



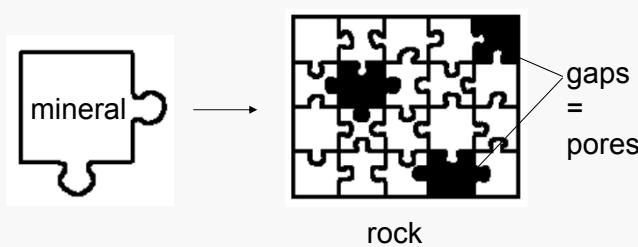
# NATURAL STONE

## 1 - MINERALOGY



### Definitions

**Natural Stone = Rock** = natural material constituting the crust and mantle. Generally, it is solid ( $\neq$  unconsolidated sediments like sand) and made of aggregate of **minerals** more or less closely knitted together (gaps = pores)





## Definitions

**Mineral** = **inorganic** natural compound (although some of them may be bioproducts like apatite, calcite, oxalates...) with a **definite chemical composition**, an **atomic structure** and **physical properties** of its own.  
Generally, it is **solid** ( $\neq$  mercury)

**Cristal** = **homogeneous solid** composed of atoms, ions or molecules with an **organized arrangement** that is **repeated periodically** in three dimensions of space  
(cristal  $\neq$  amorphous compounds)



## Classification of minerals

According to chemical composition and crystal structure.

Example: Nickel-Strunz Classification - 10th edition  
(system adopted by the International Mineralogical Association):

1. **Native elements** (C, S, Au, Ag, Cu, Bi, As, Sb,...)
2. **Sulfides** ( $S^{2-}$ ) and **sulfosalts** (selenides, tellurides, ...)
3. **Halides** ( $Cl^-$ ,  $F^-$ ,...)
4. **Oxides** ( $O^{2-}$ ), **hydroxides** ( $OH^-$ )
5. **Carbonates** ( $CO_3^{2-}$ ), **nitrates** ( $NO_3^-$ )
6. **Borates** (borax,...)
7. **Sulphates** ( $SO_4^{2-}$ ) (+ thiosulfates, chromates, molybdates,...)
8. **Phosphates** ( $PO_4^{3-}$ )
9. **Silicates** ( $(Si,Al)_xO_{2x}+/-alk.$  and alk. earth met.)
10. **Organic compounds** (formates, oxalates, acetates, hydrocarbons, amber...)



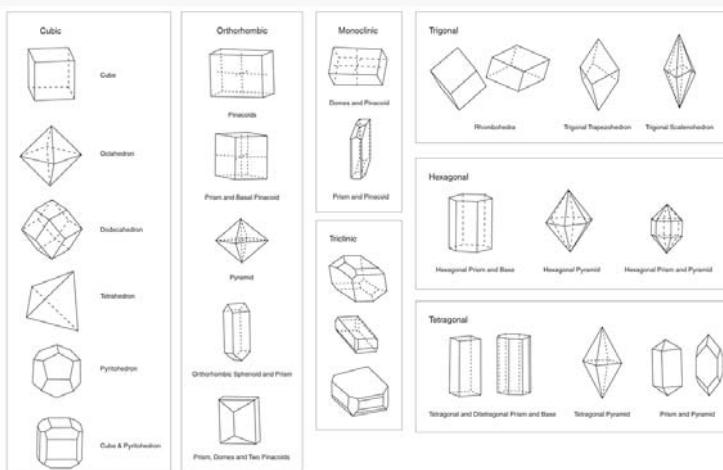
## The identification criteria of minerals

**Cleavage / fracture:** in some minerals, bonds between layers of atoms aligned in certain directions are weaker than bonds between different layers. In these cases, breakage occurs along smooth, flat surfaces parallel to those zones of weakness



## The identification criteria of minerals

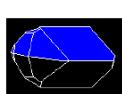
**Crystal shape:**  
the 7 crystal systems



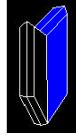


## The identification criteria of minerals

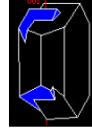
**Twinning (macle):** Crystal twinning occurs when two separate crystals share some of the same crystal lattice points in a symmetrical manner. The result is an intergrowth of two separate crystals in a variety of specific configurations.



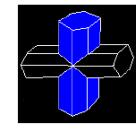
microcline



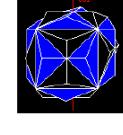
gypse



orthose



staurolite



pyrite



## The identification criteria of minerals

**Density:** physical constant ( $2.7 \text{ g/cm}^3$  for silicates)

**Colour:** not a differential criteria

**Streak (trait):** colour of the powder, more reliable than the colour of the mineral itself (Scratch unglazed porcelain => This only works for minerals which are softer than a ceramic tile (hardness  $\sim 7$ ))

**Luster (éclat):** aspect of the surface mineral when it reflects light

**Flam test:** the color of flames depends on the chemical composition (Ca: red, Na: yellow, Cu: blue or green, K: violet...)



## The identification criteria of minerals

**Hardness:** Mohs scale of relative mineral hardness



## The identification criteria of minerals

**Reaction with dilute HCl (10%):**

carbonates + HCl 10% => emission of CO<sub>2</sub> = effervescence  
(calcite (CaCO<sub>3</sub>) fizzes readily in either massive or powdered form, but dolomite (Ca,Mg(CO<sub>3</sub>)<sub>2</sub>) reacts best as a powder or with heated acid)

**Touch**

**Flavour**

**Smell**

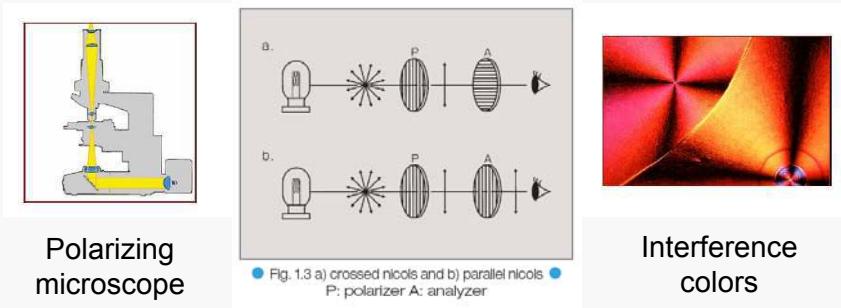
**Radioactivity**

**Magnetism,...**



## The identification criteria of minerals

## Optical properties:



**For more details, see for ex.:**  
[http://www.olympusamerica.com/files/seg\\_polar\\_basic\\_theory.pdf](http://www.olympusamerica.com/files/seg_polar_basic_theory.pdf) (english)  
<http://www.kasuku.ch/pdf1.php# a microscope> (french)



Additional document on <http://www.csc-sarl.ch>:

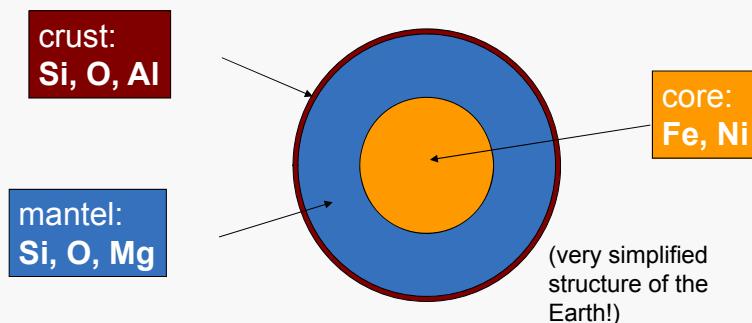
(under the schedule)

**Table of minerals** (from Dr Jan-Michael Lange of the Senckenberg Natural History Museum in Dresden, adapted by Dr Christine Bläuer of CSC, Fribourg)





## Distribution of elements within the earth

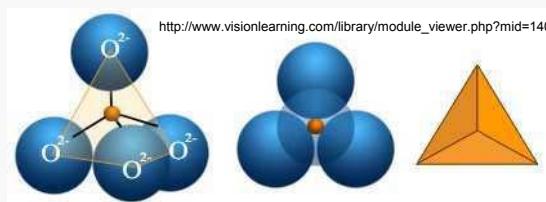


➔ silicates (& other light minerals) are the most abundant minerals in the earth's surface



## The silicate class

The silicates are the largest, the most interesting and the most complicated class of minerals. ≈ 30% of all minerals are silicates and 90% of the Earth's crust is made up of silicates.



The basic chemical unit of silicates is the  $(\text{SiO}_4)$  tetrahedron shaped anionic group **with a negative four charge (-4)**.  
**But a mineral must be neutral !!!**



## The silicate class - Neutralization of charges...

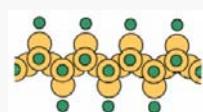
- with cations :



- polymerization with sharing the O<sup>2-</sup> anions :



- combining the two previous solutions :



## The silicate class - The 6 groups of silicate minerals

<b>Nesosilicates</b>  $(\text{SiO}_4)^{4-}$ ex.: olivine, garnet, zircon,...	<b>Sorosilicates</b>  $(\text{Si}_2\text{O}_7)^{6-}$ ex.: epidote,...	<b>Cyclosilicates</b>  $(\text{Si}_3\text{O}_{10})^{12-}$ ex.: beryl, tourmaline,...
<b>Inosilicates</b>  $(\text{SiO}_3)^{2-}$ ex.: pyroxene, amphibole,...	<b>Phyllosilicates</b>  $(\text{Si}_2\text{O}_5)^{2-}$ ex.: mica, clay,...	<b>Tectosilicates</b>  $(\text{SiO}_4)^0$ ex.: quartz, feldspar,...



**Additional document on  
<http://www.csc-sarl.ch>:**  
(under the schedule)  
**Structure of a few silicate minerals**



LES SILICATES		O et Si sont les éléments les plus abondants de la croûte et du manteau. Ils s'associent pour former des tétraèdres $[Si_4O_10]^{4n-}$ .	
NÉOSILICATES Tétraèdres isolés $[Si_4O_10]$			
Péridot Fayalite		Mg <sub>2</sub> SiO <sub>4</sub> Fe <sub>2</sub> SiO <sub>4</sub>	O Mag bas O et ultrabas
Kükürt d'olivine			
Andalousite			O Met
Sillimanite		Al <sub>2</sub> SiO <sub>5</sub>	O Met
Dunite		T	Met
Isomorphie		$(Al_2O_5)_x(SiO_4)_y(OH)_z$	M Met
Chloroïde		$(Fe_2Mg_2)_x(Al_2)_y(SiO_4)_z(OH)_w$	C Met
Genthis		$R^2+R^3+T^2O_2$	C Met, Mag
ou $R^2+R^3+Fe^{2+}, Mg^{2+}, Mn^{2+}, Cu^{2+}$			ultrabas.
SOROSILICATES Tétraèdres groupés par deux $[Si_4O_10]^2$			
Épidote		$R^2+Ca_2Si_2O_7(OH)_2$	O Met
Pérovskite		$R^2+TiO_2$	M Met
Zoisite		$R^3+Al^3+$	O Met
Clinozoisite			M Met
Lavevane		$CaAl_2Si_2O_7(OH)_2\cdot H_2O$	O Met
Pseudoleïte		$(Al_2O_5)_x(Ti_2O_5)_y(Ca_2Al_2Si_2O_7)_zH_2O$	M Met
CYCLOSILICATES Tétraèdres en anneaux de 3, 4, 6 ou plus.			
Corindon		$(Fe,Mg)_xAl_2Si_3O_10$	O Met, Mag
Tourmaline		$Na(Mg,Fe,Mn)_xAl_2Si_3O_10$	R Met, Mag
Beryl		$(Be_2Al_2)_xSi_3O_10$	H Mag, Met
INOSILICATES Tétraèdres en chaînes			
► Pyroxénites Chaine simple de tétraèdres, période 2 : $[Si_4O_10]^{10}$			
Orthopyroxénite		$Mg_2Si_2O_5$	O Mag, Met
Enstatite			
Hypersthène			
Olivine		$Fe_2Si_2O_5$	
Clinoxyroxénite			
Diopside		$CaMgSi_3O_10$	M Mag, Met
Augite			
Hedenbergite		$CaFeSi_3O_10$	
Agricrite		$NaFeSi_3O_10$	
Idocrase		$NaMgSi_3O_10$	
Ampibolites			
Chaine double de tétraèdres, période 2 : $[Si_4O_10]^{10}$			
Anorthopilité		$(Mg,Fe)_xSi_2O_5Si_2O_7(OH)_2$	O Mag
Tremolite		$Ca_2Mg_5Si_8O_{22}(OH)_2$	M Mag
PHYLLOSILICATES Tétraèdres en couches			
Palygorskite		$Al_2Si_4O_10(OH)_2$	M Met
Talc		$Mg_3Si_4O_10(OH)_2$	M Met
Micas			
Muscovites		$KAl_3Si_3O_10(OH)_2$	M Met, Mag
Biotites		$K_2Fe_3Al_2Si_3O_10(OH)_2$	M Met, Mag
Chalcocite		$(Mg,Fe)_xAl_2Si_3O_10(OH)_2\cdot 3Mg(OH)_2$	M Mag, Met
Argiles		$Al_2Si_4O_10(OH)_2$	14.2 Å M Sed
Kaolinite			
ILLITES Tétraèdres non liés à d'autres tétraèdres			7.1 Å M Sed
Montmorillonite		$K_2Al_3Si_3O_10(OH)_2\cdot Na_2Mg_3Si_8O_{22}(OH)_2$	H Mag, Met
Vermiculite		$Al_2Mg_3Si_8O_{22}(OH)_2\cdot Al_2O_3(OH)_2\cdot Mg_3(OH)_2\cdot Al_2O_3$	M Mag, Met
Serpentes		$Mg_3Si_4O_10(OH)_2$	14.2 Å M OMag
TECTOSILICATES Tous les tétraèdres sont liés à d'autres tétraèdres			
Quartz		$Si_2O_5$	O Met, Mag, Met, Sed
Tridymite			H Mag
Crystobalite			C Mag, Met
Cotunnite			M Imp
Epidote			
Feldspaths			
Orthose		$KAl_3Si_3O_10$	M Mag, Met, Sed
Albite		$NaAl_3Si_3O_10$	T
Plagioclases			
Abrite		$NaAl_3Si_3O_10$	T Mag, Met, Sed
Anorthite		$CaAl_3Si_3O_10$	T Mag, Met, Sed
Feldspathoïdes			
Nepheline		$Na_2K_2Al_3Si_3O_10$	H Mag
Leucite		$KAl_3Si_3O_10$	H/C Mag
Apatite		$Ca_3Si_4O_10(OH)_2$	O M-C Mag, Met, Sed
Lamprophyre		$CaAl_3Si_3O_10\cdot H_2O$	O Met
Asialcime		$Ca_2Si_3O_10(OH)_2$	C Mag

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## Minerals and rocks

### Cardinal minerals:

60 to 70% of the rock (usually white or slightly colored)  
*quartz, feldspars, feldspathoids, calcite*

### Essential minerals:

20 to 25% of the rock (often dark)  
*micas, amphiboles, pyroxenes, olivine,...*

### Accessory minerals:

5 to 10% of the rock  
*oxides, sulfides,...*



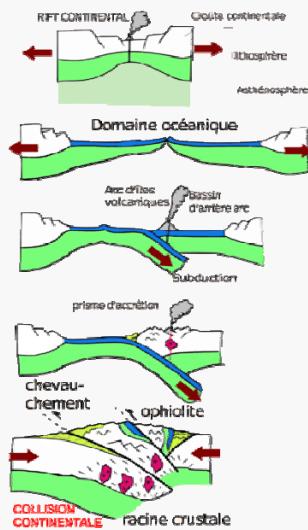
## Genesis of minerals and rocks

### Endogenous genesis (in depth)

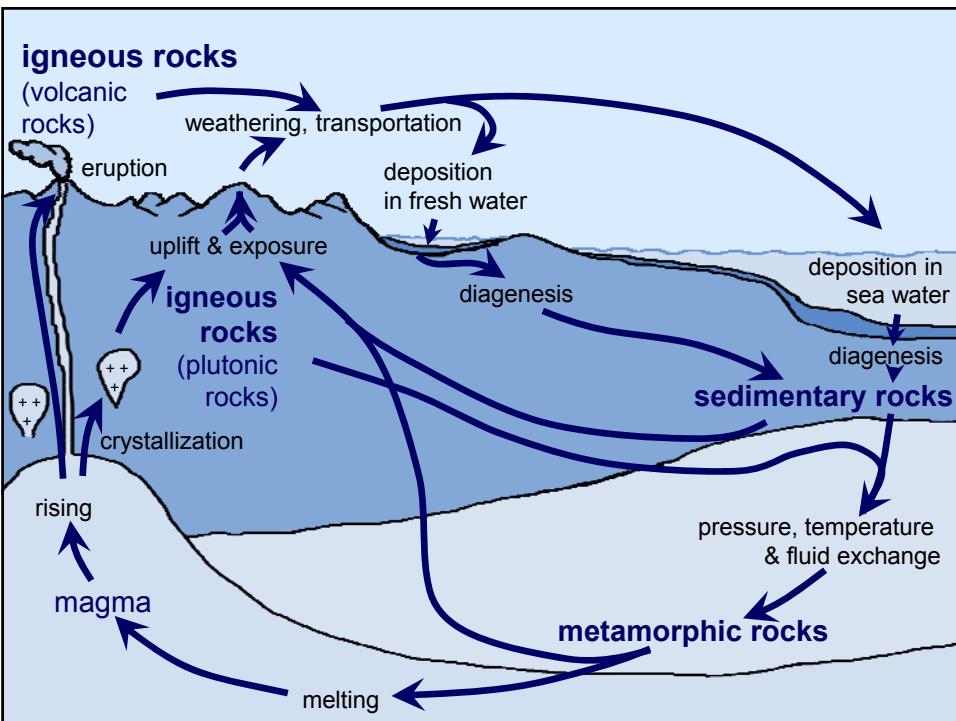
- **magmatic process:** coming from a magma
- **metamorphic process:** transformation of pre-existent mineral materials

### Exogenic genesis (at the surface)

- **sedimentary process:** pre-existent mineral materials transformation and/or neo-formation



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**Nesosilicates / Garnets** ( $X_3^{2+}Y_2^{3+}[SiO_4]_3$ )









*Use: gemstone, abrasive*

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**Inosilicates / Amphiboles**

**Brown asbestos: Amosite** ( $(Fe_7Si_6O_{22}(OH)_2)$ )











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**A few silicate minerals**



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**Inosilicates / Amphiboles**

**Bleu asbestos: Crocidolite** ( $(Na_2(Fe,Mg)_6Si_8O_{22}(OH)_2)$ )











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**Phyllosilicates / Micas**

**Muscovite**  $(\text{KAl}_2[(\text{OH},\text{F})_2](\text{AlSi}_3\text{O}_{10}))$  white mica.

**Biotite**  $(\text{KMg}_2(\text{Fe}^{2+},\text{Mn}^{2+})_3[(\text{OH},\text{F})_2](\text{Al}_2\text{Si}_3\text{O}_{10}))$  black/brown mica

**Use:** Heat, acoustic and electric insulator, paints





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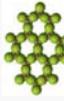
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**Phyllosilicates / Clay minerals**

**Montmorillonite**  $((\text{Na,Ca})_{0.6}(\text{Al,Mg})_2\text{Si}_3\text{O}_{10}(\text{OH})_2,\text{nH}_2\text{O})$

Swelling clay mineral exchanger of ions

**Use:** gastric plaster, cleaner of greases (Terre de Sommières), bentonite, container for the nuclear waste





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**Inosilicates / Amphiboles**

**Green asbestos. ex. : Actinolite**

$(\text{Ca}_2(\text{Mg},\text{Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2)$




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**Phyllosilicates / Clay minerals**

**Kaolinite**  $(\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4)$

**Use:** porcelain manufacture, filler in papers





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**Phyllosilicates / Chlorites**

$(\text{Mg},\text{Fe},\text{Mn},\text{Al})_6(\text{Si},\text{Al})_4\text{O}_{10})(\text{OH})_8$

**Use:**  
decorative stone

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**Tectosilicates / Quartz**

$(\text{SiO}_2)$

**Use:**  
Piezoelectric  
(clock industry, ...)  
and...

gemstones (amethyst, citrine) ...  
cryptocrystalline varieties: flint,  
agate, onyx, carnelian,  
jasper, opal

amethyst

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**Phyllosilicates / Clay minerals**

**Talc**  $(\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2)$

**Use of talc:**  
cosmetic,  
lubricant,  
manufacture of  
paper, excipient  
and lubricant in  
the  
pharmaceutical  
industry, tailor's  
chalk

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**Phyllosilicates / Serpentinites**

**White asbestos: Chrysotile**  $(\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4)$

**Use:** reinforced cement,  
machine parts under  
friction, joints for high  
temperature machines...  
because non flammable,  
imputrescible, flexible,  
resistant to the majority of  
chemicals and with a high  
breaking stress => majority  
of the world market of  
asbestos

<http://www.ec.gc.ca/nop/pdfs/consult/Rotterdam/cnfchrysotileBC.pdf>

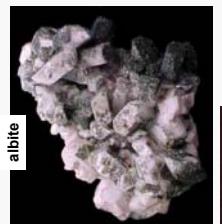
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## Tectosilicates / Feldspars

### Plagioclases $(\text{AlSi}_3\text{O}_8)(\text{Ca}, \text{Na})$








*Use:* ceramics, porcelain, glass, bricks, soaps, scouring powders, gemstones

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## A few non silicate minerals



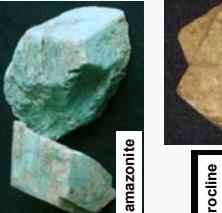
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## Tectosilicates / Feldspars

### K-feldspars $(\text{KAlSi}_3\text{O}_8)$








*Use:* ceramics, porcelain, glass, bricks, soaps, scouring powders, gemstones

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## Tectosilicates / Feldspathoids

### Lazurite $(\text{Na}, \text{Ca})(\text{Al}, \text{Si})_2\text{O}_4\text{S}_2\text{FeS} \cdot \text{CaCO}_3$






*Use:* gemstone, blue pigment

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**Carbonates / Azurite** ( $2\text{CuCO}_3\text{Cu}(\text{OH})_2$ )

Use: blue pigment, gemstone

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**Carbonates / Cerussite** ( $\text{PbCO}_3$ )

Use: cosmetic (in the past since antiquity); white pigment (= white lead)

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**Carbonates / Calcite** ( $\text{CaCO}_3$ )

Use: white pigment (calcite as chalk used since prehistory), raw material of lime

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**Carbonates / Malachite** ( $\text{CuCO}_3\text{Cu}(\text{OH})_3$ )

Use: green pigment, gemstone

polished roller

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**Sulfates / Gypsum** ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )

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Use: raw material of plaster; fertilizer and soil conditioner, Tofu coagulant, blackboard chalk

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**Sulfates / Gypsum** ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )

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Danger: coming from the air pollution, the stone itself or from cements => degrading stones

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**Sulfates / Gypsum** ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )      *Selenite (= pierre de lune)*

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Use: raw material of plaster; fertilizer and soil conditioner, Tofu coagulant, blackboard chalk

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**Sulfates / Gypsum alabaster** ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )

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Use: decorative stone

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### **Halides / Halite (NaCl)**

*Use:* table salt, road salt

*Danger for building stones:* crystallisation damp patches

Halite

2 cm

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### **Halides / Fluorite (CaF<sub>2</sub>)**

*Use:* manufacture of hydrofluoric acid, enamels, glass fibre; used as camera lens; purple pigment; gemstone

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### **Sulfates / Barite (BaSO<sub>4</sub>)**

*Use:* major source of barium, white pigment (blanc fixe), used in paper or paint manufacturing, radiography, heavy filler

1 cm

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### **Halides / Sylvite (KCl)**

*Use:* fertilizer, substitute for table salt, lethal injection

*Danger for building stones:* crystallisation, damp patches

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**Oxides / Goethite ( $\text{FeO(OH)}$ )**

Use: yellow pigment

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**Oxides / Corundum ( $\text{Al}_2\text{O}_3$ )**

Use:  
abrasive;  
gemstones

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**Oxides / Hematite ( $\text{Fe}_2\text{O}_3$ )**

Use: red pigment;  
gemstone

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**Oxides / Rutile ( $\text{TiO}_2$ )**

Use: white pigment  
(artificial); manufacture  
of paints; +/- in  
gemstones

## Oxides / Massicot (or litharge) ( $PbO$ )



Use: yellow pigment, manufacture of glass, of oils and varnishes (desiccant), production of insecticides

## Sulfides / Pyrite ( $FeS_2$ ) (= fool's gold)



Use: production of sulfur dioxide for paper industry or manufacturing of sulfuric acid

"Dangers" in building  
oxidation makes it dangerous in aggregates of concrete; rust patches on stones (marble, sandstones,...)

## Oxides / Minium ( $Pb_3O_4$ )



Use: red pigment, manufacture of glass, protecting paint against the corrosion of metals

## Sulfides / Galena ( $PbS$ )



Use: black pigment, cosmetic (khol), semiconductor in old wireless systems

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**Sulfides / Orpiment (As<sub>2</sub>S<sub>3</sub>)**

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**Use:** yellow pigment, production of semiconductors and photoconductors, fireworks

**Problems:** incompatible with pigments like lead and copper-based; it blackens in contact with the air



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**Phosphates / Apatite (Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>(OH, F, Cl))**

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**Use:** fertilizer; gemstone; new stone consolidant



Stony materials and conservation of the built heritage – Natural Stone \_Mineralogy\_ BR /57



**Sulfides / Realgar (As<sub>2</sub>S)**

Conservation Science Consulting Sàrl

**Use:** red pigment; fireworks

**Problems:** unstable with light ( $\Rightarrow$  yellow pararealgar)



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**Sulfides / Cinnabar (HgS)**

Conservation Science Consulting Sàrl

**Use:** red pigment, medicine, drug, food dye

**Problems:** it blackens in contact with the air



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**Elements / Silver (Ag)**

Conservation Science Consulting Sàrl

Use: noble metal; decorative metal; printed circuits; electrical contacts; dental alloys; antibacterial; money

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**Elements / Gold (Au)**

Conservation Science Consulting Sàrl

Use: noble metal, decorative metal, gilding; conductive coating, money

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