

**MINERALS**

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**Mines Paris - PSL**

# **MINERALOGY MUSEUM**

**Minerals are beautiful and useful.**

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**VISITOR'S GUIDE**

**Minerals and their classification**

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# — Understanding the classification



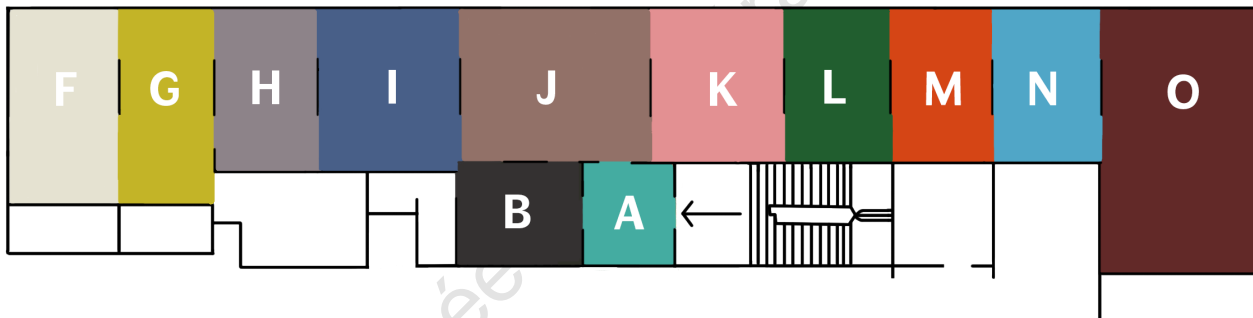
René-Just HAÜY

A mineral is defined by its chemical composition and structure. The classification of minerals is now internationally recognized. It is based on the chemical composition and is divided into 10 families (STRUNZ classification):

- **native elements**
- **sulfides** and sulfosalts
- **halides**
- **oxides** and hydroxides
- **carbonates** and nitrates
- **borates**
- **sulfates**, selenates, tellurates, chromates, molybdates, and tungstates
- **phosphates**, arsenates and vanadates
- **silicates**
- **organic compounds**

# — Understanding the classification

Mineralogy museum map



- A: Etrance room**
- B: Room Haüy**
- F to O: Main gallery**

The entrance room (A) and the Haüy room (B) are made up of didactic and generalist display cases. The gallery rooms (G to O) introduces the classification of minerals:

- |          |                                 |
|----------|---------------------------------|
| - Room G | Native elements                 |
| - Room H | Sulfides and sulfosalts         |
| - Room I | Halides and oxides              |
| - Room K | Oxides and carbonates           |
| - Room L | Carbonates and borates          |
| - Room M | Sulphates                       |
| - Room N | Phosphates                      |
| - Room O | Silicates and organic compounds |

# Room A

In this room, you will find minerals that are among our finest specimens. While some of these minerals are perfectly common, all are exceptional in size, shape or color. Here, aesthetics are a major focus! Let yourself be immersed into the diversity and richness of our collection.

## — Aragonite

This curious formation, which one could think to be of coral origin, does not come from an exotic lagoon but from the Eisenerz iron mine in Tyrol, Austria ! Aragonite and calcite have the same chemical composition: calcium carbonate ( $\text{CaCO}_3$ ). It is the way in which atoms are stacked that differentiates these two minerals: they are said to be polymorphic. At ambient pressure and temperature, aragonite is less stable than calcite. In a few million years, a slow rearrangement of atoms will have transformed this crystal into calcite.



N°6298 - display A3

## — Sepiolite



N°6280 - display A5

This piece from Eskisehir, Turkey, is a nodule of sepiolite, a fibrous mineral of the clay family (silicates) that can agglomerate into small masses. Once rid of their crust, these nodules have surprising shapes reminiscent of Henry Moore or Fernando Botero's sculptures. Very light, they float on water, hence their nickname of sea foam. The scientific name of this mineral comes from the Greek "sêpion" meaning "cuttlefish bone", in reference to its structure. The entanglement of this silicate's tiny fibers (less than  $2\text{ }\mu\text{m}$ ) gives it its remarkable properties. The electrically polarized microchannels can absorb water or other liquids. They can let molecules or ions of a well-defined size through, making this mineral a real "molecular sieve". Highly insulating, it turns into metasepiolite at around  $700^\circ\text{C}$ , which resists to high temperatures. This makes it a material of choice for carvings, in order to make high-end tobacco pipes. The clays of the sepiolite family can also be used, once reduced to powder, to treat stomach aches (smectite) or to remove grease stains on carpets (attapulgitite).

## — Synthetic aluminium oxide / corundum

This historical specimen shows a fragment of the crucible in which Edmond Frémy, with the help of his adopted son and assistant Auguste Verneuil, synthesized ruby (red variety of corundum) through the so-called molten salt method. The bottom of the crucible is lined with ruby crystals larger than a millimeter. Until this test, the two chemists had only obtained microscopic or very light-colored rubies. Later becoming a professor at the Museum of Natural History, Verneuil developed from 1896 onwards another process for the synthesis of rubies by anhydrous fusion, which is still known today as the Verneuil process and provides better quality stones to the watchmaking industry.

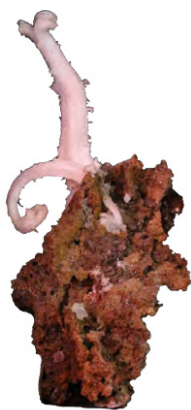


N°6302 - display A3



## — Gypsum

N°6288 - display A11



Often described as stalagmites or slightly quirky stalactites, these curious gypsum “flowers” still distinguish themselves by their structure: they do not have a channel in their center and have an almost mono-crystalline character to them. This suggests that the mechanism at work is very different. Originally, gypsum deposits are formed in lagoons or shallow seas by evaporation of seawater. This mineral can then, through geological disturbances, recrystallize in many shapes. In former abandoned mining operations, the circulation of water in the rock and the possible bacteria mode of action attack the sulfide ores. The sulfate-rich water can percolate and then evaporate on the outer walls, leaving behind these pretty gypsum wires. The crystals grow from the base up, similarly to hair, in only a few decades.

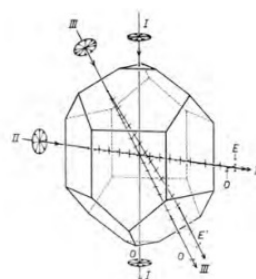
## — Calcite “Iceland spar”

This beautiful calcite crystal comes from Eskefjord, Iceland. In operation since the 17<sup>th</sup> century, this deposit was mainly formed by a very large cavity of 15m x 4m x 3m, almost completely filled with large clear crystals of calcite, also known as “Iceland spar”. The largest crystal from this cavity was 6m long and 2m wide. It is possible that the specimen on display represents the top of this crystal. The dull faces of the calcite are its natural growth faces. The shinier faces are breaks caused during extraction. The spars surprised the scientists of that time, such as Erasmus Bartholin and Christian Huygens, with their ability to double the images. In his “Light treatise” (1690), the latter gave a reasoned explanation of this phenomenon by formulating the undulatory wave theory of light. Each of the two images follows a specific path in the crystal. One image is normal, it could be seen at exactly the same position if the crystal were removed; the second is “extraordinary”, deviated because of the structure of the crystal. This optic phenomenon has been exploited to manufacture polarizing materials, used among others in microscopes, flat screens, sunglasses and cameras, including the famous Polaroid.



N°6269 - display A8

Principle of calcite birefringence



## — Dioptase

N°6257 - display A15



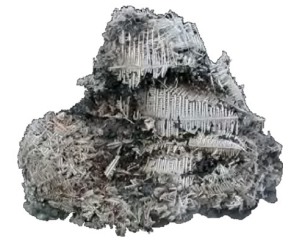
Dioptase is a mineral prized for its color. Its intense green color might be confused with emerald, but its lower hardness makes it easily distinguishable. It is René Just Haüy who identified and named it this way, according to the Greek “dia opteuein”: “to see through”. Indeed, we can easily see the cleavage planes inside the crystals. Besides, its fragility limits its jewellery use. Dioptase is a rather rare mineral of the silicate group, rich in copper. Its forming mode is quite complex. It is found mainly as a secondary mineral in oxidation zones of copper deposits. This exceptional sample was added to the collection in 1958, coming from the Renévilles mine in Congo-Brazzaville. From the early 20<sup>th</sup> century to the decolonization in 1960, copper from the region was subject to research and then major mining operations by the French Mining company of the Congo. It was during these years that the mine delivered some of the finest specimens worldwide.

# Room B

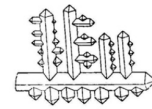
This didactic room provides an introduction to mineralogy and crystallography but it also showcases spectacular specimens.

## — Silver

The rock from which this specimen was extracted was found at over 100 meters in depth in the Pöhla mine in Saxony, Germany. The hydrogen peroxide attack partially cleared the dendritic crystallizations of native silver from their native arsenic matrix. Each fishbone structure of native silver, also called "herring bone" by Saxon miners, consists of a single crystal. This type of growth, quite common in native metals such as gold, copper and silver, is due to temperature differences between the edge and the center of the liquid that solidifies - the edge cooling faster. The central part grows very quickly at the beginning of crystallization, followed by primary and secondary "bones", maximizing the crystallized liquid/solid contact surface. It is also this phenomenon that gives rise to the star-like shapes of snowflakes.



Dendritic growth of native silver



N°63958 - display B3

## — Diamond

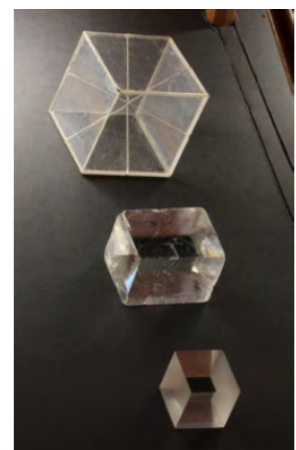


N°6367 - display B6

In 1868, the farmer Erasmus Jacobs found South Africa's first diamond, paving the way for a century and a half of unbridled exploration and mining. This block was found between 1871 and 1914 at the Premier Mine, at a time when mining was done by pick and shovel. Today, diamond mining methods using explosives, no longer makes it possible to find diamond-bearing rocks of such large size. The matrix here consists of a conglomerate of kimberlite, a volcanic rock that supplies most of the world's diamonds. This rock, present in the oldest regions of the continental crust, called cratons, is linked to extremely brutal volcanic explosions, of which there is fortunately no equivalent on Earth today. Their very fast emplacement - about 10 to 30 m/s in the last phases of ascent - allows the diamond to reach the surface without much alteration along the way. The slightly yellowish color of this diamond, due to the presence of trace amount of nitrogen in the crystal, is less appreciated by jewellers than perfectly colorless diamonds. On the other hand, the very regular octahedral shape of this diamond is remarkable.

## — Calcite

Calcite has played an important role in the science of crystallography. It is indeed thanks to a calcite crystal, such as the one presented in the central case, that René-Just Haüy is said to have laid the foundations of this discipline. A posthumous legend tells of an experience he had before he became a teacher at the School of Mines and curator of the museum. When he broke a rhombohedral calcite crystal, he noticed that the breakage was always made at very particular angles, producing smaller rhombohedra. It was then that he would have cried out, "Everything is found!" - a phrase as hypothetical as Archimedes "eureka". Inside the calcite, the areas of fragility according to which the crystal breaks indicate the regular stacking mode of small elementary forms, which he called "integrating molecules". This has since paved the way for scientific understanding of crystals.





## — Bastnäsite

N°6375 - display B5

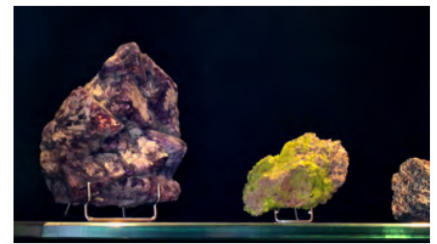


Bastnasite is a mineral discovered in 1838 at the Bastnäs mine in Sweden. The Bastnäs deposit consists of granitic to pegmatitic rocks (see definition in case B11 in this room). It is from a deposit of the same type, located in northern Madagascar, that this massive specimen was sampled. Claude Guillemin, then curator of the School of Mines collections, added it to the collection in the early 1960s. At the time, the industrial potential of this mineral had not yet been realized. Indeed, his study had led, at the end of the 19th century, to the identification of a series of chemical elements grouped under the term "Rare Earth Elements" (REE), whose remarkable properties had long remained unnoticed. Until the 1970s, they were only used as lighters or sleeves incandescent gas lamps. Today, these elements have become eminently strategic because their uses are innumerable, mainly in new technologies. The bastnäsite remains today, with monazite, the main ore of these Rare Earth Elements.

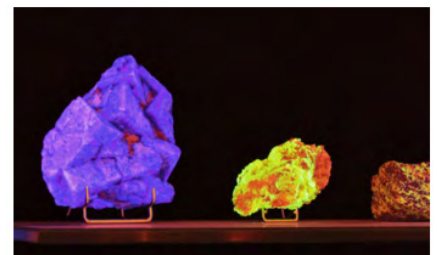
## — Fluorescent minerals

In 1807, on the initiative of René Just Haüy (1743-1822), the French National Institute offered a prize of 3,000 francs for a competition on the subject: "To establish by experimentation the relationships between the different modes of phosphorescence (...)". Haüy had identified many minerals that emit light by friction or under different types of lighting, and sought to explain this kind of phenomenon. The results of the competition were not very convincing because what Haüy meant by "phosphorescence" was not, and it will be necessary to wait a few years before one can clearly distinguish the different types of luminescence. Fluorescence refers to the ability of some materials to re-emit almost instantly light when illuminated by certain types of radiation (in this case, ultraviolet light). As soon as this lighting is turned off, the phenomenon stops. Georges Gabriel Stokes (1820-1903) called this phenomenon fluorescence in 1852, referring to the fluorite that possesses this property. However, it was only with quantum physics at the beginning of the 20th century that a satisfactory explanation of this mechanism was provided. This display case also illustrates the fact that the color of a mineral depends on the light source that illuminates it. Color is therefore a good descriptive criterion, but it is not sufficient to characterize a mineral species.

(a) under visible light



(b) under ultraviolet light



## — Crystallographic models



These crystallographic models have been used for teaching crystallography. There is nothing like being able to examine and manipulate to learn how to recognize the morphology of crystals. The first models, mainly made of terracotta, were created by Romé de l'Isle (1736-1790). It was about twenty years later that René Just Haüy developed wooden models (preferably pearwood) for his classes. These were manufactured by Krantz. Founded in 1833, Adam August Krantz's company specialized in supplies for geologists, and acquired a quasi-monopoly for the manufacture of these wooden models; it is still active nowadays.

# Room B

Room B offers a few definitions as an introduction to the mineral gallery. You will find here the translation of the texts presented in the different display cases.

## Display B11: Definitions of ROCK, MINERAL, CRYSTAL, GEMSTONE

### – ROCK

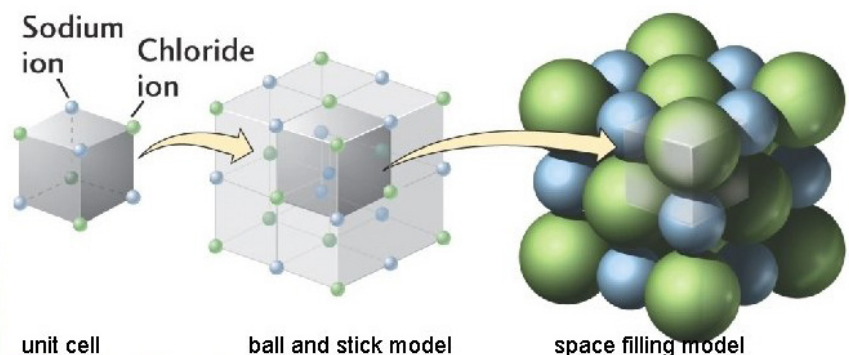
A rock is a natural material, usually solid, formed by an assemblage of minerals. These minerals can be of the same or different nature, and of similar or different size. A rock is classified by its formation mode (see Room F), by their texture and the minerals they are made of.

### – MINERAL

A mineral is a natural crystalline solid, defined by a specific chemical composition combined with a specific atomic arrangement (=UNIT CELL). A mineral can be made of only one element (rare - they are called the native elements) or, most of the time, several chemical elements.

There are a few exceptions to this simplified definition, such as mercury, which is a mineral but is liquid under room temperature. A few solid minerals lacking atomic arrangement are considered as minerals, such as opals.

**Model of the UNIT CELL of the mineral HALITE (commonly called salt) : NaCl crystallizing into the cubic system.**



### – CRYSTAL

A crystal is a solid (natural or synthetic) in which the components (atoms, molecules or ions) are assembled in an ordered manner, by a periodical stacking of a large number of them ("long distance ordering"). Some minerals are not well crystallized, such as opal, which is amorphous or "pseudo-crystalline", lacking this long distance arrangement of its components.

All crystals are not minerals: synthetic (man-made) crystals and sugar crystals for example are not minerals.

### – GEMSTONE

A gemstone (=gem) is a natural material, including minerals and rocks, that are beautiful and durable enough to be used in jewelry. Clarity, color, hardness, luster and other qualities are determining.



## SOME INTERESTING ROCKS

### – Limestone - calcite alabaster (ENSMP 80829)

Made mostly with one kind of mineral - calcite - , limestone is a sedimentary rock. Alabaster is the translucent variety of limestone, used for carving.

### – Granite (ENSMP 74821)

The most common rock of continents, granite is an igneous magmatic rock. It is composed mostly of quartz, micas and feldspars.

### – Pegmatite (ENSMP 50264 and 37357)

Pegmatite is a magmatic rock made of large crystals, which has a chemical composition close to granite, but contains more evolved elements (such as lithium, beryllium, cesium, tantalum, niobium, etc.) trapped in accessory minerals (such as spodumene, beryl, pollucite, colombo-tantalite, etc.). Pegmatite can be formed from a residual liquid after the crystallization of a granitic magma. With time and space to cool down and crystallize, some minerals can achieve large sizes, up to several meters! This favorable environment is suitable to form perfect minerals - gemmy crystals. For this reason, many gemstones are found in pegmatitic deposits.

# Display B1: MINERALS AND THEIR CHARACTERISTICS

The essential characteristics of a mineral are its chemical composition along with its crystalline structure. These two characteristics combined define the "mineral species", allowing the establishment of a scientific classification. Other characteristics (color, luster, clarity) do not define a mineral but can define species within a mineral (ex: ruby and sapphire are the red and blue varieties of the mineral called corundum, the aluminum oxide that crystallizes in the trigonal system).

## DETERMINING CHARACTERISTICS

### – CHEMICAL COMPOSITION

The chemical composition, determined by chemical analyses, can be:

- very simple - ex: SULFUR, a mineral composed of only element, sulfur (native element): S.
- simple - ex GALENA, a mineral composed of lead and sulfur (lead sulfide): PbS
- complex - ex ELBAITE tourmaline, composed of many elements, silicon, oxygen, aluminum, boron, sodium, iron, lithium, etc... (complex silicate):  $\text{Na}(\text{Li}_{1.5}\text{Al}_{1.5})\text{Al}_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH})_3(\text{OH})$ .

### – CRYSTALLINE STRUCTURE

The crystalline structure, revealed by X-ray diffraction, is the arrangement and packing of atoms, which follows a specific geometric order. The identification of the structure allows to group minerals with close chemical compositions ("isomorphism" such as with garnets - also called "solid solution") and differentiate minerals that have the exact same composition but different structure ("polymorphism", such as diamond and graphite, both made of carbon, but with a different structure - cubic for diamond and hexagonal for graphite).

**NOTE :** The mineralogical classification (called "Strunz") used in this museum follows a classification based on the chemistry of minerals.

## OTHER CHARACTERISTICS (not determining of the species)

### – COLOR

Minerals of different species can have the same color (ex: pink in some fluorite, beryl, and tourmaline; green in epidote and in some beryl and fluorite).

Minerals from the same species can sometimes have different colors (ex: purple, orange, blue fluorite; quartz: smoky, colorless, green, pink, purple - amethyst variety, yellow - citrine variety).

### – LUSTER

Minerals display luster: dull, metallic, vitreous, adamantine, etc. A same species can be dull or can display a less or more vivid luster.

### – CLARITY

Minerals can be opaque, translucent or clear. Gemstones are remarkable for their transparency and clarity. A same species can present a variety of clarities. For example, calcite is more or less translucent, but can exceptionally be clear - it is then called "Spar".

## DISPLAY B2: OTHER PROPERTIES

Most properties of minerals are in close relationship with their crystalline structure and chemical composition. They can therefore be used as means of recognizing the mineral species, using different techniques and measurements.

Some of these useful properties: shape ("habit"), hardness, cleavage, luster, clarity, fluorescence, reaction to acids, electric conductivity, magnetism, radioactivity, etc.

### – HARDNESS: THE SCALE OF MOHS

The hardness of a mineral can be estimated by its capacity to scratch or be scratched by another mineral of known hardness, from the Mohs scale. For example, galena has a hardness between 2 and 3 because it scratches gypsum (hardness of 2) but it is scratched by calcite (hardness of 3).

Caution: the hardness of a mineral is not to be compared with its fragility. Diamond, the hardest of all minerals, is fragile : it breaks easily (see "cleavage"). To the opposite, gold is tender (not hard) but not fragile: it deforms instead of breaks.

Mohs' scale (from hardest to softest):

- 10- Diamond
- 9- Corundum
- 8- Topaz
- 7- Quartz
- 6-Orthoclase
- 5- Apatite
- 4- Fluorite
- 3- Calcite
- 2- Gypsum
- 1- Talc

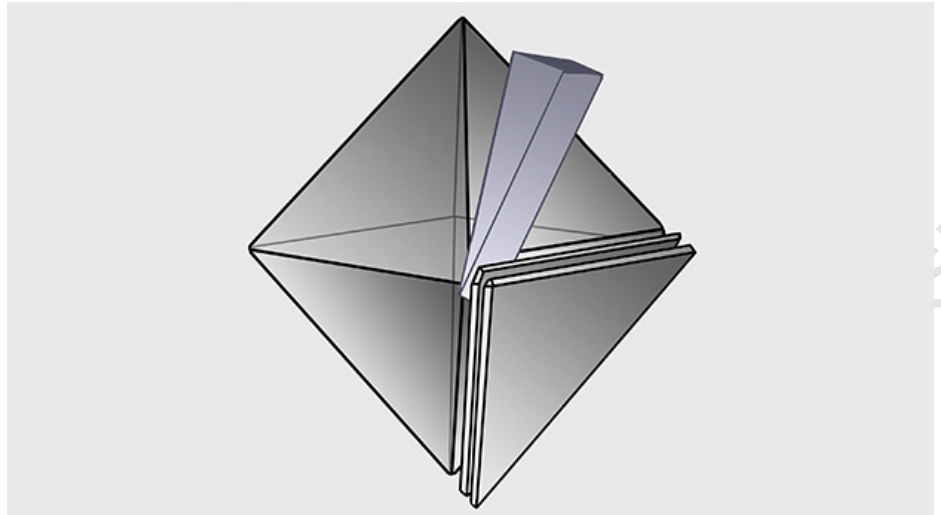




## – CLEAVAGE

The break of a mineral sometimes reveals planar surfaces named cleavage. The geometry of these break planes ("cleavage planes") helps determining and understanding the structure of minerals. Some minerals have easy cleavage, such as calcite (and even diamond), some others do not, such as corundum.

**Cleavage planes within a diamond (represented here by its ideal octahedron - double pyramid - shape), parallel to the faces of the octahedron.**



From: V. C. Venkatesh and S. Izman, Precision Engineering, 2007, p. 54, modified by GIA.

## – TWINNING



Amazonite Pikes Peak from Teller Co., Colorado in USA (ENSMP 6271) by Carla Barreto (Mines Paris - PSL 2022)



A twin is a symmetrical association of two or more crystals from the same species, following specific geometrical laws. Some mineral species regularly show twins (like cassiterite, staurolite or cerussite), while other do not (like garnet, beryl or tourmalines for example).

**Staurolite from Coray in Brittany, France, presenting a twinned penetration cross (ENSMP 15643). The two individuals of the twin, normal to each other, share one same atomic plane.**

# DISPLAY CASE B3: CLASSIFICATION OF MINERALS

Once the mineral species is defined thanks to its chemical composition and crystalline structure, it can be attributed to a special group within families. The classification system used in the mineral gallery is named "Strunz" classification and groups the minerals in 10 families / classes. There were 5,800 mineral species described in 2022, with new minerals discovered every month (usually micrometer in size)!

- 1- ELEMENTS (Metals and intermetallic alloys; metalloids and nonmetals; carbides, silicides, nitrides, phosphides)
- 2- SULFIDES and SULFOSALTS (sulfides, selenides, tellurides; arsenides, antimonides, bismuthides; sulfarsenites, sulfantimonites, sulfbismuthites, etc.)
- 3- HALIDES
- 4- OXIDES (Hydroxides, vanadates, arsenites, antimonites, bismuthites, sulfites, selenites, tellurites, iodates)
- 5- CARBONATES (NITRATES)
- 6- BORATES
- 7- SULFATES (selenates, tellurates, chromates, molybdates, wolframates)
- 8- PHOSPHATES, ARSENATES, VANADATES
- 9- SILICATES (Germanates)
- 10- ORGANIC COMPOUNDS

Mineral abundance known, by class:

- 1- Elements: 2.7 %
- 2- Sulfides: 14.8%
- 3- Halides: 4.1%
- 4- Oxides: 13.6%
- 5- Carbonates (and nitrates): 5.3%
- 6- Borates: 3.5%
- 7- Sulfates: 8.4%
- 8- Phosphates, arsenates, vanadates: 18.5%
- 9- Silicates: 28%
- 10- Organic compounds: 1%



Forsterite from Datso Mine, Kohistan in Pakistan (ENSMP 45645) by Camille Srecki (Mines Paris - PSL 2020)

## DISPLAY CASE B4: X-RAY CRYSTALLOGRAPHY

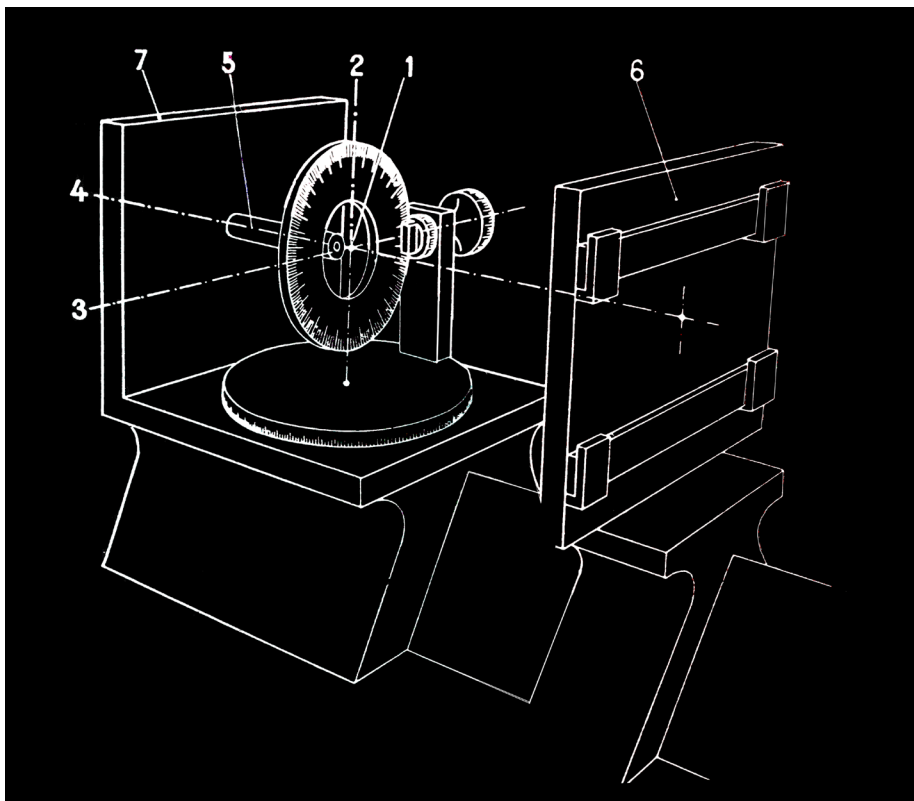
The mathematical theory of crystallography was established by Hessel, Bravais, Fedorov, Schönflies and Barlow and Fedoroff in the late 1880s, early 1890s, demonstrating the existence of 230 groups of symmetry of the unit cell (the smallest repeating unit of elements having the full symmetry of the crystal structure). However, until then, there was no physical means allowing to see the positions of atoms inside a crystal. X-Ray diffraction did allow it.

### FONDAMENTAL EXPERIENCE OF LAÜE (1913).

An X-ray beam goes through a crystal behind which a photographic plate is placed. After the plate is developed, it shows a number of spots scattered around a center. Each of these spots is due to the diffraction of X-rays by a series of reticular planes of the crystal.

In 1912, Bragg established a formula allowing to calculate the position of diffracted rays, showing that by studying a diagram, it was possible to determine the structure of a mineral, to measure the dimensions of the unit cell and distances between the atoms. Different apparatus were realized with X-rays, using a monocrystal spinning or oscillating in many positions, using rolled films. In order to study specific details of the atomic structure on the diagram, the intensity of the diffracted rays can be measured thanks to Geiger-Müller captors. Sometimes even, true photography of atoms of a crystal can be obtained.

Thanks to the study of structures and their defects, the science of crystallography undertook an important development in all domains of hard and applied sciences that study solid materials: theoretical chemistry, chemical industries (plastic materials, textile...), metallurgy, ceramic and so on. The knowledge about mineral species, specific to mineralogy, becomes more precise, constantly shedding new lights on geological phenomena, on the formation of deposits (metallurgy) and rocks (petrology), on the migration of elements in the continental crust (geochemistry), facilitating the research and exploitation of raw natural resources necessary to our industry and economy.



Caption of the figure: Apparatus of Laue's diagrams. A sample (1) is placed at the center of the Fedorov stage, which can be oriented around 3 axes with coordinates 2, 3 and 4. The collimator (5) is fixed to a frame (7) and oriented following the axis (4) normal to the photographic plate.

Powder diffraction (by Debye & Scherrer) used to identify mineral species, each usually giving a characteristic diagram (a few milligrams of mineral powder is used).

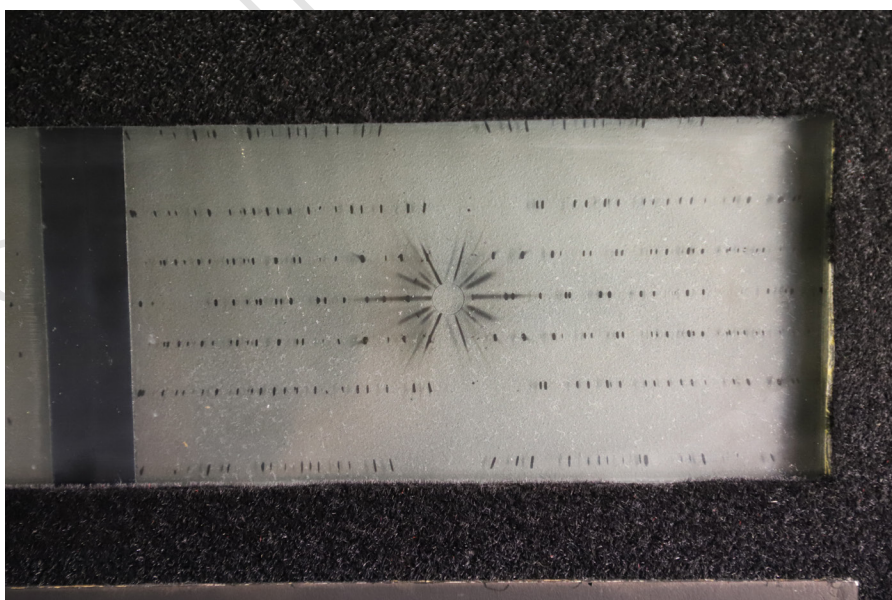
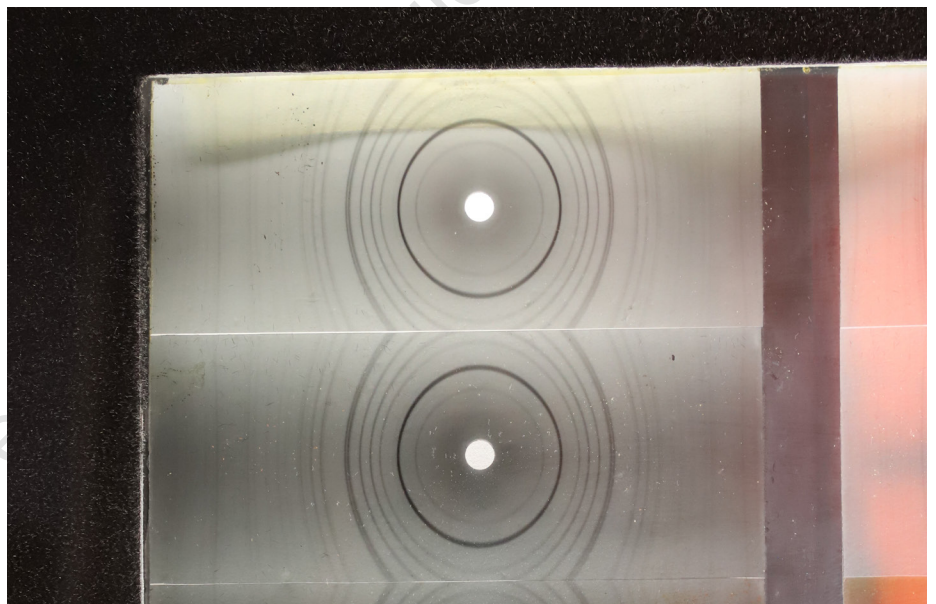


Diagram of a rotating crystal allowing to measure, depending on the rotation angle, the distances between the planes of the networks. The unit used is the Angström ( $1\text{\AA} = 0.0000001\text{ mm}$ ).



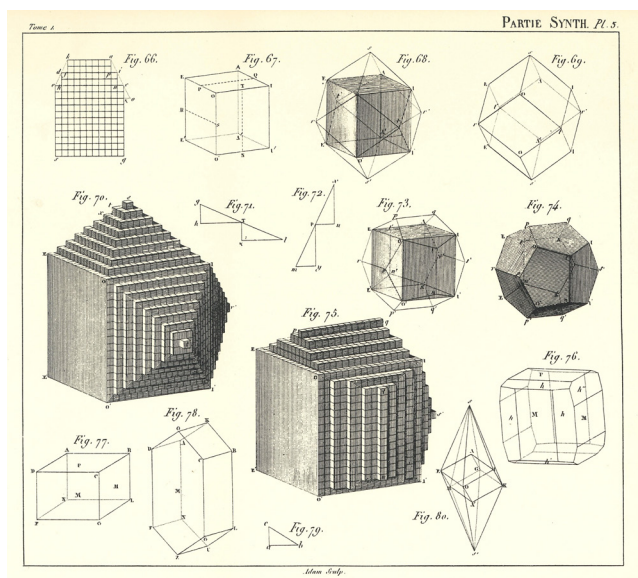


Plate 5: The cubic system and some of its habits. By adding or subtracting the same building block ("molecule intégrante" as referred by Haüy), the different shapes (habits) of cubic minerals can be obtained.

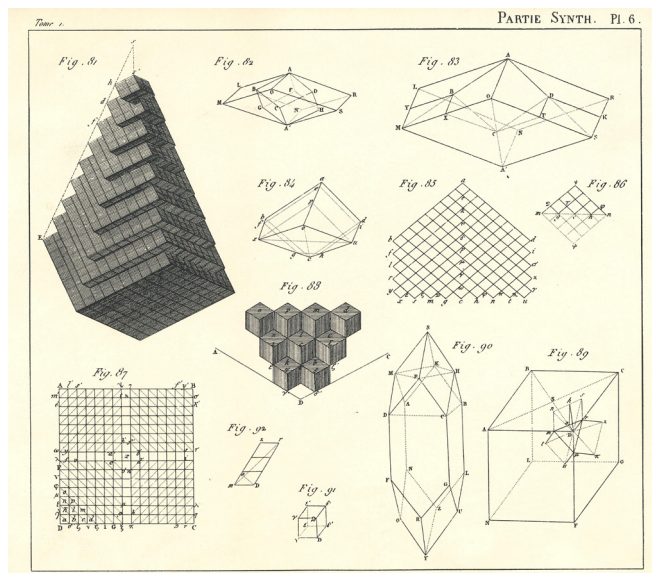
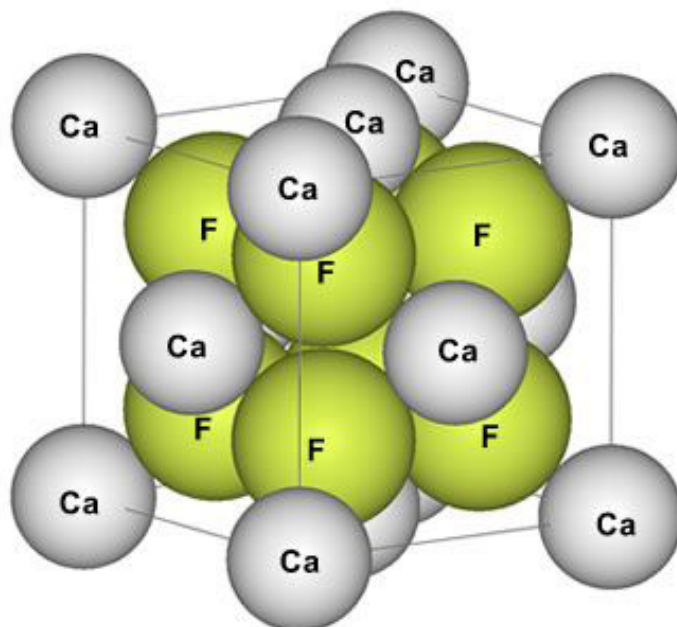


Plate 6: The rhombohedral (now called trigonal) system and some of its habits. By adding or subtracting the same building block ("molecule intégrante" as referred by Haüy), the different shapes (habits) of rhombohedral minerals can be obtained. In fig. 2, a scalenohedron, typical of calcite, is obtained.



Scalenohedron of CALCITE formed by a stacking of rhombohedra, coming from Dalnegorsk, Primorsky Kray, Russia. Gift, ABC Mines, 1999. ENSMP 46971. This exceptional specimen illustrates perfectly Haüy's theory.

Model of the UNIT CELL of the mineral FLUORITE ( $\text{CaF}_2$  that crystallizes in the cubic system).

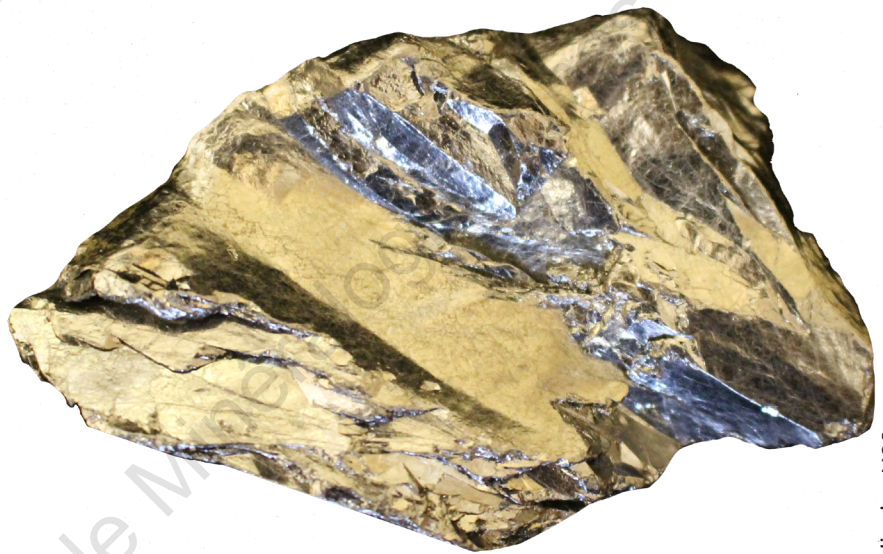


# Room G

Native elements, the first family of minerals, are composed of only one type of atom. This is how we find native gold, silver, copper, sulfur. The Earth machine has concentrated very useful elements to mankind in these minerals. For this reason, they played an essential role since the dawn of civilization.

## — Graphite

Graphite and diamond have the same composition: carbon. But it is the arrangement of atoms that differentiates them. These minerals are said to be polymorphic (or allotropic). Specimen #89, from Canada, was donated by Gabriel-Auguste Daubrée, director of the School of Mines between 1872 and 1884. From the pencil to brake linings and electrodes (for electric batteries or metallurgy), graphite is frequently used. However, its main application in steel mills and foundries remains as a refractory material. Note that the so-called "carbon fiber" materials are not only made of graphite: the carbon microfibers materials contain about 10% nitrogen, oxygen and hydrogen, and are combined with a plastic resin.



N°89 - display H26

## — Diamond



N°16013 - display H26

A combination of extremely high pressures and temperatures is required for the carbon atoms to combine in the diamond form. These conditions prevail at dizzying depths: at least 150 kilometers underground. Some very rare diamonds even come from 600 kilometers deep. That's a record number ! On the surface level, this mineral is metastable: its atoms reorganize over long period - virtually infinity - to form... graphite! The typical shape of a gemmy diamond is an octahedron (a double pyramid). Specimen #16013 is twinned (see definition case B2, room B): it consists of the growth of two crystals at a specific angle. In specimens #44505 and 16057, the cuboid forms are due to a faster growth of crystals, which then present very numerous impurities.



## — Native sulfur

Like other relatively common native elements (copper, silver, etc.), sulfur has been known since ancient times. It is mentioned for its many uses several centuries before our era, mainly in China, Greece or Egypt. Lavoisier demonstrated in 1777 that sulfur is a simple body, not a compound. Contrary to popular belief, the main deposits of native sulfur are not found in volcanic areas but in sedimentary formations. The reduction of a sulfate, gypsum or anhydrite in the presence of hydrocarbons can lead to the formation of sulfur crystals. It can also be "synthesized" by anaerobic bacteria from gypsum. Specimens from Sicily (such as #10967) or Spain are particularly aesthetic and sought-after. The element sulfur can crystallize in several crystal systems. It is, with carbon, the element with the most allotropes: more than thirty counted from man-made crystals. In nature, the most frequently encountered is native sulphur "S8" formed by rings of eight sulfur atoms linked together by weak chemical bonds, the Van der Waals forces. The weakness of these bonds explains its low melting point : 113°C. It burns with a blue flame.



N°10967 - display H27

## — Native gold



N°46084 - display H24



N°16570 - display H24

The native gold sample #46084 comes from the County of Devon, England, where fairly old rocks dating back about 400 million years outcrop. The geological era corresponding to this period, the Devonian, was named after the region. Cape Hope's territory (Hope's nose), at the extreme south of this area, consists of limestone rocks crossed by veins of calcite, hematite and dolomite. It is in these veins that gold and other rare palladium and selenium minerals have been found. It seems that, about 250 million years ago, the surrounding rock suffered from "hot spring" type hydrothermalism at moderate temperature and high salinity, which allowed the mineralization of gold in the veins. In general, this process is an efficient mechanism to concentrate chemical elements in their native form, which are originally only present in trace amount in Earth's crust. Gold nuggets, such as sample #16570, are formed in a secondary manner, after erosion of primary deposits such as veins and dikes. These nuggets are therefore found in alluvium, in rivers for example.



# Room H

Sulfides are minerals for which the sulfur atom is generally associated with metals. It is in this family that the main ores of zinc, copper, lead, iron, molybdenum, mercury, silver, antimony and tin are found. They play an important role in the history of humanity.

## — Stibnite

Stibnite crystal #432 (antimony sulfide) is considered to be the most beautiful crystal found in France, for both its impressive shape and size. It comes from La Lucette mine in Mayenne. This deposit, discovered in 1891, was intensely mined until 1934. At that time, it enabled France to become the world's leading producer of antimony. As in many sulfide deposits, precious metals, such as gold, have been found there. Today, China is of the world's first producer of antimony. This metalloid is also increasingly recycled, accounting for 20% of its consumption.



N°432 - display 126

## — Cinnabar



N°416 - display 125

Cinnabar is a mercury sulfide known for thousands of years. Reduced to a powder, it results into an intense red pigment: vermilion. Historians have found traces of this dye on 4000-year-old objects in Egypt and China. Through a physical process that is still poorly understood, this mineral deteriorates in daylight and darkens, which is why the museum's samples are stored in a dark environment. Many works of art that have incorporated vermilion have degraded as a result of this phenomenon. The blackening of the frescoes of the Villa Dei Misteri in Pompeii is a perfect illustration of this. Many of our fine specimens come from the Almaden mine in Spain. From antiquity to the industrial era, it is from this deposit that the greatest quantity of cinnabar has been extracted. Theophraste (-371 to -288 BC), a Greek scientist, evokes the ore of this region, already prized for its beautiful color. Cinnabar is the main mercury ore. The use of this element is now highly restricted because of its toxicity. Unfortunately, it is still misused by gold panners for gold recovery.

## — Pyrite

Pyrite is a mineral that crystallizes in the cubic system. This is why iron and sulfur atoms form elementary stacks of cubic shape. Thus, on a large scale, pyrite can form almost perfect cubes, such as #16715, typical of the Spanish Navajun deposit. But the morphology of pyrite crystals is diverse, correlating to forms derived from the cube, due to slightly different growth conditions. Thus pyrite can form surprising twelve-sided pentagonal polyhedra called pyritoedra, such as #83083, from a recently discovered deposit in Tanzania. The same chemical elements can crystallize according to the orthorhombic system. We are then in the presence of another mineral called marcasite. Pyrite and marcasite are therefore polymorphic.



N°16715 - display 127

## — Sphalerite



N°82506 - display H30

Sphalerite #82506 is unusual. Indeed, it reminds us of chalcopryite with its sphalerite shape and color. As a matter of fact, these two minerals are indeed present: chalcopryite has been deposited on the surface, taking the shape of sphalerite (when two minerals grow in this way, successively one on top of the other, we call it epitaxy). The Dalnegorsk deposit, north of Vladivostok (Russia), where this specimen comes from, is exceptional. It is found in a magma intrusion into calcite (skarn). There are many sulfides (such as sphalerite and galena) as well as borosilicates such as danburite. Some of the crystals found in these mines are very impressive and reach the size of one meter! Thus, this site is interesting for science, appeals to mineral collectors and has economic importance for boron mining.

## — Galena

Galena is a lead sulfide known and used since ancient times. Among its many uses, let us mention the black eye shadow, called kohl, already used by the Egyptians 4 000 years ago! Closer to home, following the discovery of electromagnetic waves by Heinrich Rudolf Hertz (1857-1894), researchers discovered that metallic crystals, such as galena or pyrite, have semiconductor capabilities. This paved the way, at the beginning of the 20<sup>th</sup> century, for the manufacture of detectors used in the first radio sets. Thus galena is linked to the origin of the telecommunications industry. This is a considerable boom when you put into perspective the different avatars of this evolution, from galena phones to mobile phones! Many fine specimens come from the Weardale area of the United Kingdom. Lead and silver mining in this region has been documented since at least the 12<sup>th</sup> century. Once covered with forest, the region is now bare, due to the high consumption of wood by mining activity (for the support of galleries, then for steam engines).



N°376 - display H34



# Room I

Halides are minerals composed of chlorine and fluoride combined with metals. 130 different species are internationally recognized. Many are soluble in water.

## — Halite

N°697 - display I35



Salt (or halite) originally comes from brackish deposits, formed by evaporation, in lagoons or salt lakes. These deposits, also known as evaporites, are then buried under geological disturbances, where they can recrystallize in the form of coating, stalactite or fine crystal. Some of them can measure several tens of centimeters in length. Wieliczka in Poland is certainly the most famous gem salt mine in the world. Some beautiful specimens presented in the museum, such as #697, come from this mine. Already active in the 13<sup>th</sup> century, this salt mine is extensive: the cumulative length of the galleries reaches more than 400 kilometers and the mine is located on about ten levels between 64 and 335 meters deep. It was listed as a UNESCO World Heritage Site in 1978. Historical visitors to the mine include Copernicus, Goethe, Chopin, Humboldt, and Mendeleev. Today it is transformed into a tourist attraction and an underground sanatorium for lung patients' recovery.

Details of an engraving by Willem Hondius (1645) showing the life in the Wieliczka mine © Wiki Creative Commons



## — Fluorite

These samples of fluorite are protected from the light. Indeed, some fluorites lose their color when exposed to light. This can happen very quickly. Prospectors report that some fluorites may see their color disappear completely following exposure to the sun for only a few hours. The blue fluorites are reputed to be very sensitive. For example, specimen #734 was dark blue when it left the King's mine in Kongsberg, Norway, from where it was extracted. The pink fluorites from Haute Savoie (16047) are extremely rare and are a highly collectable item. Their color, like their fluorescence, is linked to the presence of Rare Earth Elements such as yttrium, in trace amount, spread in the crystal lattice.



N°16047 - display I37



## — Boleite and Cumengeite

N°778 - display I38



Edouard Cumenge (1828-1902), an engineer at the School of Mines, participated in the creation and operation of the Boleo copper mine in Baja California, Mexico. He brought back from this deposit some exquisite blue boleite and cumengeite crystals, which were discovered for the first time in that mine. It was originally believed that the star-looking crystals of cumengeite were an interpenetration twin of 3 boleite crystals, until Georges Friedel (1865-1933) showed that they were in fact the result of cumengeite growth on top of a central boleite or pseudoboleite crystal (a species close to boleite, in this same display case). The School of Mines holds both the reference sample (type specimen) of the boleite mineral species and also its largest and most beautiful representative: crystal #778 is considered to have no equivalent in the world. Crystal #5659 is certainly one of the best pseudoboleite crystals known.

## — Corundum

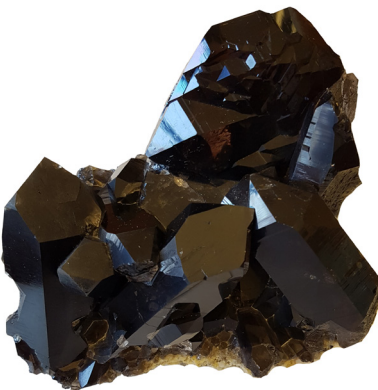
The name of this mineral is not very revealing. However, its colorful varieties are well known to neophytes: they are two of the most famous gemstones. When corundum displays a beautiful red hue, it is called ruby. When the corundum is blue, yellow, pink, or purple, we are dealing with sapphire. These trade names were given at a time when their composition was not known. René-Just Haüy is the one who, based on their hardness and their lack of cleavage in particular, has harmonized the terminology. Ruby and sapphire are made of aluminium oxide. The color differences are explained by the nature of the impurities that are present inside the crystal lattice. Traces of chromium ( $\text{Cr}^{3+}$ ) result in the red of the ruby ; iron and titanium ( $\text{Fe}^{2+}$  -  $\text{Ti}^{4+}$  charge transfer) explain the blue of the sapphire. Ruby #5743 from Mogok in Myanmar (Burma) displays the "pigeon's blood" color which is very popular among jewellers.



N°5743 - display J28

## — Quartz

N°70623 - display J32



The issue of quartz classification has been an ongoing controversy for a long time in mineralogy. From a chemical point of view, this mineral can be assigned to the oxide family. It is composed of oxygen and silicon (silicon oxide or silica). Strunz' criteria, the international classification selected in our museum, has chosen to place it this way. However, it can also be structurally attached to silicates. Indeed, the common point of silicates is the  $\text{SiO}_4^{4-}$  tetrahedron (see diagrams and room O). The latter is in a way the basic pattern for this family. Subfamilies are established depending on the pattern trend: in cycles, chains, sheets, etc. However, the structure of quartz can be described as the polymerization of  $\text{SiO}_4^{4-}$  tetrahedra in all directions in space. Each corner, occupied by oxygen, is shared with a neighboring tetrahedron. As a result, some scientists advocate for the classification of quartz to the silicate family. This mineral is common, especially in rocks of the continental crust. It would make up about 10% of the lithosphere. Specimen #70623 was found close to Chamonix. The region is ideal for great discoveries. The combined interplay of tectonic movements and erosion, which led to the formation of the Alps, sometimes reveals beautiful crystallizations.

# Room K

Oxides and hydroxides represent 14% of known mineral species. They contain iron, tin, aluminum, tantalum, niobium and uranium ores. They are often the result of the alteration of other minerals.

## — Opal

Opal is a mineral that has been well-known and valued for thousands of years: its name comes from the Sanskrit word “uppala” passed to Greek and then to Latin. The striking play-of-colors that opal may show has fascinated many collectors. This phenomenon is called iridescence. However, this property is not systematic. For example, specimen #1245 is only intrinsically colored; specimen #1260 is translucent; specimen #83317 is iridescent. The combination of different variables explains this great diversity. On one hand, their water content can vary from a few percent to about 20%. On the other hand, the degree of crystallization is not homogeneous. A distinction is made between amorphous and micro-crystalline opals. The former have no specific atomic arrangement; the latter have a complex crystalline structure at the nanoscale. Recent studies are beginning to shed light on this still misunderstood aspect. The green hue of opal #1245 is believed to come from microscopic nickel-rich inclusions. The iridescent of opal #83317 is caused by light diffraction caused by a 3D arrangement of hydrated silica nanospheres.



N°1245 - display J36



N°83317 - display J36

## — Goethite



N°1423 - display K27

Goethite is, alongside other minerals such as siderite, magnetite or hematite, one of the main iron ores. It is a relatively common mineral on Earth. It is generally found in the soil and subsoil at shallow depths. It is sometimes found in peat bogs, where it forms through precipitation from running water thanks to bacteria activity. It was a famous iron ore in northern Europe, used in particular in the Middle Ages by the Vikings. This mineral is also present in the rest of the solar system, as evidenced by the discovery of deposits containing this mineral by the Nasa Spirit rover in 2004 in a Martian crater. This discovery provided one of the first evidence of the past presence of water on this planet. Indeed, this iron oxyhydroxide is often the product of the action of water on iron-rich minerals. Nowadays, synthetic goethite nanoparticles are studied as a heavy metal adsorbent material in case of water pollution.

## — Tantalite

Tantalite is the main ore of tantalum, a strategic chemical element. It is used in the composition of micro-capacitors present in our phones and laptops, cameras, satellites, etc. Specimen #5676 is from Spargoville in Western Australia. The country alone has a quarter of the world's tantalum reserves. Although Central Africa represents only a small part of the currently known reserves, this region now accounts for most of the world's production. In 2013, for example, 260 out of 590 tonnes were extracted in only two countries: Rwanda and the Democratic Republic of Congo (DRC). The pressure on mineral resources partly explains the regional conflicts. According to international observers, many of the 5 million deaths in recent years in Kivu, eastern DRC, are related to raw materials issues, including tantalum and cobalt.



N°5676 - display K25

## — Calcite



N°2275 - display K30

From molluscs to microalgae, many marine organisms have a shell mainly composed of calcium carbonate. The external skeleton of sea urchins, for example, consists of calcite elements, each of which is a single crystal. When they die, these organisms can accumulate on the ocean floor and participate in the formation of future limestone rocks. The Maastrichtian chalk (Cretaceous era extending from 72 to 66 million years ago) present in Fresville in the English Channel was thus formed by the accumulation of carbonate tests (the "shells") of planktonic micro-organisms called coccolithophorids. It is within this rock that the fine specimen #2275 was discovered. Small calcite crystals grow on an urchin shell of the echinorchys family.

## — Aragonite

In nature, calcium carbonate is found mainly in two forms: aragonite, crystallized in the orthorhombic system and calcite, in the rhombohedral system. External conditions determine which crystalline system can be adopted. The most stable form, at ambient pressure and temperature in a pure medium, is calcite. But changes in these factors, changes in acidity or the presence of other ions ( $Mg^{2+}$ ,  $Ba^{2+}$ ,  $Sr^{2+}$ , etc.) can promote the formation of aragonite. In some ocean areas, it can precipitate directly, thus serving as cement for marine sediments. Some marine organisms also manage to synthesize aragonite. For example, they are found on the inner layer of many shellfish. This is what constitutes the mother-of-pearl, therefore the pearls. It also forms the skeleton of corals. Finally, underground crystallizations can take the spectacular appearance of fine rods or hexagonal prisms, such as #2386.



N°2386 - display K35



# Room L

Carbonates are minerals composed of the group  $[\text{CO}_3]^{2-}$  and one or more metals. Some contain water molecules. The most common calcite and dolomite represent 2.5% of the weight of the Earth's crust.

## — Malachite

N°46084 - display K38



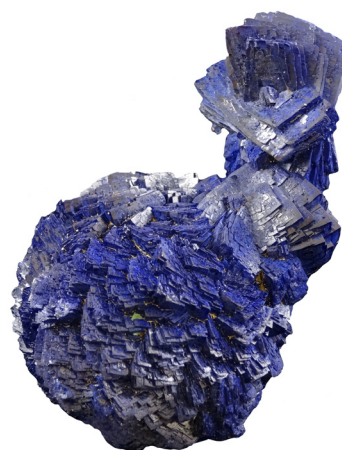
Malachite is a hydrated copper carbonate. It rarely occurs in large crystals visible with a bare eye. However, it can form microcrystalline masses of relatively large dimensions. This is the case, for example, in Katanga (Democratic Republic of Congo) or Siberia: large malachite stalactites are found in underground cavities near copper deposits. Specimen #10979 is a polished slice of such a concretion. As an aesthetic mineral, it is used to make jewellery or decorative objects. The Grand Trianon Palace in Versailles offers superb examples. Some sculpted and polished pieces are also presented in display case L18, next to the gems.

Malachite's room - Grand Trianon - Château de Versailles, France © Wiki Creative Commons



## — Azurite

Azurite is a copper carbonate chemically close to malachite. These two minerals are frequently found together: malachite is sometimes the product of the alteration of azurite. Thus, specimen #5349 is an azurite crystal that has almost completely transformed into malachite. The ball-shape specimen #2435 comes from the Chessy mine in Rhône, France. Intertwined veins of azurite were discovered there in 1810. This "blue mine", within Triassic sandstones and clays, was about 400 meters long and 40 meters thick. This discovery has made it possible to relaunch very successfully the activity of this mine, which has already been in operation for several centuries. Between 1812 and 1828, it supplied 4,000 tons of copper. After a major collapse in 1857, production declined rapidly and then stopped. The remarkable minerals released during this period quickly spread throughout the European mineral collections. The azurite species was first characterized with minerals from Chessy, which makes it the type locality for azurite.



N°2435 - display K37

## — Celestine

N°16328 - display L28



Mineral #16328 is from Katsepy, Mahajanga region, Madagascar. Since the 1960s, this place has supplied hundreds of tons of celestine in a beautiful blue color, one of the most popular among collectors. This mineral is found in 65 million year old sediments. These sediments were deposited in a shallow sea shortly after the separation of India and Madagascar. At the same time, on the Indian side, cataclysmic volcanic eruptions, the Deccan traps, contributed to the disappearance of dinosaurs. Nowadays, local villagers are digging narrow holes up to 10 to 15 meters deep in basic security conditions. It is from this locality that beautiful celestine geodes, that can measure several tens of centimeters, are found.

## — Anglesite

The conditions of formation of this lead sulfate are similar to those of cerussite (which is a lead carbonate): both are formed when primary lead ores such as galena are altered. However, it is much rarer, due to its less frequent stability conditions. This mineral has the same structure as its neighbors baryte and celestine: these three minerals are said to be isomorphic. Generally, the crystals are colorless, grey or white, but sometimes yellow, and even blue or green crystals are observed. The famous localities producing beautiful crystals are Sidi-Amor-Ben-Salem (Tunisia), Tsumeb (Namibia), and Touissit (Morocco). The Museum preserves an unrivalled collection of anglesites from North Africa, including a splendid selection of Sidi-Amor-Ben-Salem crystals, including a 15 cm single crystal (#5760), a group of perfect crystals (#5761), and an association of transparent crystals (#15934). All were mined at the upper levels of the mine between 1920 and 1930. They were acquired by Paul Sainfeld, (1916-1998), future assistant curator of School of Mines Museum, who was then a geologist in Tunisia. He donated them to the museum in 1961.



N°16767 - display L29

## — Rhodizite

N°16216 - display L27



This mineral contains boron, cesium and beryllium. It is rare, found only in granitic pegmatites where it is associated with red elbaite tourmaline (called "rubellite"), spodumene and lepidolite. The fine group of perfect crystals #16216, presented in room B (case B3), constituted of a 6 cm tall crystal, was discovered in Antsongombato, Madagascar, during the years 1964-1965 by Mr de Saint-Ours, geological engineer, and presented to the museum in 1972 by Madame de Saint-Ours, his widow. It is currently, by far, the best known example of this very rare beryllium borate. The other rhodizites are visible in the L27 display case.



# Room M

In the 7<sup>th</sup> family of minerals, sulfates, composed of the group  $[\text{SO}_4]^{2-}$  associated with metals or semi-metals, made the majority of the group. They may contain water molecules. This family also includes chromates, molybdates and tungstates.

## — Gypsum

Gypsum is a fairly common mineral that can form very large crystals. Specimen #2841, found in Greece, is of a rather remarkable size. But there is much more impressive : in Naica mine in northern Mexico, crystals more than 12 meters long have been discovered. Water at 50°C, loaded with calcium sulfate, has circulated for millennia in these natural caves at a depth of 300 meters: these are ideal conditions for the growth of gypsum. It is estimated that crystal growth began 600 000 years ago, but it has not necessarily been continuous.



N°2841 - display L33

Gypsum crystals from the Naica mine in Chihuahua, Mexico © MyBestPlace



## — Wulfenite



N°15887 - display L36

Wulfenite is a mineral often appreciated by collectors. The crystals have various, often intense, hues: grey and brown in the Congo (M'Fouati, Renneville); brown and orange in Mexico (Los Lamentos); yellow in Morocco (Touissit, Djebel Mahseur) and Yugoslavia (Mezica); bright red in Iran (Shah Kharboze) and especially in the United States (famous Red Cloud mine, Arizona). This last deposit has offered the most beautiful wulfenites in the world. The museum has an incomparable specimen from it: it is a 4 cm crystal of a sumptuous bright red color delicately hosted on its matrix (#15887). This mineral was one of the most beautiful pieces in Colonel Vésignié's personal collection (1870-1954). This amateur mineralogist, who gathered one of the most important collections of his time, had bought it for 770 francs from the American A. Montgomery in April 1938.



## — Crocoite

Crocoite is a rare mineral, first discovered in 1761 in the Ural Mountains. It was first mistaken for an alloy of lead, iron, and selenium. It took a few years to discover its true nature, most likely thanks to a specimen from our collection. In 1797, Nicolas Louis Vauquelin, then a teacher at the School of Mines, analyzed this mineral and, by etching it with hydrochloric acid, managed to produce an oxide of a new kind. He understood that he was dealing with a new chemical element, which he managed to isolate shortly afterwards by reducing this oxide by heating it in a coal furnace. On the advice of his colleagues Fourcroy and Haüy, he named this element "chromium" because of the bright colors of the compounds in which it is present. Two specimens presented in this showcase (#2902 and #2896) come from Beresowsk, in the Ural Mountains, the place where this mineral was discovered. The others were found in Dundas, Tasmania, the place that provided the most beautiful crocoite crystallizations.



N°2902 - display L35

## — Scheelite



N°16356 - display L35

Scheelite is a calcium tungstate. It was in this mineral that Karl Wilhelm Scheele (1742-1786) discovered tungsten, but failed to isolate it. The Swedish chemist left his name to the mineral, which remains a very important tungsten ore. It would represent 70% of the world reserves of this element. When very pure, scheelite exhibits a sky-blue fluorescence when illuminated with a short-wave length ultraviolet light ; it then becomes easy to spot in mines. However, the presence of iron in impurities, as in specimen #16356, removes this property.

## — Sturmanite

Mineralogy is a science that is still evolving. New minerals are discovered every year. Sturmanite was discovered in 1983. This mineral is found in only two places in the world, only one of which has provided beautiful crystals. These are the N'Chwaning mines in the Kalahari Desert in South Africa. It is therefore not surprising to see the origin of the beautiful crystal #83308. The chemistry of sturmanite is surprising: this mineral is largely made of water ! Indeed, four out of five atoms are part of a water molecule or a hydroxide group. Its cousin, ettringite, is very similar to it. It is also very important to distinguish them as both have very similar shapes, density, brightness and colors.



N°83308 - display L34

# Room N

5% of mineral species are phosphates. They are composed of the group  $[\text{PO}_4]^{3-}$  combined with Rare Earth Elements and metals. They may also contain water molecules, uranium, fluorine or chlorine. Phosphorus is the 6<sup>th</sup> element present in the human body.

## — Brazilianite

N°6124 - display N23



In 1942, at Corrego Frio (Minas Gerais, Brazil), a farmer discovered a few kilograms of a greenish mineral that was first mistaken for beryl or chrysoberyl. The deposit was therefore mined, but the lapidaries quickly realized that the mineral in question was relatively soft and therefore of limited interest for jewellery. Three years later, two Americans identified it as a new phosphate, Brazilianite, named after its country of origin. The small Corrego Frio mine was opened the same year by the American merchant E. Swoboda, who operated it for two years. It was during this research that the most beautiful brazilianite crystals in the world were extracted. Some well-crystallized, translucent, olive-green to chartreuse-green individuals reach two kilograms. While other deposits have subsequently been discovered in the area, most of our specimens come from this mine, which is the type locality. Crystal #6124 is remarkable, but the Mineralogy Museum also has an exceptional piece, 16 centimeters high, displayed in the J8 display case (#8814), which is probably the best brazilianite crystal ever found.

## — Vanadinite

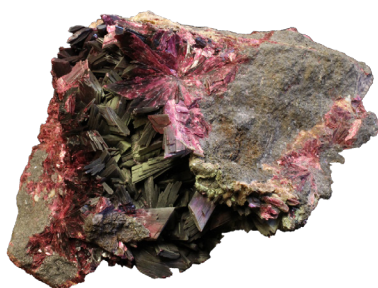
Vanadinite is a relatively rare mineral that contains chlorine, lead and vanadium. The simultaneous presence of these elements with different chemical behaviours explains the rarity of this mineral. Vanadium tends to be found in silicate minerals while lead has an affinity for sulfur. The conditions for bringing them together and concentrating them to the point of forming crystals such as #16728 do not occur frequently. It takes place in the context of an alteration zone, linked to water infiltration of the upper parts of lead deposits, known as the "iron cap". The primitive cell of vanadinite crystals has a hexagonal symmetry. This internal structure is often visible on a large scale: this mineral often crystallizes in hexagonal prisms, and sometimes hexagonal pyramids.



N°16728 - display N27

## — Erythrite

N°3164 - display N29



Erythrite crystals, frequently grouped into spray and rosettes of an intense purple color, are among the most sought-after specimens of collectors. They are produced during the alteration of arsenic-rich minerals by infiltration of water in cracks and breaks of rocks, at shallow depths. To find beautiful erythrites, one has to travel to Schneeberg (Saxony) and especially to Bou-Azzer (in southern Morocco). It is from this last locality that the formidable series of two specimens, each composed of numerous crystals reaching 2 cm (#3164 and 3165), comes from. They were considered to be among the best in the world. They were collected by Mr. Bertheau in 1959 during a memorable mission organized by the S.C.E.M.

## — Monazite

Monazite crystal #16727 is a remarkable example. Indeed, monazite is a rather rare mineral, especially in such large crystals. Most of the time, it is found in alluvium, in the form of small grains. Despite their limited abundance, monazite deposits are the second largest reservoir of Rare Earth Elements (see bastnäsite, room B). Among its countless uses, are permanent magnets, superconductors, lasers, aeronautics and medical imaging. This crystal was added to the collection in 1985, at a time when the industrial mining of monazite had not reached its current peak. It was found in central Madagascar in a rock formation made of granulite. These coarse-grained rocks, composed mainly of quartz and feldspar, are characteristic of a fairly advanced metamorphism, at very high temperatures and moderate pressure. Further analyses indicate that they were first formed 2.5 billion years ago and then underwent this metamorphism several times, especially during the formation of the Gondwana supercontinent.



N°16727 - display N20

## — Pyromorphite



N°8016 - display N26

Pyromorphite is one of three or four mineral species forming large crystals, the best pieces of which have been found in France. The most appreciated specimens, of a bright apple green color, were first found in Vézis (Aveyron), where specimen #8016 from our collection comes from. It was acquired in 1962 by the S.C.E.M. More recently, very beautiful groups from the Farges lead mine (Corrèze), and especially from the Daoping and Yangshuo mines in Guangxi, China, have appeared on the market. The latter have intense green hues, so spectacular that they seem to be artificial.

## — Odontolite

The odontolites (word formed from the Greek odontos, "tooth", and lithos, "rock"), mainly found in the Pyrenees region, have been a source of curiosity since at least the Middle Ages. Long confused with turquoise because of its colors ranging from green to pale blue, this material has been used to make art objects. Many scholars have studied this strange stone. Let us mention in particular Réaumur (1683-1757) who documented the way in which the heat modifies the color of these so-called "western turquoises". It is only very recently that light has been shed on its precise composition and the reasons for its coloring. It is fossil ivory (ivory, like mammalian teeth and bones, is composed of apatite), colored by trace amount of manganese ( $Mn^{5+}$ ). This specimen comes from the collection of the Marquis de Drée. Brother-in-law of the famous geologist Dolomieu, politician and enlightened mineralogist, he gathered an impressive mineralogical collection of nearly 15,000 pieces, sold at the School of Mines between 1810 and 1845.



N°3230 - display N25



# Room O

The basic structure of silicates is the tetrahedron  $[\text{SiO}_4]^{4-}$  which combines itself with other elements. Tetrahedra can polymerize to form circles (cyclosilicates), chains (inosilicates), planes (phyllosilicates) or three-dimensional structures (tectosilicates).

## — Beryl

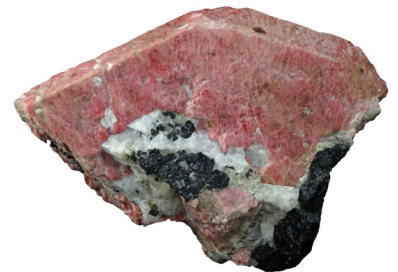
N°4742 - display O53



About 100 kilometers northwest of Bogota, Colombia, sits an area known as the "green triangle". The abundance and quality of emeralds (green variety of beryl) found in this area allows the country to deliver more than half of the world production of this mineral. The Muzo mine, from which this exceptionally intense color specimen comes from, was in operation at least five centuries before the arrival of the Spanish conquistadors. Still in operation, this mine has provided the most beautiful gems in the world over centuries ; a perfect example of this is the legendary 1384-carat emerald of the Duke of Devonshire, which can be seen at the Museum of Natural History in London. Under tension, the region is not recommended for tourists; it arouses the greed of prospectors who, like in the time of the conquistadors, hope to become multimillionaires in a single blow of a pickaxe... or fire!

## — Rhodonite

Rhodonite is a silicate belonging to the group of pyroxenoids (silicates whose  $\text{SiO}_4$  groups are arranged in chains). This mineral often crystallizes in small size grain rocks, without well defined faces, marked by black veins of manganese oxides. Very rarely, it can crystallize to form well defined faces, such as shown in #15559. This very regular crystal is one of the largest in the world. It comes from the famous Franklin mine in the United States. Located about 60 kilometers from New York, this iron and zinc mine was very active from the 18<sup>th</sup> century until its closure in the 1950s. Many varieties of new minerals have been described from there. It can claim a special place in the country's industrial history; the metals it produced are probably found in New York's skyscrapers.



N°15559 - display O53

## — Okenite

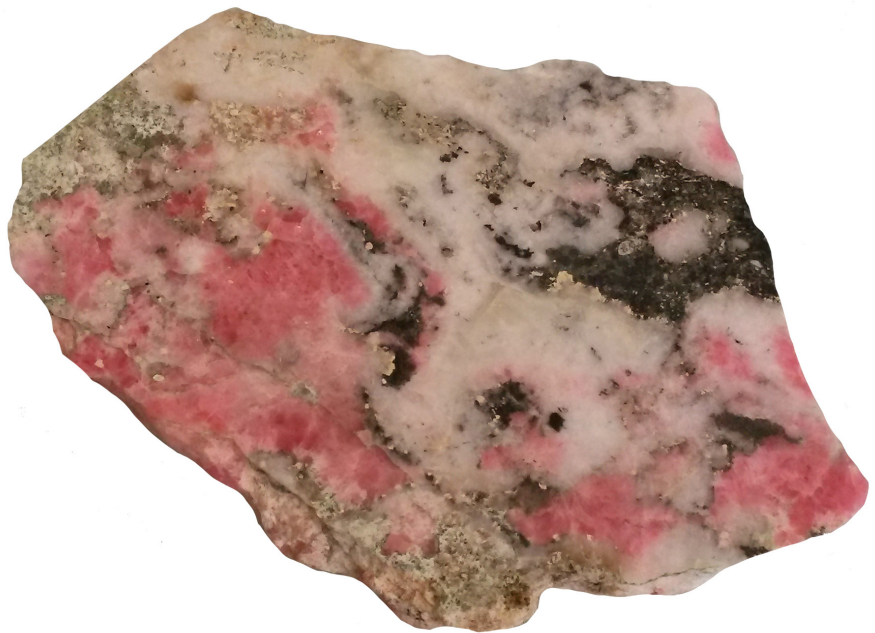
N°163846 - display O66



As fine as a hair and quite brittle, these small okenite needles are to be handled with care! The slightest contact damages them, which makes it difficult to transport them. Most of the time, this mineral forms small cotton-looking balls coating cavities of basaltic rocks, and are often associated with zeolites. Okenite has also been detected as tiny crystals in old and chemically altered cement. These elements suggest that okenite geodes in basalt are formed by alteration of surrounding silicates. These samples come from the Deccan region of India. About 65 million years ago, this region suffered a series of cataclysmic volcanic eruptions. In a few tens of thousands of years, piles of lava flows have covered the equivalent of three times the surface of France under two kilometers of lava! This phenomenon, called volcanic traps, is associated with the disappearance of dinosaurs.

## — Tugtupite

Tugtupite is a very rare mineral, discovered in the 1960s in Tugtup (a name that means caribou in Inuit language), Greenland. This sample was extracted not far from this type locality and passed through the Copenhagen Museum before entering our collection in 1965, as part of an exchange. Since its discovery, this mineral has been found in only two other locations (in North America and in the Kola Peninsula of Russia). Tugtupite, like hackmanite (another feldspathoid of the sodalite group) has an original property : it is tenebrescent. When it is placed in sunlight, its color is strengthened. The phenomenon is reversible: a few days in the dark and its color fades again.



N°16865 - display 078

## — Feldspar group

Feldspar : plagioclase (albite to anorthite)  
or alkaline (orthoclase, sanidine, microcline)



N°6271 - display 075

In the feldspar family, there is quite a crowd ! From the legendary 50 meter long Devil's Hole microcline crystal to the dashing little labradorite jewellery, not to mention the alkaline feldspars used in the manufacture of ceramics or those used in paints... They take various forms and can be found everywhere! This group of minerals is the most abundant on the globe (and in the Universe?) : they are found in more than 60% of the rocks on the Earth's surface, most of the time in magmatic and metamorphic rocks. Beautiful crystals are quite rare since pegmatite veins are prone to fracture and erosion, leaving few crystals intact. Amazonite (#16865, the green-blue variety of microcline) is part of this family. It has long been assumed that its color comes from traces of copper, as this element often produces similar shades. In the 1980s, studies showed that the color came more likely from lead and water impurities.

## — Whewellite

Most of the time, this mineral does not nestle in rocks, but in... our kidneys ! Renal stones are composed of calcium oxalate, also known as whewellite. Under certain circumstances, this mineral may crystallize underground. This requires low-temperature hydrothermal fluids to come into contact with carbon-rich rocks. The complex chemical reaction, involving the partial oxidation of these rocks, leads to the formation of oxalic acid. This double crystal, found near Chemnitz, Saxony, proves this process. It comes from deep veins (1500 meters deep) rich in uraninite, native silver and various sulfides, hosted in carbonate rocks. The richness of these veins has made it an important place since the Bronze Age. It is one of the oldest traces of the transition to large-scale metallurgy, heralding a kind of industrial revolution.



N°6225 - display 084



# Room O

Silicates are the most important family of minerals both in terms of diversity and representativeness. About a third of known minerals belong to it. They are by far the most abundant minerals found on Earth : 97% of the crust's weight is composed of silicate !

## — Zircon

N°15659 - display O42



Zircon is a mineral that crystallizes from magmatic rocks. It is excessively resistant to alteration and metamorphism. Therefore sometimes the rocks containing them disappear, but the zircons are preserved. Over the succeeding geological eras, some zircons can therefore be found successively trapped in different rocks. As a result, tiny zircon crystals from Australian rocks have been recognized as the oldest remaining minerals on Earth. The oldest are 4.3 or 4.4 billion years old, only a hundred million years after the planet's formation. Radioactive elements with long decay time such as some of the isotopes of uranium, thorium and lead, present at trace levels, are used for dating. The Harts Range region of Australia, where #16490 has been found, has much more recent zircons ("only" 1.7 billion years), but of impressive size and quality. This is one of the very few deposits where zircons are found that are suitable for jewellery use. Be careful not to confuse zircon (the natural zirconium silicate) with cubic zirconia (the artificial zirconium oxide). It is the latter, very hard and with a lot fire, that is frequently used to make imitations of diamonds.

## — Grandidierite

Grandidierite is an extremely rare silicate, rich in boron. It was first observed by Alfred Lacroix in 1902 in the cliffs of Cape Andrahomana, west of Fort Dauphin, Madagascar. Its rarity can be understood by considering that boron is present only in very low concentrations within the solid Earth. Rather, it tends to concentrate in the ocean floor, sediments or evaporative deposits (large salt lakes), areas that are generally low in silica. Specimen #16093 is the most famous grandidierite crystal to date. It is a perfect flat, striated and long crystal of 10 cm, perfectly terminated on one end, transpiercing its matrix. This mineral is prized by collectors and recently cut into rare gemstones. It shows pleochroism: depending on the angle at which it is observed, it may appear pale blue, dark blue, greenish, brown-yellow, etc.



N°16093 - display O47



## — Olivine group



N°45645 - display O39

Olivine is a common silicate, having an intermediate chemical composition between the ideal poles of forsterite (magnesium-rich pole -  $\text{Mg}_2\text{SiO}_4$ ) and fayalite (iron-rich pole -  $\text{Fe}_2\text{SiO}_4$ ). For example, in crystal #45645, there is about 5 times more magnesium than iron (one could write  $\text{Mg}_{1.7}\text{Fe}_{0.3}\text{SiO}_4$ ). It was found near Sapat, Pakistan. This deposit provides the jewellery market with the best quality gem olivine, marketed under the name "Kashmir peridot". Due to extreme weather conditions, operations can only take place between June and September. Indeed, this deposit is located at an altitude of more than 4,000 meters in the Himalayan range. It consists of dikes rich in magnetite intersecting peridotite. The fact that peridotite, a rock typical of the Earth mantle, is found at such a high altitude, seems surprising. This is actually a testament to the power of tectonic forces causing the slow surrection of mountains.

## — Garnet group

Garnet is not a single mineral, it covers a whole family of minerals. Subtle variations in chemical composition cause beautiful variations in color: orange for most spessartines, green in some andradites (demantoid). This family is appreciated in jewellery. However, their main use is industrial: their strong hardness makes them suitable for many abrasive materials. If their composition varies, garnets often show a common geometry. Many of them present diamond-shaped faces, and are called "rhombic dodecahedron". Spessartine is a rare garnet variety, rich in manganese. Specimen #16622, of remarkable size and regularity, is from the Broken Hill mining region in Australia. The mineral deposits found there appear to be the 1.8 billion years old and are similar to the current "black smokers". The intense metamorphism endured by these terrains, over thousands of years, has greatly changed the rocks. The minerals have recrystallized and the result is spectacular, since it is one of the most diversified - and best studied - mineral assemblies in the world. More than 1,500 type minerals have been discovered there.

Andradite is another rare type of garnet that can present colors ranging from black to green, brown, red and yellow. The so-called "demantoid" variety is the most valuable. It has a green color, the intensity of which is related to the amount of chromium replacing iron. Sometimes with a comparable color, demantoid has fires that emerald lacks. Specimen #15736, with large crystals of demantoid on a serpentinized rock, obtained by the museum in 1970, is considered as one of the best in the world. It comes from the Val Malenco in the Lombardy Alps. Demantoid is found in serpentinite-filled cavities that are extremely difficult to access.



N°15736 - display O42



N°16622 - display O41