh water
uplift & exposure
deposition in
sea water
diagenesis
igneous
rocks
(plutonic
rocks)
diagenesis
sedimentary rocks
crystallization
rising
pressure, temperature
& fluid exchange
magma
metamorphic
rocks
melting