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Educational case "Mines and minerals"

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Canada

"Mines and Minerals" Case

Assembled by Valérie Bécu, Anne-Aurélie Sappin and Stéphanie Larmagnat, GSC-Quebec

The purpose of the educational case project is to facilitate scientific awareness and outreach activities by assembling simple and educational content as well as ready-to-use facilitation scenarios, all contained in sturdy cases with wheels and handles for easy handling, transport and storage (Figure 1.1). This initiative received financial support from the Canadian Geological Foundation (Grant 19-26) as well as the Geological Survey of Canada, Quebec division (GSC-Quebec) in addition to several donations (samples and others) from several GSC-Quebec staff members and their entourage. The material assembled is intended to be a starting point that can be modified and adapted as presenters see fit for various scenarios and facilitation contexts. As such, the content of this guide should not be considered exhaustive and can easily be modified to reflect the resources available in each province or territory.

Figure 1.1: "Mines and Minerals" case with additional material for exhibitions on ores and minerals present in everyday objects and for activities pertaining to the physical properties of minerals. The carrying case measures 68.6 X 27.9 X 53.3 cm and has a total weight of approximately 25 kg (27 X 11 X 21 inches and 55 lb).

The "Mines and Minerals" case contains a collection of minerals and ore samples representative of some of Canada's leading mineral resources, as well as everyday items in which the elements and metals derived from these minerals and ores are used (see the documents contained in folder *2- Minerals and everyday objects*). The purpose of this exhibition is to raise public awareness regarding the presence and importance of minerals in our modern lifestyle and thus promote the interest of geoscience for society. This toolkit also contains copies of a children's book (Figure1. 2) published by the Québec Mining Association (QMA), which explains how metals extracted from mines are used in everyday objects (only available in French). This book could be supplied to teachers after classroom workshops. Moreover, the exhibition contained in the "Mines and Metals" case offers the presenters a variety of samples of gold and base metal ores, such as copper, zinc and nickel, illustrating the diversity of types of deposits and mineralization styles present in Canada with ore specimens from Quebec and Ontario (see *Section 3- Ore and mines*). While offering a good opportunity to inform the public about the mining industry's good practices (see *Section 5b-Challenges-and-industry-innovations*), this collection of ore samples makes it possible to explain that gold is mainly found in association with or included in certain minerals instead of in its native or pure form. This means that the gold mined nowadays is found, in many cases, in the form of complex ore, contrary to what was the case historically, as during the Klondike Gold Rush, for example, when prospectors were looking for nuggets.

Figure 1.2: "À bord les trésors", book published by the Québec Mining Association (QMA) that presents uses of metals in everyday items (target audience ages 4 to 8). Only available in French.

The complementary material contained in this case also allows presenters to address some of the physical properties of minerals (for example: colour, hardness and magnetism) and their usefulness in identifying them through a semi-supervised exercise. To do this, six kits are available to use with a mineral identification placemat developed by the Canadian Museum of Nature (© Canadian Museum of Nature), and for which the GSC has obtained a non-exclusive and non-transferable licence for reproduction and use. Samples of ulexite and birefringent calcite (two samples) are also included to address optical properties of minerals.

The two exhibitions, namely the one concerning minerals used in everyday objects (*Section 2- Minerals and everyday objects*) and the one presenting various examples of gold and base metal ores (Section *3-Ore and mines*), in addition to individual toolkits and placemats for a mineral identification activity, can be transported together in the carrying case shown in Figure 1.1 (see inventory *Case Mines and Minerals* on pages 4-6). A smaller case (55.9 X 25.4 X 43.2 cm with a total weight of approximately 13.6 kg or 22 X 10 X 17 inches and 30 lb) is also available to transport only the material pertaining to minerals used in everyday objects (objects and samples inventory *Case Minerals and everyday objects* on pages 7-8). A portfolio, as shown in Figure 1.1, can then be used to transport the placemats and toolkits necessary for the identification activity based on the physical properties of minerals.

Content structure for the “Mines and Minerals” case

Thanks to Patrick Mercier-Langevin for critically reading the document. His comments and suggestions helped to improve and clarify the content.

Sources:
http://www.canadiangeologicalfoundation.org/
https://www.nrcan.gc.ca/science-and-data/research-centres-and-labs/geological-survey-canada/17100

Niveau supérieur/ Upper level

MALLETTES « MINES ET MINÉRAUX »/ “MINES AND MINERALS” CASE

Inventaire niveau supérieur/ Upper level inventory:

1. Ensemble de neuf minéraux et d’outils pour l’activité interactive « Clé d’identification des minéraux » *(voir encadré)* / Kit of nine minerals and tools for the interactive activity “Mineral Identification Key” *(see inset).*

2. Ulexite (roche TV) et calcite biréfringente pour une activité sur les propriétés optiques des minéraux/ Ulexite (TV stone) and birefringent calcite for an activity on optical properties of minerals.

3.Objets pour exposition « Métaux et minéraux dans notre vie quotidienne» / Everyday objects for the exhibit “Metals and minerals in our lives”.

Niveau médian/ Mid-level

MALLETTES « MINES ET MINÉRAUX »/ "MINES AND MINERALS" CASE

Inventaire niveau médian/ Mid-level inventory:

4. Mine: Stockwerk minéralisé (Au), mine Éléonore, Eeyou Istchee Baie-James, Qc / Mine: Mineralized stockwork (Au), Eleonore mine, Eeyou Istchee Baie-James, QC
5. Mine: Stockwerk minéralisé (Au), mine Éléonore, Eeyou Istchee Baie-James, Qc / Mine: Mineralized stockwork (Au), Eleonore mine, Eeyou Istchee Baie-James, QC
6. Minéral: sphalérite / Mineral: sphalerite
7. Minéral: magnétite / Mineral: magnetite
8. Minéral: halite / Mineral: halite
9. Minéral: spodumène / Mineral: spodumene
10. Styromousse pour soutenir échantillons de mines / Styrofoam for mine samples support
11. Échantillon de leucogabbro (roche) avec des phénocristaux de plagioclases (minéral) / Leucogabbro (rock) sample with plagioclase phenocrysts (mineral)
12. Minéral: chalcopyrite et cuivre natif / Mineral: chalcopyrite and native copper
13. Minéraux: eudialyte et talc / Minerals: eudialyte and talc
14. Minéraux: biotite, muscovite, talc / Minerals: biotite, muscovite, talc
15. Minéral: graphite / Mineral: graphite

Niveau inférieur/ Lower level

MALLETTES « MINES ET MINÉRAUX »/ "MINES AND MINERALS" CASE

Inventaire niveau inférieur/ Lower level inventory:

16. Fiches minéraux (FR) - affiche « Du roc à la technologie - cellulaire »
17. Mine: échantillons d'or visible de la zone « high grade », mine Red Lake, On / Mine: sample with visible gold, Red Lake mine "high grade zone", ON
18. Mine: or orogénique, mine Beaufor, Val d'Or, Qc / Mine: orogenic gold. Beaufor mine, Val d'Or, QC
19. Analytique: nodule de pyrite aurifère et lames-mince / Analytical: gold bearing pyrite nodule and thin section
20. Mine: or orogénique, mine Beaufor, Val d'Or, Qc / Mine: orogenic gold, Beaufor mine, Val d'Or, QC
21. Loupes pour activité pour activité « Clé d'identification des minéraux » / Hand lenses for the "Mineral Identification Key" acitivity
22. Mine: sulfures massifs volcanogènes, mine LaRonde, Preissac, Qc / Mine: volcanogenic massive sulphides, LaRonde mine, Preissac, QC
23. Mineral cards (EN) - poster "From Rock to Technology - cellphone"
24. Mine: sulfures massifs volcanogènes, mine LaRonde, Preissac, Qc / Mine: volcanogenic massive sulphides, LaRonde mine, Preissac, QC
25. Mine: Ni-Cu-ÉGP magmatique, mine Raglan, Cap Smith, Qc / Mine: magmatic Ni-Cu-PGE, Raglan mine, Cape Smith, QC

Niveau supérieur/ Upper level

MALLETTE « MINÉRAUX ET OBJETS VIE QUOTIDIENNE »/ "MINERALS AND EVERYDAY OBJECTS" CASE

Inventaire niveau supérieur/ Upper level inventory:

1. Ulexite (roche TV) et calcite biréfringente (2 échantillons) pour une activité sur les propriétés optiques des minéraux / Ulexite (TV stone) and birefringent calcite (2 samples) for an activity on optical properties of minerals.

2. Objets pour exposition « Minéraux dans les objets de la vie quotidienne » / Objects for exhibit "Minerals in objects from everyday life".

Niveau inférieur/ Lower level

MALLETTE « MINÉRAUX ET OBJETS VIE QUOTIDIENNE »/ "MINERALS AND EVERYDAY OBJECTS" CASE

Inventaire niveau inférieur/ Lower level inventory:

1. Minéral: graphite / Mineral: graphite
2. Minéral: magnétite / Mineral: magnetite
3. Minéral: sphalérite / Mineral: sphalerite
4. Échantillon de leucogabbro (roche) avec phénocristaux de plagioclases (minéral) / Leucogabbro (rock) sample with plagioclase phenocrysts (mineral)
5. Minéral: talc (2 échantillons) / Mineral: talc (2 samples)
6. Minéraux: biotite et muscovite / Minerals: biotite et muscovite
7. Minéral: spodumène / Mineral: spodumene
8. Minéral: halite / Mineral: halite
9. Minéral: eudialyte / Mineral: eudialyte
10. Minéral: chalcopyrite et cuivre natif / Mineral: chalcopyrite and native copper

Section 2: Minerals and everyday objects

Minerals and their constituent elements are used in manufacturing various products or in industrial processes thanks to their physical or chemical properties. What would life be like without metals or minerals: no steel, no electricity, no plumbing, no household appliances, no aircrafts, and no automobiles? Have you ever realized that minerals are also involved in manufacturing cosmetics, drugs, vitamins, and all the electronic devices we use!

Figure 2.1: "Minerals and Everyday objects" exhibition with one of the rigid posters accompanying the toolkits (From Rock To Technology – courtesy of the CIM Foundation)

The case contains a collection of ten minerals associated with certain examples of use in everyday items (Figure 2.1). In nature, these minerals are found in variable concentrations in various geological contexts and types of rocks. Some key chemical elements, such as certain metals and other elements considered critical to our current lifestyle are extracted from these minerals, which must first be concentrated by different mechanical and chemical processes. The metals and other elements derived from these materials (e.g. copper in chalcopyrite) then can be incorporated into the manufacturing of several consumer goods and other industrial applications. Although some metals can be found occasionally in their pure state (e.g. gold or copper, then said to be "native"), the majority are associated with other chemical elements to form a crystalline solid (mineral). In some cases, the mineral itself is used instead of only some of its constituents - for example, micas in cosmetics. Some of the samples in the toolkit contain minerals and/or elements identified as critical for Canada (Figure 2.2). Essential for applications related to renewable energy and clean technologies (e.g. batteries, permanent magnets, solar panels and wind turbines), these minerals and elements are also necessary inputs in the supply chains linked to high-tech manufacturing, particularly for defence and security technologies, mass market electronic products, agriculture, medical applications and critical infrastructures. Critical infrastructures (CI) refers to processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of public institutions. (source: https://www.publicsafety.gc.ca/cnt/ntnl-scrt/crtcl-nfrstrctr/cci-iec-en.aspx)

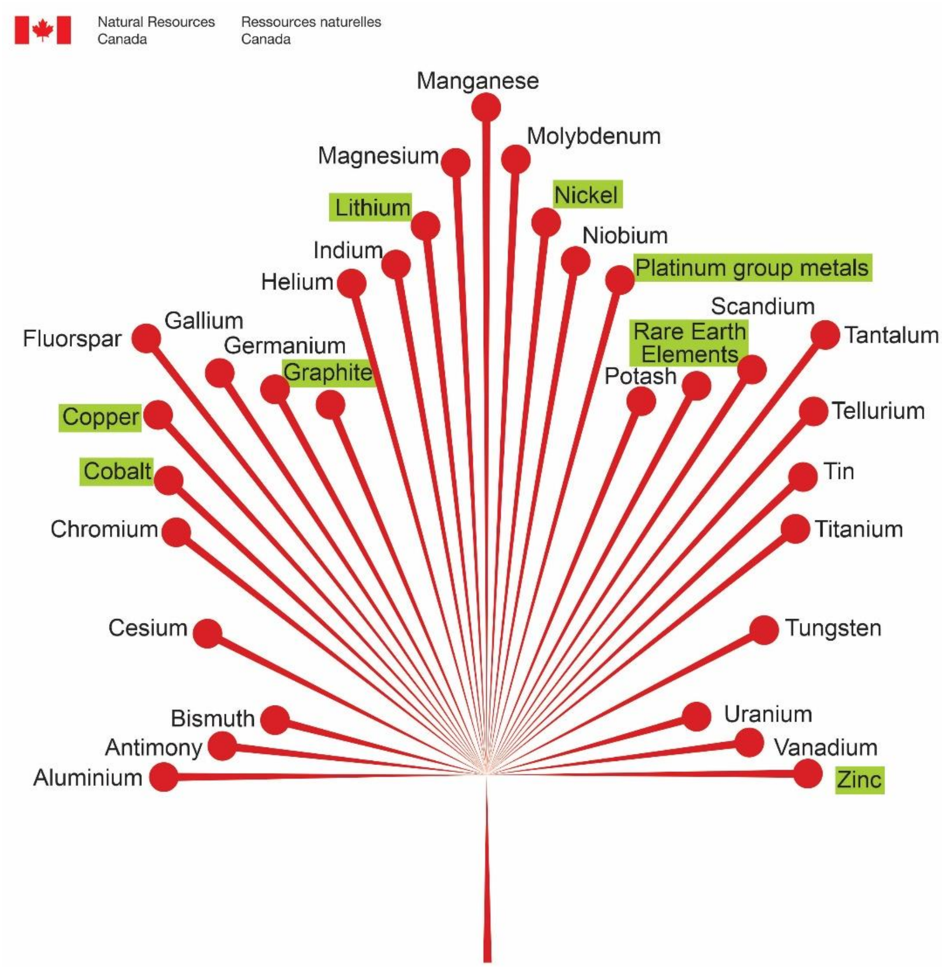

Figure 2.2: List of Canada's critical minerals, as published in 2021. The minerals and metals highlighted in green correspond to examples contained in the "Mines and Minerals" case.

A portable tripod and two rigid (Coroplast) posters accompany the mineral collection and are stored with the carrying case.

1- *From Rock To Technology* – minerals providing elements involved in the manufacturing of cellular phones (courtesy of the CIM Foundation)
2- “Les minéraux, leur composition et leur utilisation quotidienne” [Minerals, their composition and their everyday use] – Ministère des Ressources naturelles et des Forêts [in French]

PDF versions of these posters are also available in the “2- Minerals and everyday objects” folder.

<u>What's the difference between a rock and mineral?</u>

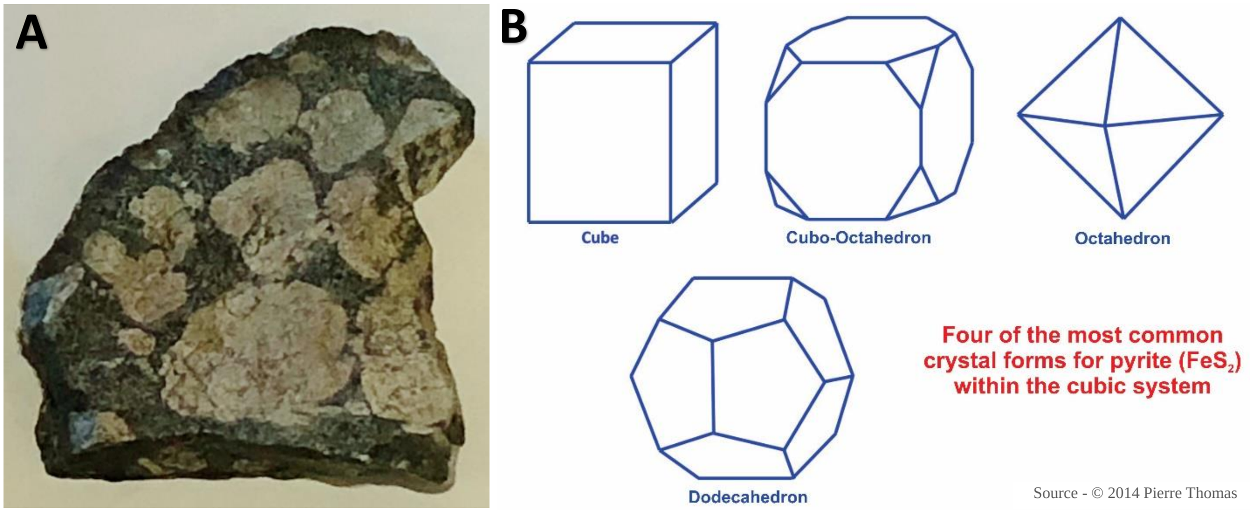

Figure 2.3: *A) Example of a rock, in this case a porphyritic gabbro, composed of plagioclase minerals (silica and aluminium based mineral) whitish in colour surrounded by a matrix of fine dark-coloured minerals composed essentially of amphibole (pyroxene) and chlorite (silica, iron, magnesium and calcium based minerals). B) Example of various crystalline forms that pyrite (FeS_2) can take in the cubic system, one of the seven major crystalline systems.*

A rock is a generally solid material formed by an array of minerals (Figure 2.3A). The rocks are composed of minerals and the minerals are composed of chemical elements. A rock can be composed of one or more mineral species (e.g. granite composed of quartz, feldspar and biotite versus marble that is essentially composed of carbonates).

A mineral is a natural homogeneous solid with a defined (although not fixed) chemical composition with a very orderly atomic arrangement. It is generally formed by inorganic processes. There are seven major crystalline systems (cubic, quadratic, hexagonal, rhombohedral, orthorhombic, monoclinic and triclinic) defined by a basic polyhedron that corresponds to the simplest shape based on which a given mineral will form. It should be noted that a crystalline system encompasses several crystalline shapes and a mineral will often crystallize under a variety of shapes (see the example of pyrite in Figure 2.3B).

The sample in Figure 2.3A shows whitish plagioclase minerals embedded in a matrix of finer amphibole (pyroxene), plagioclase and chlorite crystals. This rock is called a gabbro on the basis of the relative abundance of the constituent minerals. This gabbro has a so-called porphyritic texture because very large crystals are embedded in a finer rock matrix. An analogy with ingredients (minerals) going into the making of chocolate chip cookies (rocks) where certain elements remain quite visible (chocolate chips in cookies and plagioclase in the example above) can be used to properly illustrate the difference between a mineral and a rock.

HALITE

Figure 2.4: Halite sample from the Seleine mine located in the Magdalen Islands, Quebec (donated by V. Bécu).

Halite is a sodium chloride (NaCl) best known as salt (Figure 2.4). Although essential to our diet, salt is also widely used as a de-icing material for roads, sidewalks and stairways during the winter.

The sample in our collection comes from the Seleine mine, located at Grosse-Ile, in the Magdalen Islands. This is the only salt mine in Quebec. The Magdalen Islands are located at the centre of a vast marine shoal called the Magdalen Shallows. About 360 million years ago, these shallows were located at the Equator. At that time, they formed in a valley exposed to the sun. Periodically, the sea filed this valley with salt water. The water evaporated under the sun's rays, leaving salt deposits. For several million years, hundreds of metres of salt crystals accumulated, then assembled and hardened to form salt rocks. With continental drift the Magdalen Shallows left the Equator to reach their current position in the Gulf of St. Lawrence. The salt domes maintain the Magdalen Islands on the surface of the Gulf of St. Lawrence.

Sources:
http://www.attentionfragiles.org/en/who-we-are/15-transport-ecologique.html
http://minesqc.com/fiches-dinformations/mines-seleine-seule-mine-de-sel-au-quebec/#_ftn1

GRAPHITE

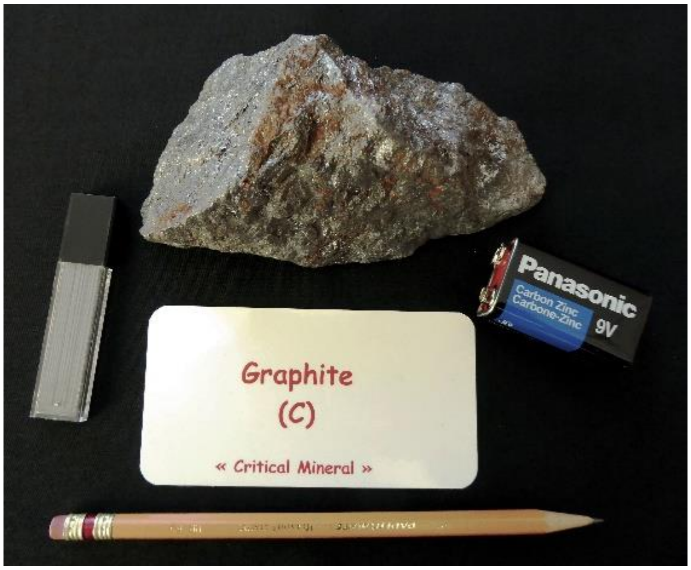

Figure 2.5: Graphite and objects of everyday life in which it is used (Minroc Science Inc.).

Graphite (C – Figure 2.5) is a soft mineral (hardness of 1.5 on the Mohs scale) and its greasy and shiny lustre have made it an excellent substitute for lead, an element with which it was associated until the 18th century. The mineral was then called graphite in reference to its use in writing. Originally used in its raw state in the manufacturing of pencil leads, graphite is now mixed with ceramic clay, making it possible to vary the hardness of the lead based on what proportions of the two materials are used. The higher the proportion of ceramic clay, the harder the pencil lead and inversely, if there is more graphite, the pencil lead will be softer and provide a thicker and darker pencil mark. Today, manufacturers use numberings associated with the letters H (hard) and B (bold) to indicate the various degrees of hardness in their pencils.

Graphite is also an essential component in the manufacturing of lithium-ion batteries that power electric vehicles and most of our other electronic devices such as cellphones, laptops, smartwatches, etc. It is the main material in the making of anodes, the part of the battery that absorbs current. Interesting fact, lithium-ion batteries require 20 to 30 times more graphite than lithium. Thus 10 kg of graphite are required for a hybrid vehicle whereas an entirely electric vehicle needs 40–50 kg.

In Quebec, graphite is mined at the Stratmin mine in the Lac-des-Îles sector south of Mont-Laurier in the Upper Laurentians. Graphite mineralization is associated with bands of dolomitic marble, calcitic marble*, quartzite and calc-silicate rocks found in the Central Belt of metasedimentary rocks of the southwestern Grenville Province. The Matawinie Project is also under development in Saint-Michel-des-Saints in the Lanaudière region. This project, spearheaded by the company Nouveau Monde Graphite, is looking to become the largest open pit mining operation entirely operated using electric vehicles. Graphite occurs in fine to coarse granules, disseminated in the biotite-graphite paragneiss in variable thicknesses (10–15 m). It is locally accompanied by iron sulphides (pyrrhotite, pyrite). (*see sample contained in the "Sedimentary Rock and Fossils" case)

Sources:
https://www.lateliercanson.com/le-crayon-mine graphite#:~:text=1.,d'une%20vari%C3%A9t%C3%A9%20de%20plomb.
https://nmg.com/operations/
https://gq.mines.gouv.qc.ca/portail-substances-minerales/graphite/
For additional information regarding lithium-ion batteries, refer to "Section 5a- Critical Minerals".

Graphite and diamonds are both polymorphs of carbon, i.e. they are both exclusively composed of carbon atoms, but they are crystallized based on different structures under distinct pressure and temperature conditions. The carbon in graphite forms hexagonal structures placed in layers one on top of the other (sheets), making the mineral very friable. In diamonds, the atoms are organized in a more tri-dimensional structure that is responsible for this mineral’s exceptional hardness (hardness of 10 on the Mohs scale).

Diamonds are refractory xenocrysts (crystals that are foreign to the magma in which they are found), pushed up by kimberlite magma* to the sub-continental lithospheric mantle (Figure 2.6). Here, the magma is just a vehicle transporting the diamonds quickly to the surface under high-pressure and high-temperature conditions, preventing them from transforming into graphite. (*see sample of kimberlite contained in the “Magmatic Rocks” case)

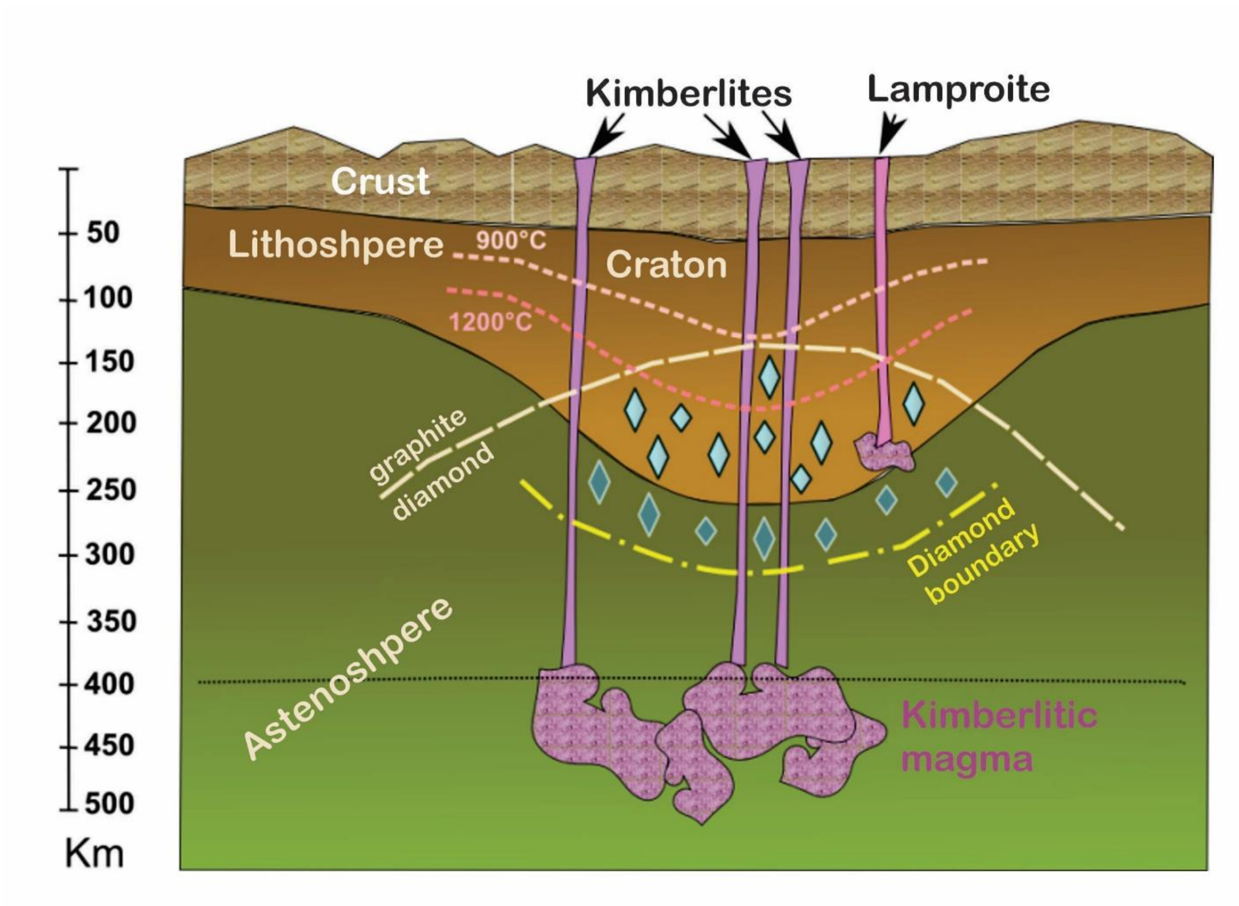

Figure 2.6: Diagram illustrating the various stability fields for graphite and diamonds as well as the mechanism for diamonds coming to rest in the continental crust when pushed up by the kimberlite magma, located at great depths in the earth's mantle. (source : https://www.pairform.fr/doc/17/138/500/web/co/grain2_1_2.html)

BIOTITE and MUSCOVITE

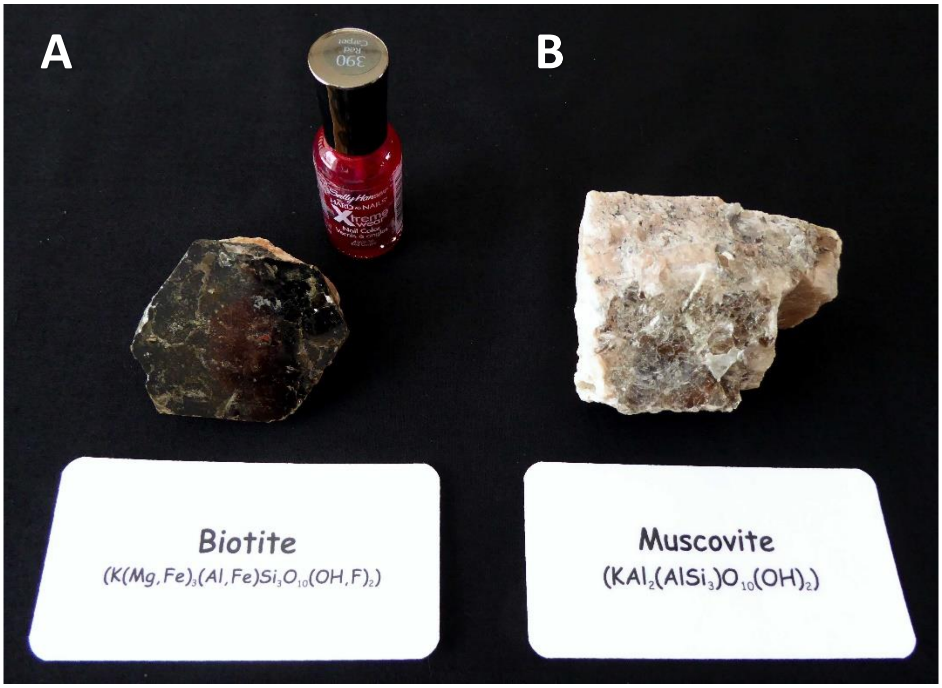

Figure 2.7: A) Biotite sample exhibiting thin hexagonal sheets and example of its use in cosmetics. B) Muscovite sample showing translucent flexible sheets. The two samples come from the GSC-Quebec collection.

Biotite ($K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$) and muscovite ($KAl_2(AlSi_3)O_{10}(OH)_2$) (Figure 7A and B) are mica varieties that belong to the phyllosilicate group, like talc. These minerals present a perfect cleavage and are constructed by stacking of tetrahedral layers, which gives them a multi-layered structure conferring them plastic and absorbent properties, in addition to great thermal resistance. Biotite and muscovite are mined for their physical characteristics rather than their chemical compositions.

Micas are used in household appliances (toaster, microwave oven) for their electrical insulating and heat resistance properties. Chemically inert with good covering characteristics, they are also used in paint, plastic, rubber, ceramic, joint compounds, plaster, roof shingles and decorative items. They are also used in manufacturing of pigmented products, such as makeup powders and nail polish, to provide opacity (or better coverage) and give the products a sparkling effect.

In Quebec, micas, particularly phlogopite, which is a highly magnesian variety of biotite, have been used intermittently at the Lac Letondal mine in Haute-Mauricie for nearly 50 years.

Source:
https://mern.gouv.qc.ca/mines/industrie/mineraux/mineraux-proprietes-micas.jsp

CHALCOPYRITE

Figure 2.8: Sample of chalcopyrite, a brassy yellow mineral with metallic lustre, from the Rouyn-Noranda area in Abitibi, Quebec (donated by P. Mercier-Langevin) with an example of native copper (GSC-Quebec collection) and objects in which it is used.

Chalcopyrite is an iron and copper sulphide ($CuFeS_2$ – Figure 2.8). Although copper is occasionally found in its native state in nature, copper sulphides such as chalcopyrite are the most common constituent of copper ores. Copper has been known for a very long time and was the first ever metal worked by humans because it is relatively malleable. Ancient traces of copper melting date back to the first half of the 5^{th} millennium BC. Once alloyed with tin, copper became the basis of a technological revolution; the bronze age (2300 years BC). More recently, the ability of copper to conduct electricity make its essential for renewable energy.

Copper is used in various industries, such as the manufacturing of various equipment, and in building and infrastructure construction projects. It can also be found in giant generators, power plants, electric transformers, electric motors, vehicle starters and generators, as well as in all of our household appliances and electronics such as computers, cellphones, video game consoles, etc. In Canada, more than half of the copper consumed annually is used in the electricity sector, mostly in the form of wiring. Underground copper cables form communication and electricity distribution networks that are used to serve urban and rural populations. Copper is also essential to all living organisms in the form of a micro-nutrient. An adult human body contains between 1.4 and 2.1 milligrams of copper per kilogram of body weight.

The transition to a digital economy and the increasing use of new technologies associated with renewable energy such as solar cells, wind turbines and electric vehicles will increase the demand for copper. In fact, electric vehicles require two to four times more copper than conventional vehicles.

Chalcopyrite can be found in a multitude of geological environments, varying in composition and age, and is frequently associated with other metals such as gold, zinc, nickel and platinum group elements (e.g. platinum, palladium, iridium). In Quebec, the main sources of copper are in volcanogenic massive sulphide deposits located in the Abitibi (e.g. the LaRonde Penna Mine in Preissac, Abitibi*) and magmatic deposits associated with mafic-ultramafic magmas (rich in magnesium) located in Northern Quebec (e.g. Raglan mine in Nunavik*). (*See samples in *Section 3- Ore and mines*)

Sources:
https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/copper-facts/20506
Côté, T., Fradette, N., and Lévesque, R., Module 3: Les cailloux, des matériaux très modernes, Geology and Geological Engineering Department, Université Laval, Quebec City

<u>EUDIALYTE</u>

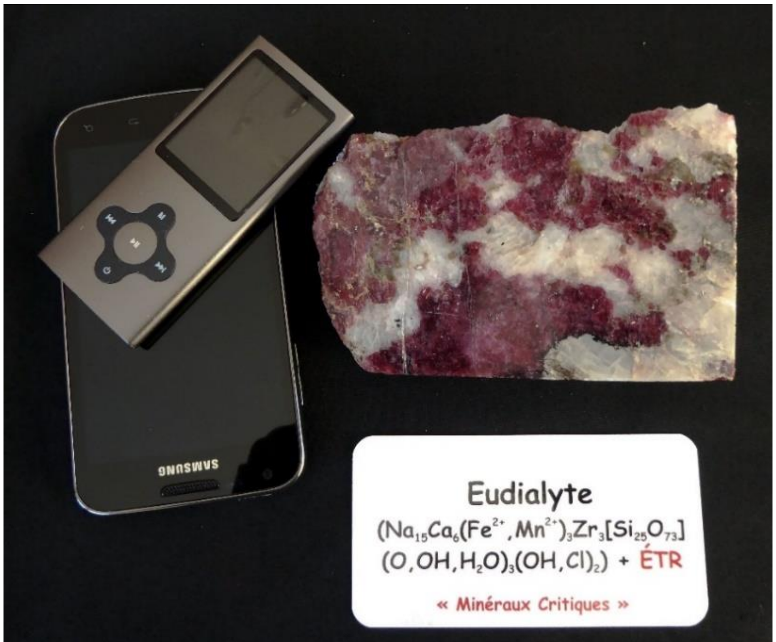

Figure 2.9: Sample of eudialyte (pink minerals) from the Kipawa deposit, located in Témiscamingue, Quebec (donated by V. Bécu and P. Mercier-Langevin). Eudialyte can contain rare earth elements, or REEs, which are essential for the manufacture of many common electronic products.

Eudialyte (Figure 2.9) is a rare cyclosilicate mineral, comprising sodium (Na), calcium (Ca) and zirconium (Zr), with the chemical formula $Na_{15}Ca_6(Fe^{2+},Mn^{2+})_3Zr_3[Si_{25}O_{73}](O,OH,H_2O)_3(OH,Cl)_2$. In some cases, eudialyte can be enriched with rare earth elements (REEs) such as lanthanum (La), cerium (Ce) and neodymium (Nd).

REEs define a group of 15 elements in the periodic table called lanthanides. Scandium (Sc) and yttrium (Y) tend to be associated with the same ore deposits because of their similar properties to lanthanide elements. REEs are essential components in numerous electronic devices that we use daily and that are used in various industrial applications, namely electronics, clean energy, aerospace, automotive and defence.

Magnet manufacturing represents the largest and most important end use of REEs, representing 38% of demand. Permanent magnets are an essential component in the modern electronic technologies used in cellphones, TVs, computers, vehicles, wind turbines, jets and many other products. REEs are also widely used in advanced and ecological products due their luminescent and catalytic properties.

Canada has some of the largest reserves and known resources of REEs (measured and indicated) in the world. However, the country only made the list of producers in the summer of 2021 with the Nechalacho mine (Northwest Territories). In order to increase production, a certain number of mining projects are currently under development. In Quebec, the main rare earth deposits include the Strange Lake and Ashram deposits in Nunavik and the Kipawa deposit in Témiscamingue. The sample in our collection comes from the latter deposit. In the case of the Kipawa deposit, the rare earths are incorporated into the complex mineral structure of eudialyte, associated with units of syenite composing an intrusive peralkaline complex (magmatic rocks containing minerals rich in sodium and potassium).

<u>Sources:</u>
https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/rare-earth-elements-facts/20522
https://mern.gouv.qc.ca/mines/industrie/metaux/metaux-exploration-terres-rares.jsp
See "Section 5a- Critical Minerals" for additional information and videos on rare earth elements.

SPODUMENE

Figure 2.10: Sample of spodumene (light green mineral) from the North American Lithium mining site in La Corne in Abitibi, Quebec (donated by P. Mercier-Langevin).

Spodumene is an aluminum (pyroxene) and lithium silicate ($LiAlSi_2O_6$), apple green to white in colour (Figure 2.10) found in pegmatites (coarse-grained magmatic rocks) in crystals of sometimes gigantic size (e.g. the crystal logs from the Etta mine in South Dakota can in some cases reach lengths of 14 m). Spodumene is commonly associated with minerals that also have economic potential in terms of rare earth elements (REEs).

The lithium (Li) contained in spodumene has long been mined for its integration in the production of ceramics, glass and lubricating grease. However, lithium is now considered one of the 31 critical elements needed for the country's transition to a digital, low-carbon emission economy. In fact, since lithium is the most electro-positive chemical element and the lightest metal, it is an element of choice in the manufacturing of lithium-ion batteries that are both rechargeable and have a high charging density, i.e., they can store a lot of energy per unit of volume and unit of mass. They are therefore smaller and lighter than many other types of batteries. Furthermore, lithium-ion batteries run down relatively slowly and, compared to other technologies, they can operate at a wide range of temperatures. These batteries are used broadly in electric vehicles as well as in a multitude of other small electronic devices such as computers, cellphones, smartwatches, wireless headphones and many others. Lithium is also used in the manufacturing of drugs for treating bipolar disorders and mood stabilisation.

The main resources and reserves of lithium in the world are located in three types of deposits: (1) pegmatite, including the family of granitic pegmatites rich in lithium-cesium-tantalum (LCT) and certain peralkaline intrusions (magmatic rocks containing minerals rich in sodium and potassium), (2) volcanic clay where the lithium is concentrated in hectorite or other clayey minerals, and (3) brines (and hydromorphic deposits, e.g. salars from the Andes), where the lithium was initially in a solution, but which was then concentrated through evaporation or by geothermal processes. In Quebec, several deposits have been mined and several projects are currently being studied for possible reopening of activities (e.g. North American Lithium, formerly Québec Lithium, La Corne, Abitibi) or undergoing feasibility studies (e.g. Whabouchi Project, Eeyou Istchee Baie-James). They are contained in LCT-type pegmatites where the lithium is concentrated in spodumene minerals.

Sources:
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https://www.nrcan.gc.ca/simply-science/what-type-batteries-do-electric-vehicles-use-natural-elements/22212
https://letstalkscience.ca/educational-resources/stem-in-context/how-does-a-lithium-ion-battery-work?_ga=2.132852616.704502211.1645187712-993412037.1645187712
Robert J. Bowell, Laura Lagos, Camilo R. de los Hoyos and Julien Declercq, 2020. Classification and Characteristics of Natural Lithium Resources; *Elements*, v.16 (4), p. 259–264. doi: https://doi.org/10.2138/gselements.16.4.259
For additional information regarding lithium-ion batteries, refer to "Section 5a- Critical Minerals".

SPHALERITE

Figure 2.11: Sample of sphalerite (ZnS) from the Chisel North mine, located in Snow Lake, Manitoba (donated by P. Mercier-Langevin) and examples of products that incorporate zinc in their manufacturing process.

Sphalerite (Figure 2.11), a zinc sulphide (ZnS) brownish black to yellow in colour and semi-metallic to resinous in lustre. It is the main mineral mined for its zinc content (Zn).

Zinc is used to plate iron and to give them greater resistance to rust and corrosion, through a process called galvanization. Approximately 48% of the world's zinc production is used to that purpose. The vehicle industry is the main consumer of galvanized steel. Zinc can also be alloyed to other metals and used for the pressurized casting of parts such as door handles. When alloyed with copper, it is used to create brass and when alloyed with copper and tin, it makes bronze. Brass connectors are used in plumbing in houses across Canada and go into the manufacturing of heat exchange equipment.

Zinc is also used in non-rechargeable (alkaline) batteries. However, it would seem that researchers have successfully created a rechargeable battery costing far less than a lithium-ion battery, using zinc and air as electrodes. Research is still ongoing, but this technology could eventually compete with lithium-ion technology, currently used in electric vehicles.

This element can also be added to fertilizer to increase crop yields and when transformed into zinc oxide, it becomes an ingredient used in the composition of skin creams and shampoos in addition to being used in the manufacturing of tires.

Sphalerite is a mineral commonly associated with chalcopyrite (copper ore) in volcanogenic massive sulphide deposits. In Canada, large and numerous deposits are found in the Canadian Shield and Appalachians. In Quebec, the Matagami mining camp, located about 200 km north of the city of Rouyn-Noranda, was one of the main zinc producers where no less than 12 mines have been in operation since 1963. The last one, the Bracemac-McLeod mine, ceased operations in June 2022. Zinc is also a sub-product, like silver and copper, at the LaRonde Penna gold mine*, in Preissac in the Abitibi region. (*See samples in *Section 3- Ore and mines*)

Recycled materials account for approximately 10% of the zinc's world production. Galvanized steel scrap and batteries are the main sources of recycled zinc. Products such as galvanized steel last a long time, which has an impact on the quantity of materials available on the market for recycling for a given year.

Sources:
https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/copper-facts/20506
Côté, T., Fradette, N., and Lévesque, R., Module 3: Les cailloux, des matériaux très modernes. Geology and Geological Engineering Department, Université Laval, Quebec City.

TALC

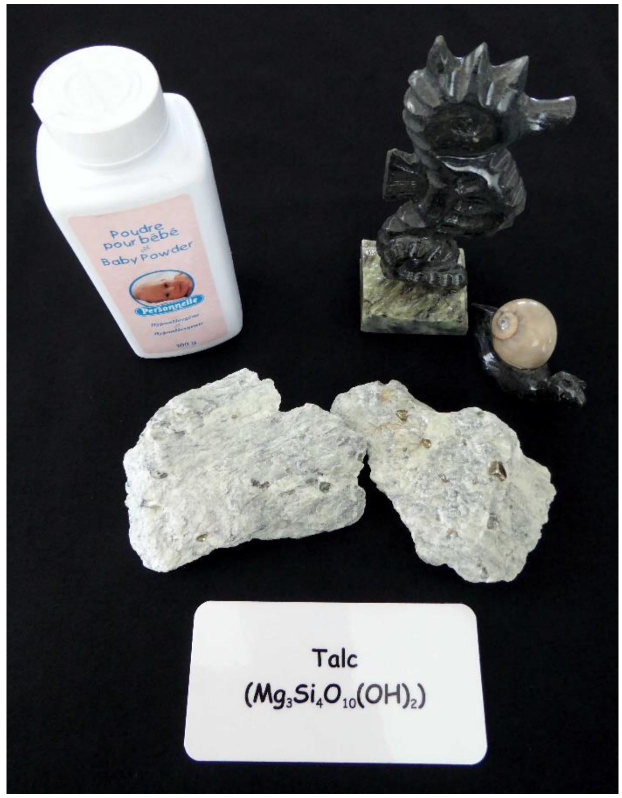

Figure 2.12: Talc sample containing cubic pyrite crystals (FeS_2), coming from the Saint-Pierre-de-Broughton quarry, located in the Chaudière-Appalaches region of Quebec (donation F. Létourneau). The steatite sculptures are donations from M.-C. Mercier and M. Langevin.

Like micas, talc ($Mg_3Si_4O_{10}(OH)_2$) is a phyllosilicate which is soft (smooth) to the touch and forms flexible sheets and flakes that have a perfect cleavage (Figure 2.12). This is a very soft mineral with a hardness of 1 on the Mohs scale, chemically inert. Its colour generally varies from white and whitish to greenish. Its compact or granular variety, steatite (soapstone), is a metamorphic rock that contains a variable quantity of mineral impurities, including mica, chlorite, pyroxene, amphibole, serpentine, quartz, calcite and iron oxides. Steatite results from the partial or total transformation of serpentinites associated with rocks very rich in magnesium, or of ultramafic composition.

The use of steatite dates from antiquity: the first Egyptians sculpted it into scarabs and seals; in China and India, it was used for ornaments, tools and household utensils. The First Nations and Inuit in Canada, like the Scandinavians, have used it in the same way, in different periods, over the past 7500 years. Steatite blocks are sculpted. Nowadays, it is also used for production of refractory plates for fireplace linings.

Talc, when reduced to powder, is essentially used in cosmetics due to its absorbent and mattifying properties. It enters in the composition of various cosmetics, such as lipsticks, nail polish, foundation and eye shadow, and can be used in dry shampoo. It has long been used as a powder to prevent diaper rash in babies, but increasingly it is being abandoned to make way for organic compounds, such as cornstarch, due to risks in case of inhalation. The lamellar structure of talc confers lubricating power that makes it an interesting material for manufacturing of certain pharmaceutical products, particularly as a coating agent to facilitate ingestion of certain medications.

Several talc and steatite deposits exist in Quebec, and some of them were already operated in the 20th century. These deposits are located in the Appalachian geological Province, particularly in the Chaudière-Appalaches and Estrie regions, and in Nunavik.

Sources:
https://www.thecanadianencyclopedia.ca/en/article/soapstone
https://gq.mines.gouv.qc.ca/portail-substances-minerales/

MAGNETITE

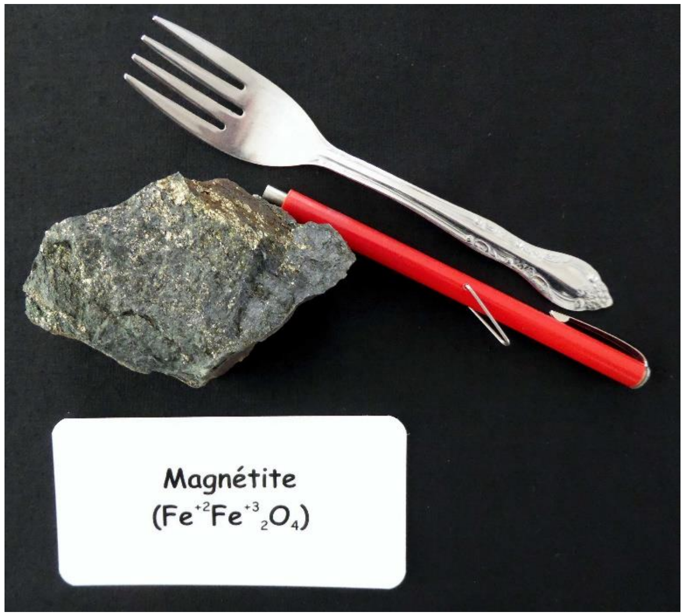

Figure 2.13: Magnetite sample (with pyrite and chalcopyrite) coming from the Brosman ore deposit in Chibougamau, Quebec), a polymetallic gold, silver and copper deposit (donation of V. Bécu). The majority of everyday utensils are made of stainless steel, a metallic alloy that contains over 50% iron, a minimum of 10.5% chromium (chromite) and a maximum of 1.2% carbon (graphite). The magnet emphasizes one of the mineral's main characteristics, its highly magnetic property.

Magnetite is an iron oxide ($Fe^{2+}Fe^{3+}{}_2O_4$) known as highly magnetic (Figure 2.13). Generally common in disseminated form in small grains in high temperature igneous rocks and metamorphic rocks, magnetite is also one of the main minerals associated with iron deposits, titanium, iron and vanadium anorthosites*, and iron oxide copper gold (IOCG) and uranium deposits. It is also associated with porphyry copper and gold deposits, where it constitutes a good exploration vector, because it is easily detectable by geophysical methods, i.e. soil or airborne surveys measuring the magnetic properties and conductivity of rocks, for example. (* see samples in the "Critical Minerals" case)

Iron ore is mainly used for manufacturing steel (98%), which is an essential metal alloy in the construction, industrial, home-building and automotive fields. Steel is composed of at least two elements, mostly iron followed by carbon in proportions between 0.02% and 1.67% in mass. The carbon content is essentially what confers on the alloy the properties of the metal called "steel". Other iron-based metals exist that are not steels, such as cast irons and ferronickels. The remaining 2% is used in various applications, such as:

- **iron powder** — for certain types of steel, magnets, automobile parts and catalysts
- **radioactive iron (iron 59)** — for medicine and as a tracer element in biochemical and metallurgical research
- **iron blue** — in paints, printing ink, plastics, cosmetics (e.g., eye shadow), paint colours, laundry bluing, paper dye, fertilizer, baked enamel finishes on vehicles and household appliances, and industrial finishes.
- **black iron oxide** — as pigment in polishing compounds, metallurgy, magnetic inks and ferrites for the electronics industry.

Steel is 100% recyclable, which means it can be reprocessed to produce material of the same quality, as many times as desired. Recycling represents major savings in energy and raw materials.

- Electric arc furnaces allow steelmaking completely from scrap metal. This considerably reduces the energy necessary for steelmaking, compared to primary steel production from ore.
- The increasingly widespread shift to the use of electric arc furnaces for steelmaking will support the global market for steel scrap, which should reach 755 million tonnes by 2024.

Practically all of Canada’s iron ore comes from the Labrador Trough region and its equivalent in Grenville Province, located along the border between Quebec and Newfoundland and Labrador. It is extracted from Lake Superior-type banded iron formations, which are banded sedimentary rocks formed on continental shelves and form thick continuous units over several kilometres. Hematite (specularite) and magnetite are the main minerals extracted from Lake Superior-type iron formations and the Mont-Wright and Fire Lake mines, located near Ville de Fermont, are the leading iron producers in Quebec.

Sources:
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https://www.futura-sciences.com/sciences/definitions/chimie-acier-inoxydable-16677/
https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/iron-ore-facts/20517

From Rock To Technology - Du roc à la technologie

INTERESTING FACTS ABOUT CELL PHONES:

- In 1983, Motorolla presented the world with the first smartphone for a mere $4,000 per phone
- Nokia has sold the most smartphones worldwide – their 1100 model has been purchased by over 250 Million users
- The average person unlocks his/her smartphone 110 times each day
- 80% of the world's population has a smartphone
- Phones today are more powerful than the computer originally used for the moon landing
- Nearly 65% of emails are opened on mobile phone devices

QUE SAIT ON SUR LES « SMARTPHONE »?

- En 1983, Motorolla a présenté au monde entier le premier téléphone intelligent (smartphone) à un prix unitaire de 4 000 $
- Nokia a vendu le plus de ces téléphones à travers le monde leur modèle 1100 a été acheté par plus de 250 millions d'utilisateurs
- La personne moyenne déverrouille son téléphone intelligent 110 fois chaque jour
- 80% de la population mondiale possède un « smartphone »
- Les téléphones d'aujourd'hui sont plus puissants que l'ordinateur utilisé à l'origine pour l'alunissage
- Près de 65% des courriels sont consultés sur des appareils de téléphonie mobile

SCREEN / ÉCRAN

SILICA SILICE	INDIUM	TIN ÉTAIN
QUARTZ	SPHALERITE SPHALÉRITE	CASSITERITE CASSITÉRITE

SPEAKER / HAUT PARLEUR

IRON OXIDE OXIDE DE FER	STRONTIUM
IRON ORES (Hematite/Goethite) MINERAIS DE FER (Hématite/Goethite)	CELESTITE CÉLESTINE
COPPER CUIVRE	**CERAMICS CÉRAMIQUES**
CHALCOPYRITE	KAOLINITE

CAPACITORS CONDENSATEURS

MANGANESE MANGANÈSE
PYROLUSITE

CASE / BOITIER

STAINLESS STEEL ACIER INOXYDABLE	IRON FER
HEMATITE SPECULARITE L'HÉMATITE SPÉCULARITE	HEMATITE HÉMATITE
CHROMIUM CHROME	**CARBON CARBONE**
CHROMITE	GRAPHITE

BUTTONS TOUCHES

PETROLEUM PRODUCTS PRODUITS PÉTROLIERS
BITUMINOUS SANDS SABLES BITUMINEUX

CIRCUIT BOARDS / CIRCUITS IMPRIMÉS

SILICON SILICIUM		
QUARTZ	NATIVE COPPER CUIVRE NATIF	GOLD OR
		CLAYS ARGILE
SILVER ARGENT	PLATINUM PLATINE	KAOLINITE

BATTERY / PILE

LITHIUM	COBALT	SILICON SILICIUM
SPODUMENE SPODUMÈNE	PENTLANDITE	QUARTZ

Presented by / Présenté par:

LES MINÉRAUX, LEUR COMPOSITION ET LEUR UTILISATION QUOTIDIENNE

L'IMPORTANCE DES MINÉRAUX POUR VOTRE CORPS

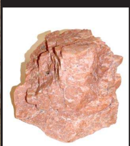
TITANE

	Minéral	Élément chimique	Application		Description
	**Ilménite** (oxyde de fer et titane) $FeTiO_3$	Titane Ti	Crème solaire Prothèse de hanche, vis, plaque et tige de métal lors d'opérations dans le corps		L'oxyde de titane a la particularité de bloquer les rayonnements solaires. Le titane est non toxique et est un bon matériau pour les prothèses orthopédiques et orthodontiques. Au Québec, une mine à ciel ouvert d'ilménite est exploitée, au nord de Havre-Saint-Pierre.

TALC

	Minéral	Élément chimique	Application		Description
	**Talc** (silicate de magnésium) (la roche de talc est appelée stéatite) $Mg_3Si_4O_{10}(OH)_2$	Magnésium Mg	Maquillage Crème hydratante Poudre à talquer		Le talc est très doux au toucher et peut être transformé en une fine poudre douce et soyeuse. C'est un produit idéal pour le maquillage. La mine de Saint-Pierre-de-Broughton (Chaudière–Appalaches) a été la dernière mine de talc exploitée au Québec.

FELDSPATH

	Minéral	Élément chimique	Application		Description
	**Feldspath** (silicate d'aluminium et de potassium) $KAlSi_3O_8$	(silicate d'aluminium et de potassium)	Dent Dentier Porcelaine		Ce minéral de teinte rosée à blanchâtre est utilisé principalement dans la fabrication de dents artificielles. Au Québec, une seule mine de feldspath est exploitée, au nord de Buckingham, dans la région de l'Outaouais.

LITHIUM

	Minéral	Élément chimique	Application		Description
	**Spodumène** (silicate de lithium) $LiAlSi_2O_6$	Lithium Li	Pilule (antidépresseur)		Le lithium est utilisé dans la fabrication de médicaments pour traiter les troubles bipolaires dans le but de rétablir l'humeur des personnes dépressives. Au Québec, le spodumène se trouve dans les pegmatites et les granites. Les principaux projets miniers sont situés en Abitibi et à la Baie-James.

FER

	Minéral	Élément chimique	Application		Description
	**Hématite** (oxyde de fer) Fe_2O_3	Fer Fe	Nourriture Suppléments vitaminés		Le fer fait partie des sels minéraux indispensables retrouvés dans les aliments. Le fer joue aussi un rôle très important dans le transport de l'oxygène et dans la formation des globules rouges du corps humain. Au Québec, l'hématite est le principal minerai de fer exploité dans la région de Fermont et de Schefferville.

ALUMINIUM

	Minéral	Élément chimique	Application		Description
	**Bauxite** (oxyde d'aluminium) $Al_2O_3\cdot3H_2O$	Aluminium Al	Antisudorifique		Sous forme de sels, l'aluminium peut servir dans les antisudorifiques. Le principal minerai d'aluminium est la bauxite qui est absente au Québec. On trouve des mudstones (argilites) riches en alumine dans la région de Grande-Vallée en Gaspésie.

BARITE

	Minéral	Élément chimique	Application		Description
	**Barite** $BaSO_4$	Baryum Ba	Lavement baryté		L'hydroxyde de baryum est un composé minéral opaque aux rayons X, utilisé en radiologie pour visualiser certaines régions de l'intestin. Aucune exploitation de barite ne se fait actuellement au Québec. On trouve de la barite à Saint-Honoré au Saguenay, et en Outaouais.

MICA

	Minéral	Élément chimique	Application		Description
	**Mica (muscovite)** (silicate d'aluminium et de potassium) $KAl_2(AlSi_3O_{10})(F,OH)_2$	(silicate d'aluminium et de potassium)	Vernis à ongles		La muscovite est un mica blanc qui est incorporé en fines paillettes dans plusieurs produits cosmétiques. La muscovite donne de la brillance et de l'éclat. Au Québec, la muscovite a été exploitée à partir de pegmatites dans la région de Grandes-Bergeronnes (Côte-Nord).

ZINC

	Minéral	Élément chimique	Application		Description
	**Sphalérite** (sulfure de zinc) ZnS	Zinc Zn	Shampoing Onguent de zinc		Le zinc est ajouté à des produits capillaires pour contrôler les pellicules et aussi pour la cicatrisation de fines blessures. Au Québec, on exploite le zinc en Abitibi.

GT 2014-02
Rédaction : Pierre Lacoste, N'golo Togola, Denis Raymond et Julie Gagné
Réalisé et publié par : Ministère de l'Énergie et des Ressources naturelles
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Graphisme : André Tremblay
Source des photographies : Ministère de l'Énergie et des Ressources naturelles et domaine public
Québec

Section 3: Ore and mines

As discussed in the previous section, minerals and their constituent elements are essential to our modern way of life and are used in the manufacture of various products used daily. Although some metals can be found in their native state, the majority form groupings of chemical elements in the form of a crystalline solid (mineral). When a mineral, or group of minerals, contains metals or elements useful to human activity in sufficient concentration to justify their exploitation (revenues exceeding total development investments, operating costs and reclamation costs), it is called an ore. For example, chalcopyrite is a common copper ore, sphalerite is a zinc ore and magnetite is an iron ore when they occur in sufficient quantities to be extracted. Sometimes other elements, including gold, silver and platinum group elements (PGEs), are incorporated into the structure of certain minerals during their initial crystallisation or as a result of late processes, and the “host” minerals then become the mined ore. These minerals are found at various locations in the Earth's crust as a result of geological processes and environments that have allowed them to be concentrated and deposited en masse in a particular location.

The exploitation of a deposit, i.e. the phase of extracting and processing the ore for marketing, is mostly done by means of open-pit or underground mines. The choice of mine type depends on various factors such as the depth of the deposit, the footprint and the extraction costs. In general, if most of the deposit is relatively close to the surface, an open pit is preferred (Figure 3.1), where mining is carried out by means of a spiral pit in which benches of two to fifteen metres are blasted to extract the ore, which is then loaded by shovels onto huge trucks (which can hold hundreds of tonnes) for transport to the concentrator. Open-pit mines are often compared to a world of giants, because of the oversized machinery and the surface area of a pit can be very impressive. This is the case for the Mont-Wright open pit mine, located near Fermont, Quebec, which has an area of 24 km², equivalent to 2222 soccer fields, making it one of the largest open pits in Canada.

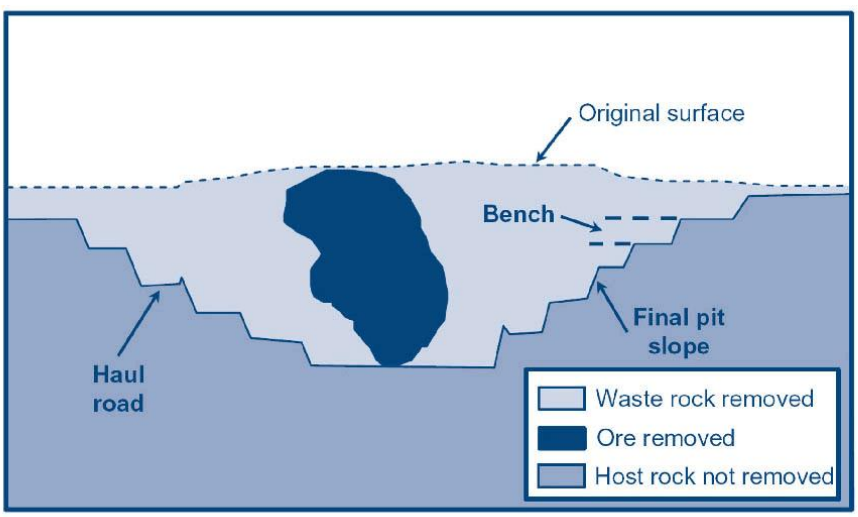

Figure 3.1: Typical cross-section of an open pit mine. Shown here is the large ore body below the land surface. Surrounding the ore is the waste rock. The waste rock pit walls slope up and outward from the bottom of the ore body, the angle of this being the final pit slope. Steps in the pit slope are called benches and the haul roads follow these. Surrounding the waste rock is the host rock, which is not removed.

(Source : https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/code-practice-metal-mines/chapter-2.html#s2_3)

An underground mine infrastructure (Figure 3.2) is preferred when the deposit continues at depth, there is a significant amount of vegetation cover, glacial sediments, barren rock, or where a river overlying the deposit or the visual impact is to be minimised (e.g. near a town). The ore, personnel and machinery are then transported via a vertical access shaft which opens onto a multitude of drifts (long tunnels) at different depths, or "levels", at regular intervals, to access the deposit (stopes). Access underground and travelling from one level to another may also be by means of ramps or manways (ladders). A ventilation shaft is also excavated to ensure ventilation, filtration and control of temperature and air quality throughout the mine levels and stopes. It is common for an old access shaft to be converted into a ventilation shaft and used as an emergency exit.

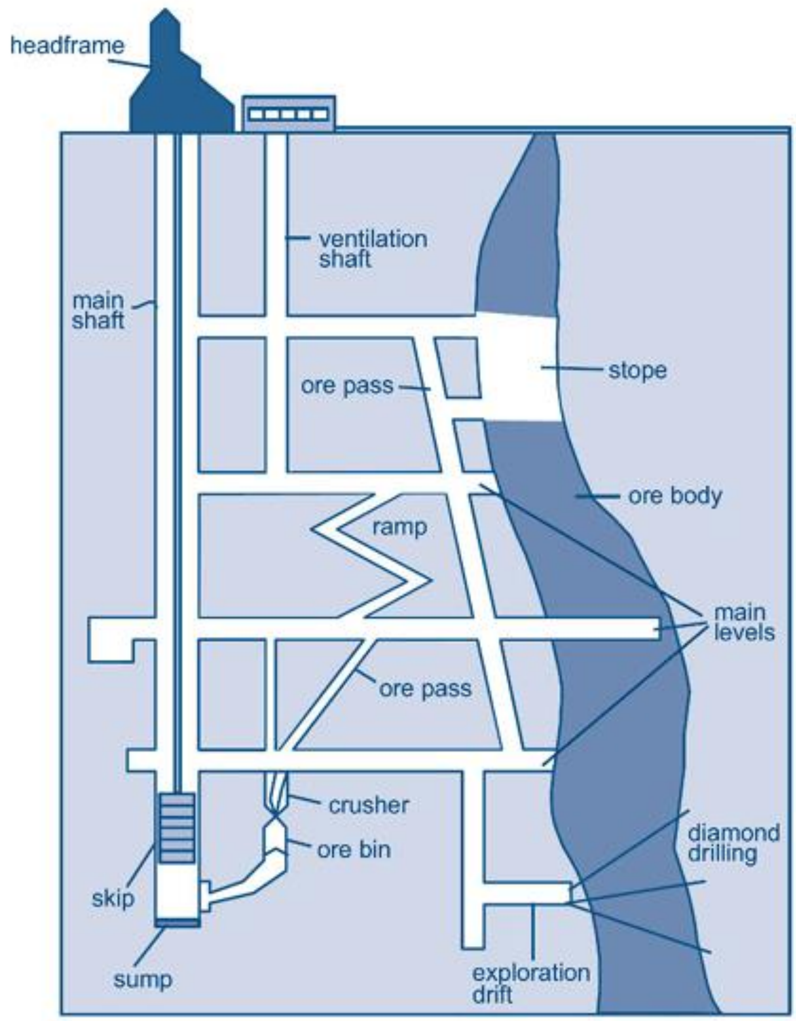

Figure 3.2: Diagram of a typical cross-section of an underground mine. The headframe of the main shaft is on the surface and houses the skip which serves as a hoist. A sump sits at the bottom of the shaft. At various levels horizontal channels from the main shaft lead to the mining area within the ore body, or the stope. Ramps are used to access various levels and ore is sent to the underground crusher and ore bin via ore passes. Exploration drifts are dug to sample lower parts of the ore body using diamond drilling. A ventilation shaft leading to the surface allows for fresh air exchange.

(Source : https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/code-practice-metal-mines/chapter-2.html#s2_3)

Source :
https://www.explorelesmines.com/fr/secteur-minier/types-de-mines.html

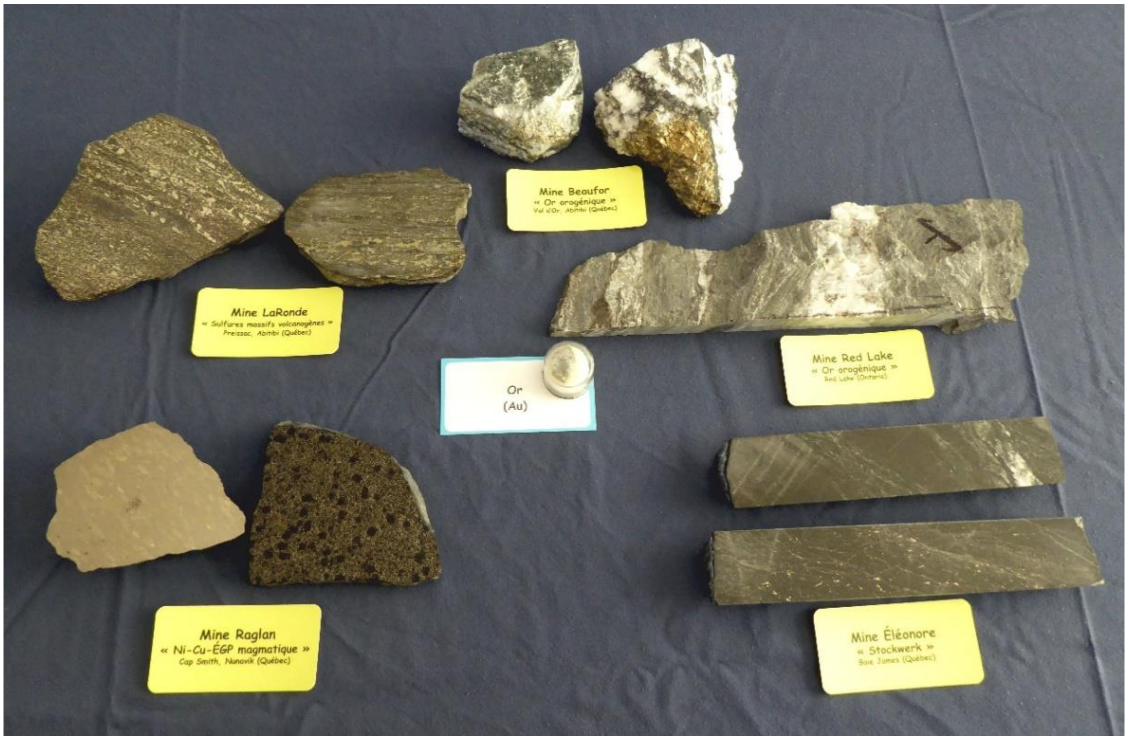

Figure 3.3: "Mines" exhibition of the "Mines and Minerals" case

The "Mines and Minerals" case contains a collection of ten ore samples, mostly coming from mines currently in production or temporarily shut down in the province of Quebec and a native gold sample contained in a plastic receptacle (Figure 3.3). Only two samples come from a gold mine located in Ontario (the Red Lake mine). The samples represent different types of gold deposits of varied styles, including gold veins, or orogenic deposits (e.g. the Beaufor and Red Lake mines), or stockwork gold deposits (e.g. the Éléonore mine) and an auriferous volcanogenic massive sulphide polymetallic deposit where gold is associated with other substances of interest, including silver, copper and zinc (e.g. the LaRonde Penna mine). The collection also includes two nickel ore samples, containing copper and platinum group elements (PGEs or platinum group metals – PGMs), associated with rocks from the most northerly mine in Quebec, the Raglan mine.

The ore samples presented in this case come from the Superior Province, an Archean (4.3 to 2.5 billion years) geologic province that covers about half of Quebec's surface with nearly 745 000 km^2. It is also in Quebec, near Inukjuak in Nunavik, where the world's oldest rock was discovered at 4.28 billion years old. The Ni-Cu-PGE ore of the Raglan mine is located in the Cape Smith Belt, in the Ungava Trough, north of the Superior Province in Nunavik. It contains Paleoproterozoïc rocks (2.5 to 1.6 billion years).

A portable tripod and a rigid poster (Coroplast) complete the collection of ore samples.

1- *Les métaux et les minéraux dans notre vie* [Metals and minerals in our lives] (Ministère des Ressources naturelles et des Forêts du Québec, poster document GT 2012-03 showing a map of Quebec with location of mines, in French. A PDF version is available after "Section 3-Ore and mines".

Source:
*Thériault, R., 2013. Les provinces géologiques du Québec; Ministère des Ressources naturelles et des Forêts du Québec, présentation ppt. [*https://mern.gouv.qc.ca/mines/trousse-educative/conferences/]

Native gold

Gold (Au - Figure 3.4) is a bright yellow metal known for its high density (19.3 times the mass of an equal volume of water), valued for its exceptional malleability, resistance to corrosion, high electrical and thermal conductivity as well as for its brilliance and scarcity. Gold is the most stable of the metals. It is found in its native state, in a relatively coarse form (visible to the eye, rare) or more or less finely dispersed within other minerals making up the ore. Sometimes it is even incorporated into the structure of the host mineral (see *Section 5c-Analytical techniques*).

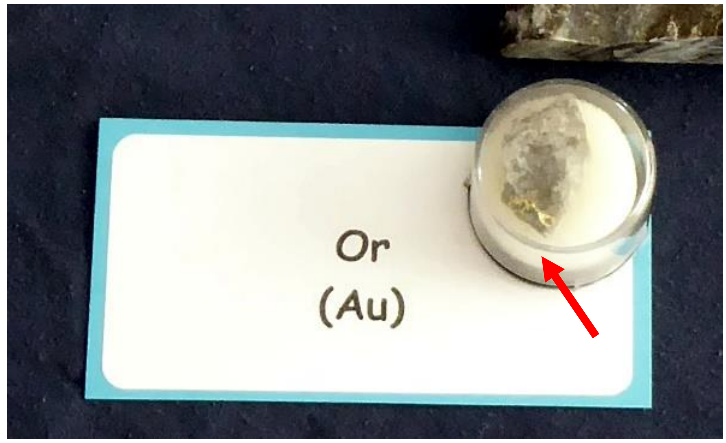

Figure 3.4: Native gold sample from a quartz-carbonate vein at the Beaufor mine, located in Val-d'Or, Abitibi (donated by V. Bécu).

Gold is mainly hosted in veins or lodes, associated with other economically valuable bedrock minerals, but also occurs as nuggets, flakes or dust in the sand and gravel of streams and rivers. Gold is also a product, or by-product, of some base metal mines. In Canada, gold production occurs in seven provinces and two territories, with Ontario and Quebec accounting for more than 70% of total production, with most of the production coming from the geological subprovince of the Abitibi located in the Superior Province. Gold is the most valuable commodity produced, with commercial production estimated at $10.3 billion in 2019.

The world's industrial demand for gold comes mainly from the jewellery, electronics and official coin industries. Since the dawn of time, gold has been a symbol of wealth. Today, gold for investment products takes the form of wafers, bars and coins, and is mainly used as a hedge against inflation and stock market volatility. Gold is a chemically inert metal and is also used in dentistry and medicine. Its corrosion resistance and electrical conductivity make it a material of choice in precision electronics (televisions, computers, laptops, phones, mobile phones, car airbags) and renewable energy technologies (electric cars, wind turbines). Interestingly, at the 2020 Tokyo Olympics (held in 2021), the 5000 or so medals awarded came from nearly 80 000 tonnes of electronic devices, including six million phones, collected in a massive recycling campaign. By this means, some 32 kg of gold, 3500 kg of silver and 2200 kg of bronze were recovered. The application of a gold film on glass improves its thermal properties phenomenally, hence its application in aeronautics, notably on the protective visors of astronauts' helmets, but also in the manufacture of special glass that reduces heat gain in summer and loss in winter in our homes. Gold is also used as a lubricant for mechanical parts in spacecraft, replacing conventional organic or synthetic compounds that would degrade in the interstellar void. More than 40 kg of gold were used in the construction of the space shuttle Columbia.

Sources :
https://www.thecanadianencyclopedia.ca/fr/article/or-104
https://www.rncan.gc.ca/nos-ressources-naturelles/mines-materiaux/faits-mineraux-metaux/faits-sur-lor/20587
Méthot, J., 2019. L'or, un contributeur clé de l'économie et à la vie quotidienne des québécois; Ressources Mines et Industrie, 6(2), 31–33.
Boule, M., 2019. Des médailles en or… recyclé; L'actualité, 11 septembre 2019. [Des médailles en or… recyclé | L'actualité (lactualite.com)]

Orogenic gold ore

Figure 3.5: Orogenic gold sample from the Beaufor mine located in Val-d'Or in Abitibi (donated by V. Bécu).

The Beaufor mine (currently on care and maintenance) is located east of the city of Val-d'Or, in Quebec's Abitibi region. This is a gold vein or orogenic deposit with quartz and carbonate veins and breccia (with tourmaline occasionally). These veins are more or less continuous over tens of metres to a few hundred metres locally. Gold, mainly confined in the veins, is found in its native state, but rarely visible to the naked eye. Instead, it is concentrated in patches of disseminated pyrite (Figure 3.5, left sample) or massive pyrite (Figure 3.5, right sample) which constitute the main ore extracted at the mine.

Quartz and carbonate vein-style deposits have produced most of the gold in the Abitibi (Ontario and Quebec) and represent typical examples of Archean age gold systems. The deposits are grouped and define mining districts distributed along major fault zones, such as the Larder Lake-Cadillac and Destor-Porcupine Faults, which are the main geological features controlling the distribution and concentration of gold zones in Abitibi. The east-west orientation of these fault zones can be observed by the distribution of gold mines and mining projects on the Ministère des Ressources naturelles et des Forêts du Québec poster GT_2012-03 "Les métaux et les minéraux dans notre vie" [Metals and minerals in our lies]. These fault zones served as conduits for the circulation and ascent of hydrothermal fluids coming from deep levels of the Earth's crust (10–20 km deep), rich in H_2O and CO_2 and containing gold. These fluids migrated to the surface and crystallised as pressure and temperature conditions in the Earth's crust changed in response to earthquakes.

"Fool's gold" is an expression that was used to refer to pyrite (FeS_2) during the great gold rushes (e.g. the California Gold Rush from 1848 to 1856 and the Klondike Gold Rush between 1897 and 1899). At the time, many gold seekers headed west in hope of finding the precious metal and becoming rich. Unfortunately, many were fooled by the resemblance of gold to iron pyrite, just like Jacques Cartier during his third voyage to Canada in 1541. His error would have been less if he had brought back pyrite from the Abitibi rather than from the banks of the St. Lawrence River, because the Abitibi pyrite is more likely to contain gold! (See *Section 5c- Analytical techniques*)

Sources:
Dubé, B. and Mercier-Langevin, P., 2019. L'or dans la ceinture de roches vertes de l'Abitibi, Québec et Ontario, Canada : un aperçu géologique et historique; Ressources Mines et Industrie, 6(2), 10–29.
https://fr.wiktionary.org/

<u>Orogenic gold ore</u>

Figure 3.6: Orogenic gold ore samples from the Red Lake Mine in Northern Ontario (donated by B. Dubé).

The Red Lake mine, located in Northwestern Ontario, is another example of an orogenic gold deposit where gold mineralization is concentrated within and close to quartz and carbonate veins and breccia. In operation more or less continuously since 1948, this is one of the world's richest mines (i.e. with the highest gold concentration) and accounts for much of the gold production of the Uchi domain of the Archean Superior Province. The samples presented in Figure 3.6 (A: sample 01-50C1 and B: sample 00-03L) both show quartz and carbonate veins and veinlets containing arsenopyrite, pyrite, pyrrhotite (and locally chalcopyrite) and visible gold! They come from the High-Grade Zone, a particularly rich sector of the deposit, where the average gold content could be as high as 50 g/t Au, which is over 10 times the average grade of typical gold mines these days. This exceptionally high grade is interpreted as the result of a local concentration of a mineralization fluid, with high silica and gold content, in lower-pressure fold hinges where the presence of carbonatized ultramafic magmatic rocks (very rich in magnesium) would have acted as a less permeable barrier, controlling the migration and residence time of the fluid along or near the contact with the folded volcanic rock sequence (basalts). Subsequent processes remobilized gold in late extremely high-grade structures to form spectacular gold concentrations.

<u>Source:</u>

Dubé, B., Willamson, K., and Malo, M., 2001. Preliminary report on the geology and controlling parameters of the Goldcorp Inc. High-Grade zone, Red Lake mine, Ontario: an update; Geological Survey of Canada, Current Research 2001-C18, 31 p.

Stockwork gold ore

Figure 3.7: Examples of stockwork gold ores from the Eleonore mine in the Eeyou Istchee Baie-James area (donated by A. Fontaine).

Opened in 2015, the Eleonore gold mine is one of the newest mines in Quebec and, along with the Renard diamond mine (opened in 2016), is one of the first large-scale mines to be located in the Eeyou Istchee Baie-James area. The gold deposit is of disseminated and stockwork-style where gold is generally hosted in quartz and dravite (magnesian tourmaline) veins and veinlets and replacement zones of microcline, dravite and phlogopite as shown on the samples in Figure 3.7 (samples EDH-14-056 and EDH-13-093). Although other styles of mineralization are recognized at the mine (e.g. laminated quartz veins, diopside, actinote and uvite, hydrothermal breccias and granitic pegmatites), all are associated with pyrrhotite, arsenopyrite, löllingite and less frequently pyrite minerals that are finely disseminated in the rock. The gold mineralization at the mine is mainly hosted in sedimentary rocks (wacke, conglomerate, arenite and iron formation) and is located in an area of strong metamorphic gradient. These sedimentary rocks are metamorphosed to the upper amphibolites facies and are cut by several types of intrusions of varying nature and composition.

Visible gold is very rare at the Eleonore mine. The chemical composition of the ore (arsenopyrite, löllingite and pyrrhotite) and of the hydrothermal alteration (modifications undergone by the rocks affected by the mineralizing fluids), and the presence of minerals of the arsenide and antimonide family indicate that the gold mineralization has undergone a complex evolution. Indeed, the ore was formed, deformed and then metamorphosed during a long-lasting tectono-metamorphic episode.

The samples in Figure 3.7 are from drill cores, which are cylindrical samples of varying diameters (larger diameters for deeper drill holes) removed from the ground using a drill with a head set with micro-diamonds. This type of sample, which is quite expensive to recover, is essential for understanding and defining a deposit.

Source :
Fontaine, A., 2019. Géologie des minéralisations aurifères de la mine Éléonore, Eeyou Istchee Baie-James, Province du Supérieur, Québec, Canada; PhD thesis, Institut national de la recherche scientifique – Centre Eau Terre Environnement, Québec, Quebec, 526 p.

Volcanogenic massive sulphide gold-rich ore

Figure 3.8: Volcanogenic massive sulphide gold-rich samples from the LaRonde Penna mine located in Preissac, Abitibi (don de P. Mercier-Langevin).

The LaRonde Penna mine is at the heart of a prolific mining camp, the Doyon-Bousquet-LaRonde camp, which is located in Preissac, halfway between the cities of Val-d'Or and Rouyn-Noranda in the Abitibi region. Although the LaRonde mine only opened in 2000, the first mining operations in the camp date back to 1939 when the Mooshla A mine, a gold mine exploiting sulphide-rich gold veins associated with intrusive rocks, went into production. The LaRonde deposit is a gold-bearing volcanogenic massive sulphide deposit and is one of the best examples in the world. Although primarily mined for its gold content, by-products such as copper, zinc and silver are also extracted. These represent a significant part of the mine's production. Lead, in the form of galena (PbS), was recovered from 2008 to 2013.

The deposit is hosted by 2.7 billion year old Archean volcanic rocks. The mineralized lenses of the LaRonde Penna deposit were formed primarily by the precipitation of sulphides from metal-bearing hydrothermal fluids that rose through the crust to the seafloor where the metals precipitated, forming a sulphide mound. Some of the ore was also formed by replacement of rock just below the seafloor. At the LaRonde Penna mine, different lenses are present at different positions in the volcanic strata resulting from successive volcanic events, interspersed with lulls during which sulphides may have accumulated. Although the deposit is polymetallic (gold, copper, zinc and silver), gold is primarily associated with copper (chalcopyrite, sample LAPL-2019-008 on the right in Figure 3.8) located at the base of the lenses and silver is preferentially associated with zinc (sphalerite) in the upper part of the lenses (sample LAPL-2019-001, located on the left in Figure 3. 8).

The LaRonde Penna mine is currently the deepest underground mine in North America with a main shaft reaching 2.25 km in depth (Penna shaft), an internal shaft reaching 2.85 km and an access ramp that allows access to the ore located 3.1 km below the surface (see suggested videos on the LaRonde Penna mine in *Section 3c- Videos mines*)

Sources :
P., Mercier-Langevin, B. Dubé et D. Fortin, 2021. La camp minier Doyon-Bousquet-Laronde, Aperçu historique et géologique d'un camp exceptionnel; Ressources Mines et Industrie, 7(1), 46–63.
https://www.agnicoeagle.com/French/exploitations/exploitations/laronde/default.aspx

Nickel ore

Figure 3.9: Magmatic nickel ore samples from the Raglan mine in the Cape Smith Belt, Nunavik (donated by M. Houlé).

Located in the Cape Smith belt of Northern Quebec, in the territory of Nunavik, the Raglan mine, which opened in 1997, is still the northernmost mine in the province. It is a cluster of four underground mines, Kikialik (meaning "where there is nickel" in Inuktitut), Qakimajurq (meaning "rich"), Katinniq and Mine 2, which exploit disseminated massive sulphide deposits rich in nickel, but also containing copper, platinum group elements and cobalt. The Raglan Complex deposits are among the richest base metal mines in the world.

At the Katinniq mine, mineralization consists of massive sulphide lenses at the base of komatiite flows (magnesium-rich lavas, i.e. containing 20% to 30% MgO). These lenses consist mainly of pyrrhotite ($Fe_{1-x}S$), chalcopyrite ($CuFeS_2$) and pentlandite [$(Fe,Ni)_9S_8$] locally accompanied by covellite (CuS). Platinum group elements (PGEs, or platine group metals) tend to occur as minor phases of platinum group minerals (PGMs) or, like cobalt, embedded within the mineral structure of the above metioned sulphide minerals. Zones of massive sulphides at the base of the flows (sample 14HUB067A01 on the left in Figure 3.9) transition vertically to zones of net-textured disseminations in the peridotites (sample 14HUB067A02 on the right in Figure 3.9). These flows form an ultramafic complex, mainly composed of peridotite (olivine-rich rock) and pyroxenite (pyroxene-rich rock), locally marked by gabbro layers overlying sedimentary rocks.

Because Raglan's facilities are isolated from all external resources, the site has all the infrastructure associated with that of a small municipality, including an accommodation complex, a water treatment plant, a power plant and an airport. A network of year-round roads links the mine complex to the warehouse and port facilities at Deception Bay. Workers are flown in from the southern part of the province, but also from nearby Inuit villages for a fly-in-fly-out shift schedule (see suggested video on the Raglan mine in *Section 3e- Videos mines*).

Sources :
https://www.glencore.ca/fr/raglan/
SIGÉOM, 2021. Système d'information géominière du Québec, Nom du corps: Mine Raglan (Katinniq); Ministère des Ressources naturelles et des Forêts du Québec. [http://sigeom.mines.gouv.qc.ca]

LES MÉTAUX ET LES MINÉRAUX DANS NOTRE VIE

VERSION 2012

GT 2012-03

MINES ACTIVES (24)

Minéraux métalliques

Or
Beaufor (Richmont)
Canadian Malartic (Osisko)
Casa Berardi (Aurizon)
Francoeur (Richmont)
Kiena (Wesdome)
Lac Herbin (Alexis)
Lapa (Agnico-Eagle)

Or, argent, cuivre, zinc
Mouska (Iamgold)
LaRonde (Agnico-Eagle)

Zinc, cuivre, or, argent
Langlois (Nyrstar Canada)
Persévérance (Xstrata)

Fer, fer et titane
Fire Lake (ArcelorMittal)
Lac Bloom (Cliffs Natural Res.)
Lac Tio (Rio Tinto Fer et Titane)
Mont-Wright (ArcelorMittal)

Nickel, cuivre, EGP, cobalt
Raglan (Xstrata)

Niobium
Niobec (Iamgold)

Minéraux non métalliques

Feldspath
Othmer (Dentsply)

Graphite
Lac-des-Îles (Timcal)

Mica
Lac Letondal (Produits Mica Suzorite)

Sel
Mine Seleine (Société canadienne de Sel)

Silice
Petit-Lac-Malbaie (Silicium Québec)
Saint-Canut (Unimin Canada)
Saint-Rémi-d'Amherst (S. M. Gerdin)

PROJETS MINIERS (40)

Or
Belleterre (Conway)
Éléonore (Goldcorp)
Goldex (Agnico-Eagle)
Joanna (Aurizon)
Lac Bachelor (Métanor)
Lac Pelletier (Alexis)
Monique (Richmont)
Rocmec 1 (Russian Kid) (Rocmec)
Vezza (N. A. Palladium)
Wasamac (Richmont)
Westwood (Iamgold)

Zinc, cuivre, or, argent
Bracemac-McLeod (Xstrata)
PD1 (Xstrata)

Fer, fer et titane, vanadium
DSO (New Millennium)
Fire Lake North (Champion Minerals)
Hopes Advance Bay (Oceanic Iron Ore)
Iron Hills (Exploration Barlow)
KéMag (Taconite) (New Millennium)
Lac Otelnuk (Adriana Resources)
Blackrock (Blackrock Métal)
Lac La Blache (Argex Mining)

Nickel, cuivre
Dumont Nickel (Royal Nickel)
Nunavik Nickel (Canadian Royalties)

Niobium, tantale
Crevier (MDN)
Niocan (Niocan)

Apatite
Arnaud (Mines Arnaud)
Lac à Paul (Ressources d'Arianne)

Terres rares, yttrium, zircon
Eldor (Commerce Resources)
B-Zone (Quest Rare Minerals)
Zeus (Matamec Explorations)

Uranium
Lavoie (Ressources Abitex)
Matoush (Strateco)

Lithium
Authier (Glen Eagle Resources)
Eastmain - Rose (Critical Elements)
James Bay Lithium (Lithium One)
Québec Lithium (Canada Lithium)
Whabouchi (Nemaska Lithium)

Diamant
Renard (Stornoway)

Alumine
Grande-Vallée (Orbite VSPA)

Graphite
Lac Knife (Focus Graphite)

Mise à jour du GT 2010-04 : Julie Gagné et Denis Raymond **Graphisme** : André Tremblay **Édition** : Joanne Nadeau

Ressources naturelles Québec

Section 3: Ore and mines

3c – Supplementary documents and videos

Supplementary documents "Ore and mines"		
Environnement and climate change Canada	Environmental Code of Practice for metal mines (2009)	Electronic monograph in PDF and HTML formats. ISBN : 978-1-100-11901-4 https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/code-practice-metal-mines.html
Ministère des Ressources naturelles et des Forêts du Québec	Géologie pour tous : Le processus de développement minéral (2021) [in French]	Many of the things we use in our daily lives contain mineral substances or processed minerals that would not exist without mining. Think of smart phones, computers, lithium batteries, electric cars, aeroplanes, dental and medical implants or even a simple lead pencil. In Quebec, to explore and exploit mineral resources in a sustainable manner, we must go through six major steps that make up the mineral development process. https://gq.mines.gouv.qc.ca/geologie-pour-tous/processus-developpement-mineral/
Videos mines:		
Minalliance	L'exploitation minière à ciel ouvert [in French]	Detailed explanation of the operating of an open pit mine, duration: 4:33 minutes (2010), in French: https://www.youtube.com/watch?v=GxLTtltXWtA&t=93s Great suggestion for presentation to groups of fifth and sixth graders (or older). Detailed overview of the facilities and steps in operating an open pit mine, overview of the various trades. Perhaps followed by the video providing a guided tour of the LaRonde Penna mine, an underground mine.
Mines QC	Nous sommes descendus à 3 km de profondeur dans le sous-sol québécois [in French]	Guided tour and presentation of the workers at the LaRonde Penna mine, duration: 5:14 minutes (2018), in French: https://youtu.be/RR22jBcssiE Good suggestion for presentation to groups of fifth and sixth graders (or older). Overview of the facilities, presentation of the ore being mined, the work conducted underground and the various tradespeople working at the mine.
AgnicoEagleVideos	The Mining Process - Le processus d'exploitation minière - 2015	Video presenting the operation of a very deep underground mine (~ 3 km), duration: 3:00 minutes (2015), French-English text: https://youtu.be/UCmQKkoVghU

Mines QC	À la rencontre des gens qui travaillent à l'extrémité nord du Québec [in French]	Tour and introduction of the people who work at the Raglan Nickel Mine, located in Quebec's far north, duration: 6:28 minutes (2018), in French: https://www.youtube.com/watch?v=r4P9Cyg08Tg Presentation of mostly the people, the harshness of the climate and the fly-in fly-out working schedule.
The videos below were presented as part of the *Journée Découverte de Québec Mines et Énergie* in 2018 as well as during the *Tempêtes des Science* at Cegep Garneau in 2022. These are videos without text showing the current infrastructure in the underground mines operated in Quebec. Good suggestions for visual support during exhibits :		
AgnicoEagleVideos	LaRonde Penna mine, Abitibi	Video showing the facilities and workers at the LaRonde Penna mine, duration: 2:55 minutes (2015): https://www.youtube.com/watch?v=5DMf-ly_rM4
AgnicoEagleVideos	LaRonde Penna 3D Animation 2013	Doyon-Bousquet-LaRonde Mining Camp, 3D animation showing the underground infrastructure, duration: 2:07 minutes (2013): https://www.youtube.com/watch?v=91OSfZj8xos
Newmont Goldcorp	Eleonore, Eeyou Istchee Baie-James – virtual underground tour	Eleonore – virtual underground tour, duration: 6:10 minutes (2015): https://youtu.be/F_ssMQQpdtw

Section 4: Physical properties of minerals activities

A mineral is an inorganic substance in the form of a crystal or crystalline solid, distinguished by its chemical composition and crystal structure (e.g. graphite and diamond are both polymorphs of carbon – see *Section 2: Minerals and everyday objects*). Over 4000 varieties of known minerals exist, the vast majority of which are essentially composed of the following eight elements: oxygen (O), silicon (Si), aluminium (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K) and magnesium (Mg). Considering that O and Si alone account for nearly three quarters (74.5%) of all the elements on Earth, it isn't surprising that minerals essentially composed of these elements, the silicates, makes up 95% of the volume of the Earth's crust. Since it may be difficult to discriminate chemical elements with the naked eye, apart from certain metals and elements found in their native state, physical properties of minerals then serve as diagnostic tools allowing their identification. Some of these properties can easily be observed, with or without instruments.

The main characteristics for identification of minerals are: colour (non-absolute criterion, because a wide variety of colours exist in a same mineral species, e.g., smoky grey quartz versus pink to violet amethyst quartz), lustre (metallic and non-metallic, including: vitreous, greasy, adamantine, resinous, silky), streak (colour of the mineral powder), hardness (scratch resistance measured by the Mohs scale – Figure 4.1), density (weight per unit of volume), crystalline form (crystalline system), cleavage (planes of weakness in the crystalline structure along which a mineral will break preferentially (e.g., micas split into sheets because of their cleavage along a single plane), effervescence (reaction to acid), magnetism and optical properties (mainly observed in thin sections with a microscope but also in samples – *see activity on the optical properties of ulexite and birefringent calcite).*

Sources:
http://www2.ggl.ulaval.ca/personnel/bourque/s2/ident.mineraux.html
N'golo, T. Les minéraux et les roches; MERN, PPT presentation: https://mern.gouv.qc.ca/mines/trousse-educative/conferences/

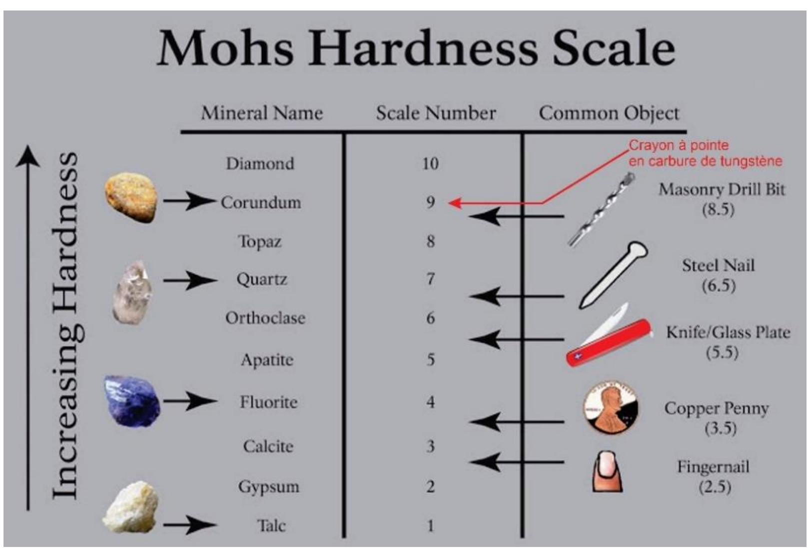

Figure 4.1: The Mohs scale was established in 1812 by the German mineralogist Friedrich Mohs to measure the hardness of minerals. It is based on ten easily available minerals. Since this is an ordinal scale, one must proceed by comparison with two other minerals of known hardness (capacity of a mineral to scratch the other).

(Sources: https://fr.wikipedia.org/wiki/%C3%89chelle_de_Mohs)

Mineral identification key (© Canadian Museum of Nature)

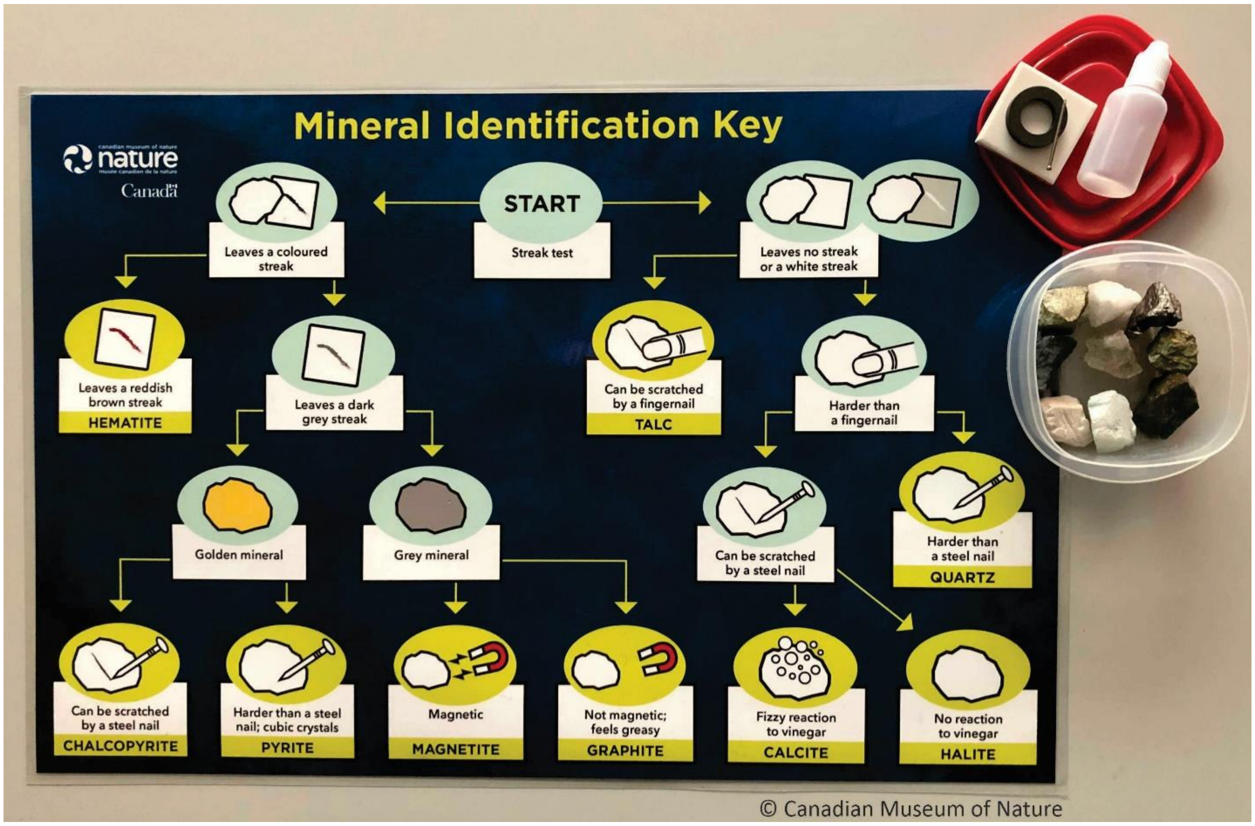

Figure 4.2: Mineral identification key developed by the Canadian Museum of Nature (© Canadian Museum of Nature) with toolkit and minerals to perform a semi-directed activity on the physical properties of minerals.

Semi-directed activity where the participants must identify a series of nine minerals, based on diagnostic tests pertaining to the physical properties of the minerals, such as streak, hardness, colour, magnetism, and effervescence. To do this, they have an identification placemat (identification key – Figure 4.2), nine mineral specimens and tools to perform tests (porcelain plate, nail, magnet, and a bottle of vinegar) (Figure 4.2). This activity is mainly intended for children from Grade 3 to 6 of elementary school and the first cycle of high school (Grades 7 to 9). This is why the use of vinegar (preferably at 10–12% acetic acid) is preferred to the use of hydrochloric acid (HCl), even if diluted. Considering that there is material for six stations, which can accommodate two to three participants each, it would be complex to oversee safe handling of HCl. To facilitate observation of the effervescence reaction, it is suggested to pour the vinegar directly on the scratch made with the nail or make a small heap of mineral powder. Needless to say, the reaction is less important than the one observed with HCl. Suggestion: have absorbent paper on hand. Although the bottles are relatively tightly sealed and have a limited flow, nobody is exempt from accidents.

For an additional activity, have sheets of white paper on hand on which the participants can produce streaks, or even write their names or make a drawing with the graphite sample. This generally offers a good context to address the similarities and differences existing between graphite and diamond as polymorphs of carbon (see *Graphite* in *Section 2- Minerals and everyday objects*).

Optical properties

Optical properties are a fundamental diagnostic factor in identifying a mineral. But determining these properties is more a matter for a specialist. In geology, technical means allow thinning of the rock or mineral slivers glued to glass slides so thin (30 micrometres) that they become completely transparent. The minerals then can be studied under the microscope, just as biologists study tissues or microorganisms. Each group of minerals has its own optical properties, meaning they transmit light differently and produce characteristic colours when they are observed in natural and polarized light, which allows them to be identified.

However, some minerals, under certain very precise crystallization conditions, form translucent specimens that allow surprising light propagation. This is the case for ulexite and birefringent calcite.

Ulexite

Figure 4.3: Ulexite specimen allowing light propagation
Source:
https://www.reddit.com/r/chemistry/comments/b9fatl/this_is_ulexite_also_known_as_tv_stone_because_of/)

Ulexite (Figure 4.3) is a double hydrated soroborate of calcium and sodium, formula $NaCa[B_5O_6(OH)_6] \cdot 5\ H_2O$, which belongs to the same class as the carbonates. This rare and fragile, light and often spongy mineral also forms a very soft evaporite rock (hardness of 1.5 to 2.5 on the Mohs cale) which sometimes contains small quantities of iron, magnesium and manganese. This is a colourless, white, grey or yellowish mineral, sometimes whitish with rare greenish shades. Its lustre is vitreous or silky and it generally has fairly good transparency. Ulexite, especially when it forms veins by filling small fractures, exhibits fibres arranged very regularly side by side. This structure allows surprising light propagation. When looking at parallel fibres, the images appear large and floating, as if they were projected on a television screen. This is the source of the name "TV rock". Fibrous clusters of this mineral, with optical fibre properties that influenced their invention, are especially coveted by collectors.

Source:
https://fr.wikipedia.org/wiki/%C3%89chelle_de_Mohs)

Birefringent calcite

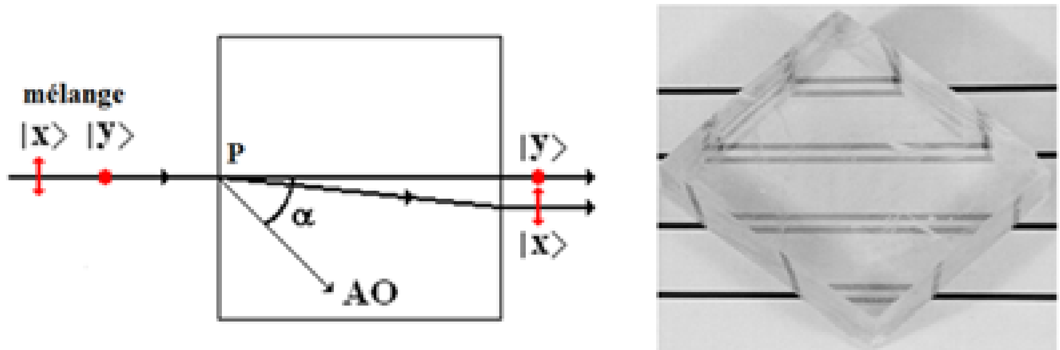

Figure 4.4: Birefringent calcite specimen
(Source: https://www.physinfo.org/chroniques/polarisation.html)

Calcite ($CaCO_3$) is a very abundant mineral in magmatic, sedimentary, and metamorphic environments. Calcite is the main constituent mineral of limestone and marble. $CaCO_3$ can crystallize either as calcite (rhombohedral) or as aragonite (orthorhombic), calcite being the most frequent form. Transparent to translucent with hardness 3 on the Mohs scale, the mineral's colour is variable, from colourless to white, yellow, brown or red. The transparent calcite variety of optical quality, Iceland spar, is birefringent, meaning that light propagates in it anisotropically. This confers the double refraction property, where a light ray penetrating the mineral is divided in two (Figure 4.4). That is why the lines are duplicated in the image above.

Sources:
http://www2.ggl.ulaval.ca/personnel/bourque/s2/ident.mineraux.html
https://fr.wikipedia.org/wiki/Bir%C3%A9fringence
https://www.physinfo.org/chroniques/polarisation.html

Section 5: Supplementary resources material

5a – Critical minerals

Thematic posters:		
Natural Resources Canada (NRCan)	Canada’s 2021 critical minerals list	Critical minerals (nrcan.gc.ca)
Ministère des Ressources naturelles et des Forêts du Québec (MRNF)	Les terres rares et leurs usages (GT 2012-01) [Rare earths and their uses]	Poster in French. https://sigeom.mines.gouv.qc.ca/signet/classes/I1102_examine?l=F
Government resources:		
NRCan	Critical minerals	Critical minerals (nrcan.gc.ca)
Gouvernement of Quebec	Minerals for the future	Critical and strategic minerals | Gouvernement du Québec (quebec.ca)
MRNF	Fascinantes terres rares [Fascinating rare earths]	Document in French. https://mern.gouv.qc.ca/mines/trousse-educative/conferences/
Wavrant et al.	Projet terres rares au Québec (MB 2017-17) [Rare earths project in Quebec]	Document in French. https://sigeom.mines.gouv.qc.ca/signet/classes/I1102_examine?l=F
Bureau de Recherches Géologiques et Minières	Ressources minérales : les terres rares [Mineral resources: rare earths]	Document in French. https://www.brgm.fr/fr/actualite/dossier-thematique/ressources-minerales-terres-rares#:~:text=Le%20groupe%20des%20terres%20rares,denr%C3%A9e%20%C3%A9conomique%20et%20m%C3%AAme%20g%C3%A9opolitique.
Various sources:		
CBC Radio	More electric cars on the road will mean increased mining for what goes in their batteries	Quirk & Quarks, blog from Bob McDonald, posted May 28, 2021, describing how the in demand for electric vehicles will require increased mining for metals and possibly increasing environmental consequences. https://www.cbc.ca/radio/quirks/more-electric-cars-on-the-road-will-mean-increased-mining-for-what-goes-in-their-batteries-1.6044010
Centre international de référence sur le cycle de vie des produits procédés et services (CIRAIG).	Analyses du cycle de vie comparative des impacts environnementaux potentiels du véhicule électrique et du véhicule conventionnel dans un contexte d’utilisation québécois	Technical report prerared for Hydro-Québec, April 2016 (in French): https://www.hydroquebec.com/developpement-durable/documentation-specialisee/analyse-cycle-de-vie.html
Let’s Talk Science	STEM in context: How does a lithium-Ion battery work?	https://letstalkscience.ca/educational-resources/stem-in-context/how-does-a-lithium-ion-battery-work

Videos and podcasts lithium batteries and rare earth elements:		
NRCan (podcast)	Simply Science: What Type of Batteries do Electric Vehicles Use?	Have you ever wondered exactly what's under the hood of an electric vehicle? Specifically, what kind of batteries do they use and how different are they from the ones you find in a gas-powered vehicle? Research engineer Kathleen Lombardi answers our pressing questions about electric vehicle batteries. https://www.nrcan.gc.ca/simply-science/what-type-batteries-do-electric-vehicles-use-natural-elements/22212
NRCan (podcast)	Simply Science: Why are rare earth elements important?	Rare earth elements are found in just about every type of high-tech device from smart phones to electric vehicles. In this episode of our Ask NRCan podcast, we sit down with expert Magdi Habib to discuss what rare earth elements are, why they are important and what type of research Natural Resources Canada is doing to help Canadian industry. https://www.nrcan.gc.ca/simply-science/why-are-rare-earth-elements-important-ask-nrcan/20667
NRCan (video)	Simply Science: Separating Rare Earth Element	Short video on the technique used to separate rare earth elements. A good introduction to metallurgy and a review of the physical properties of minerals (e.g., magnetism used in the separation process). High school and higher-level groups. Duration: 2:08 minutes, in English Separating Rare Earth Elements (Byte-sized Science) - YouTube
Pitron, G. (video)	TEDxLile : Métaux rares : la face cachée de la transition énergétique [Rare metals: The hidden side of the energy transition]	A good suggestion for a presentation to high school and higher-level groups. Provides an opportunity to think about the "clean" energy concept and invites viewers to question their consumption habits. Duration: 17:08 minutes, in French with English subtitles. https://www.youtube.com/watch?v=LVWUDLBYb-Q
Lespagnol, Q. et Marchal, A. (video)	Ressources 21 : La séparation et le traitement des minerais [Ore separation and processing]	Video on the various techniques used to separate and process ore and how extracted minerals are used in everyday items. A good introduction to metallurgy and a review of the physical properties of minerals (e.g., magnetism used in the separation process). Overview of the issues involved in the procurement of rare earths and metals and options for recycling our consumer goods. High school and higher-level groups. A good follow-up to the TED lecture "Métaux rares : la face

		cachée de la transition énergétique/ G. Pitron" [Rare metals: The hidden side of the energy transition]. Duration: 6:40 minutes, in French. https://www.youtube.com/watch?v=PM39u5B2T9M
Radio-Canada (video)	La voiture électrique, pas si écologique [The electric car, not so green]	Article by Jean-Sébastien Cloutier broadcast on Radio-Canada's Télé Journal 18h30 Montréal, accompanied by an article by Thomas Gerbet. Provides an opportunity to think about the actual eco-friendly aspects of electric vehicles and invites viewers to reflect on the concept of mobility and their means of transportation. Duration: 4:16 minutes, in French. https://ici.radio-canada.ca/nouvelle/1137184/voiture-electrique-pollution-empreinte-environnement-batterie-production-fabrication

5b- Industry challenges and innovations

Miscellaneous sources:		
Mercier-Langevin et al. (2022)	Chapitre 2.5. Une industrie en évolution : défis et innovations techniques et scientifiques dans le monde des ressources minérales *In* Chapitre 2. La ceinture de roches vertes de l'Abitibi, Canada; dans Ressources métalliques 2: cadre géodynamique et exemples remarquables dans le monde, (ed.) S. Decrée; ISTE Editions Ltd., Great Britain, p. 61–134. English version forthcoming in 2023.	Contribution to a chapter on the Archean Abitibi Greenstone Belt, published by ISTE Editions Ltd. This book Metallic Resources 2 offers a selection of studies of metallogenic provinces or remarkable deposits in America, in Africa or present at world level which make it possible to address the question of concentration of metals, including strategic, in various geodynamic contexts. Understanding the geological processes that induce the formation of deposits and influence their concentration in the earth's crust is of prime importance for the discovery of new mineral resources. As the target audience is undergraduate students, we thought it appropriate to include a section on the evolution of the mining industry with an emphasis on good practices in recent years. This provides an interesting complement to the mineral sample exhibition. For secondary school students and above.
Mines Agnico Eagle Limitée (2018)	Facts Sheet – LaRonde Mine 4.0	LTE (4G) cellular network deployed underground, example of the LaRonde mining complex (Quebec). https://abitibi.agnicoeagle.com
Ross, I. (2016)	Goldcorp going electric with Chapleau gold mine. Northern Ontario Business	Use of electric vehicles in mining, example of the Borden mine, Ontario. https://www.northernontariobusiness.com

Dumas, P. (2019)	Restauration de l'ancien site minier Manitou: la force du partenariat entre l'État et l'entreprise privée [Restoration of the former Manitou mine site: the strength of the partnership between Governement and the private sector]	Article in French. Ressources Mines et Industrie, 5(6), 30–35.
Azevedo, M., Baczynska, M., Bingoto, P., Callaway, G., Hoffman, K., and Ramsbottom, O. (McKinsey& Company)	The raw-materials challenge: How the metals and mining sector will be at the core of enabling the energy transition	Article that analyses how the energy transition presents unique challenges for metals and mining companies, and how these will need to innovate and rebuild their growth agenda. https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-raw-materials-challenge-how-the-metals-and-mining-sector-will-be-at-the-core-of-enabling-the-energy-transition
Video:		
AgnicoEagleVideos	Projet de restauration minière Manitou-Goldex [Manitou-Goldex Mine Reclamation Project]	Valorisation of mine tailings in the reclamation of an abandoned mine site, example of the Manitou Manitou project (Quebec). Duration5 :08 minutes (2018), in French with English subtitles: https://www.youtube.com/watch?v=KcPTYAPEjrs&t=197s

5c- Analytical techniques

Government resources:		
NRCan	Trace inorganic geochemistry laboratory	https://www.nrcan.gc.ca/science-and-data/research-centres-and-labs/geological-survey-canada/geoscience-labs-and-the-earth-material-collection/23846?_gl=1*1a55xor*_ga*MTI3NDExNTExNi4xNjIzOTUyODkx*_ga_C2N57Y7DX5*MTY3MTgyMjEwOS4xMS4xLjE2NzE4MjMyMjguMC4wLjA.
Miscellaneous sources:		
Sylvester, P.J. and Jackson, S.E. – Guest Editors (2016)	Studying the Earth with LA-ICP-MS	This issue of *Elements* highlights the many applications of the laser ablation technique (LA-ICP-MS) in a wide range of earth, environmental and biological science disciplines Elements, Vol. 12, No. 5, October 2016. www.elementsmagazine.org

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