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Educational case "Critical minerals"

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Canada

"Critical Minerals" Case

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The purpose of the educational case project is to facilitate scientific awareness and outreach activities by assembling simple materials 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. 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.

The minerals and their constituent elements are used in the manufacturing of various products or in industrial processes thanks to their physical or chemical properties. What would life be without metals or minerals: no steel, no electricity, no plumbing, no household appliances, no planes, and no vehicles? Were you also aware that minerals are used in making cosmetic products, medications, vitamins, electronic devices and played a key role in the transition to a digital and low carbon economy? The Government of Canada has compiled a list of the 31 minerals and/or elements that are considered critical to the economic prosperity of Canada and its allies and to position the country as a leader in the mining sector, as laid out in the Canadian Minerals and Metals Plan (CMMP). The "Critical Minerals" case shows some of the minerals that are deemed essential for the country's economic development.

Minerals contained in the "Critical Minerals" case

Deepest appreciation to Christopher Lawley for his critical reading of the document. His comments and suggestions helped to improve and clarify the content. Thank you also to Jean-François Bureau and Patrick Potter for their comments.

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https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/critical-minerals/23414
Canadian Minerals and Metals Plan (CMMP): https://www.minescanada.ca/en

MALLETTE « MINÉRAUX CRITIQUES »/ “CRITICAL MINERALS” CASE

Inventaire des minéraux/ Minerals inventory:

1. Graphite / Graphite
2. Pyrochlore / Pyrochlore
3. Molybdénite / Molybdenite
4. Malachite et cuivre natif / Malachite and native copper
5. Spodumène / Spodumene
6. Bauxite / Bauxite
7. Chromite /Chromite
8. Fluorite / Fluorite
9. Eudialyte / Eudialyte
10. Ilménite / Ilmenite
11. Titanomagnétite / Titanomagnetite
12. Chalcopyrite / Chalcopyrite
13. Sphalérite / Sphalerite
14. Pentlandite et chalcopyrite (Mine Raglan, Cap Smith, Qc) / Pentlandite and chalcopyrite (Raglan Mine, Cape Smith, Qc)

Section 2: Critical Minerals

The case contains a collection of 16 samples that include minerals and/or metals (elements) identified as critical for Canada (see the minerals, highlighted yellow, and metals, highlighted green, in Figure 2.1). Although certain metals can be found in their pure state (e.g. native gold and copper), but generally in low quantities, most of them occur in the form of a group of chemical elements found as a crystalline solid (mineral) usually formed by inorganic processes. Essential for applications associated with renewable energy and clean technologies (e.g. the manufacturing of batteries, permanent magnets, solar panels and wind turbines), these critical minerals and elements are also essential supply chain inputs for the production of advanced technologies, namely the defence and security industry, consumer 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)

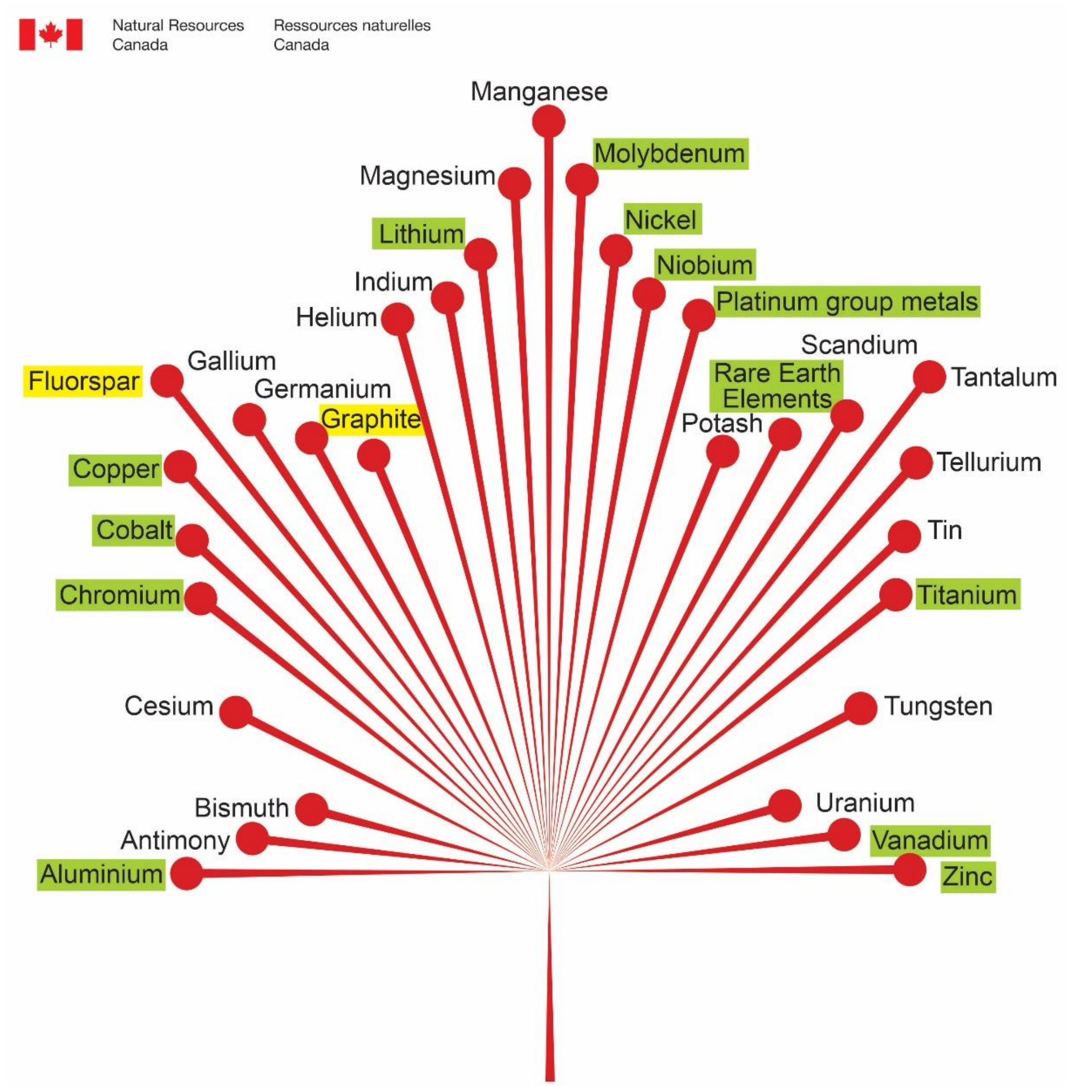

Figure 2.1: *List of Canadian critical minerals as published in 2021. The minerals, highlighted yellow, and metals, highlighted green, correspond to examples contained in the "Critical Minerals" case.*

In 2021, at the United Nations climate change conference (COP26), Canada joined more than 120 countries, including all G7 members (UK, US, Germany, Italy, France and Japan), in committing to reach the objective of net-zero emissions by 2050. A certain number of Canadian provinces and cities have also followed suit by making similar commitments. Although there is no question of the preponderant role of fossil fuels in current and future climate change, the energy transition will be associated with a large number of socio-economic impacts. For example, the proliferation of new energy efficient technologies may ultimately increase energy and resource consumption, counter to what is required to meet global climate goals (i.e. a socio-economic concept known as the "rebound effect"; Gillingham et al., 2014, RFF DP 14-39). Moreover, in a report tabled in early 2021, the International Energy Agency (IEA) stated that in order to reach net zero by 2050, the world's production of critical minerals and metals would need to be multiplied by a factor of six over the next 30 years. That is why it is important to learn a bit more about these minerals and metals and the geological environments in which they are found.

For a more complete background on the role of minerals and metals in the energy transition Emmanuel Hache, a foresight economist at *IFP Energies nouvelles*, a public research, innovation and training organization in the fields of energy, transport and the environment, suggests that the following points should be taken into consideration:

1. The production of low carbon-emission technologies requires more materials than traditional technologies. As a result, the energy efficiency associated with the development of renewable energies is accompanied by an increase in the consumption of mineral resources.

2. The definition of a metal's criticality is not universal, varying from one country to another, and over time due to changing consumption patterns and/or other technical progress. Multiple factors may lead to criticality such as geological, economic, strategic and environmental.

3. According to the demand for material model defined by Emmanuel Hache and his team, it is not lithium but copper that is, geologically speaking, the most limited metal in terms of the energy transition. Lithium is more limited economically and cobalt geopolitically.

4. Collective and individual solutions for metal recycling, sustainable mobility and even, limiting or avoiding energy consumption (i.e. energy sobriety) all have their place in the actions to be considered for our energy future.

(source: https://www.ifpenergiesnouvelles.com/issues-and-foresight/decoding-keys/climate-environment-and-circular-economy/metals-energy-transition)

A portable tripod and a coroplast (hard poster, *From Rock to Technology* - Minerals that supply elements for a mobile phone) and a poster (soft poster, Canada's Critical Minerals List 2021) accompany the "Critical Minerals" collection and are stored with the case. These posters are courtesy of the CIM Foundation and PDF versions are included in *Section 2-Critical Minerals*.

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

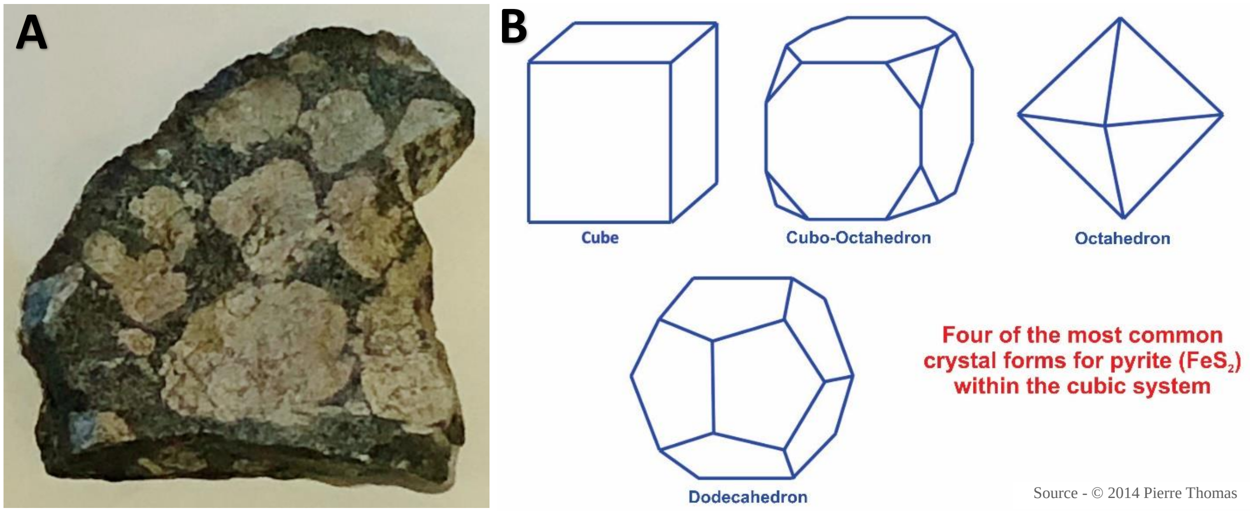

Figure 2.2: *A) Example of a rock, in this case a porphyritic gabbro, composed of plagioclase minerals (silica and aluminium based mineral) whitish in colour surrounded by a matrix of fine dark-coloured minerals composed essentially of amphibole (pyroxene) and chlorite (silica, iron, magnesium and calcium 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 2.2A). 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 2.2B).

The sample in Figure 2.2A 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 porphyry 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.

BAUXITE

Figure 2.3: Bauxite sample (GSC-Quebec collection).

In nature, aluminum (Al) does not exist in its pure state. It is extracted from bauxite ore ($AlO_x(OH)_{3-2}$ – Figure 2.3) which is composed of hydrated aluminum oxide, containing 40% to 60% alumina (aluminum oxide Al_2O_3), and which consists of an insoluble residue formed by deep weathering (alteration caused by the action of atmospheric agents) of the rock in a tropical or humid climate. The main producers of bauxite are Australia, Guinea, China, Brazil and India. Aluminum is produced by separating pure alumina from the bauxite in a refinery using a chemical process (Bayer process), then by subjecting the alumina to an electrolysis treatment at an aluminum plant. The process consists of running an electric current in an electrolyte containing dissolved alumina where aluminium is separated from oxygen atoms and collected upon carbon anodes. On average, around four tons of bauxite are required to obtain two tons of alumina, which in turn produces one ton of pure aluminum.

Light, resistant, flexible, non-corrosive and infinitely recyclable, aluminum is one of the most used and most recycled metals in the world. The automotive and transportation industry uses various aluminum alloys in the manufacturing of various components due to its light weight and durability, reducing the weight of vehicles and consequently fuel consumption and greenhouse gas emissions. Aluminum is also abundantly used in the construction sector where it is used for exterior cladding, support components for buildings, electrical components, electronic components and packaging (e.g. cans).

Although Canada has no bauxite deposits, it is still one of the main aluminum producers (4th largest producer of primary aluminum in the world in 2019) thanks to its ability to produce large quantities of electricity, specifically in the form of hydroelectricity, making it one of the lowest carbon footprint productions in the world. Furthermore, new aluminum electrolysis technology that does not emit greenhouse gases (GHGs) is currently under development. Replacing the anodes in the traditional process with no-carbon anodes would reduce costs and increase an aluminum plant's production capacity, while eliminating the GHGs directly associated with aluminum production, producing oxygen as a by-product (ELYSIS^{TM} technology). Nearly all the aluminum plants in Canada are located in Quebec, with the exception of one site located in Kitimat, British Columbia, and the country's only alumina refinery is located in Jonquière in the Saguenay-Lac-Saint-Jean region.

The hydroelectric network and ELYSIS™ technology, both developed in Quebec, are helping to respond to the global trend towards manufacturing products with a smaller carbon footprint, from smartphones and automobiles to aircraft and building materials.

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CHROMITE

Figure 2.4: Sample of chromite, a black mineral with a submetallic lustre, from the Thetford Mines sector in the Chaudière-Appalaches region of Quebec (donated by V. Bécu).

Chromite (Figure 2.4) is a mineral species in the spinel group, its formula is Cr_2FeO_4 (or $FeO.Cr_2O_3$), which can contain traces of magnesium, manganese, zinc and aluminium. Belonging to the cubic crystalline system, chromite crystals are rarely larger than a centimetre and are most often found in grainy clumps, with a submetallic lustre and a colour varying from brown to black. Chromite is the only ore mined for chrome (Cr).

Chrome is a hard metal, brittle and silvery white (melting point of 1875°C) very well known for its use as decorative trim on household appliances and vehicles. However, it is mostly used to manufacture stainless steel, which contains an average of 20% chrome. In its usual mineral form (chromite), chrome has heat resistant properties, thereby finding applications in various types of kilns. Chrome readily forms various chemical compounds that have a vast array of applications, such as pigments and tanning agents.

Chromite is a common ore in peridotites and other igneous ultramafic rocks as well as in metamorphic rocks that derive from them, including serpentinite. Formed at high temperatures, chromite can be concentrated by gravity in magma to form rich layers of chrome, in association with pyroxenes, olivine, serpentine and corundum. The sample contained in the case comes from one of many mines that have extracted the chromite contained in dunite and harzburgite units in the ultramafic rocks located at the base of the Thetford Mines Ophiolite Complex in Quebec. These mines were operated only intermittently during the first half of the 20th century and their purpose was essentially to provide chrome for the manufacturing of vehicles and various materials during the two world wars. At the moment, there are no chromite mining operations in Canada. However, given the critical role of chrome in the manufacturing of various products connected to the energy transition or defence, large deposits discovered in the Ring of Fire sector of northern Ontario could be mined in a fairly near future.

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NICKEL ORE, COPPER, COBALT AND METALS FOR THE PLATINE GROUP

Figure 2.5: Samples of pentlandite and chalcopyrite from magmatic nickel ore taken from the Raglan Mine in the Cape Smith Belt in Nunavik, Quebec (donated by M. Houlé).

Pentlandite ($(Fe,Ni)_9S_8$ – Figure 2.5) is a rather frequently found nickel sulfide in magmatic deposits of nickel (Ni) and copper (Cu). Appreciable concentrations of cobalt (Co) and platinum group elements (PGEs or platinum group metals – PGMs) are incorporated into the pentlandite crystal structure or are associated with accessory minerals (platinum group minerals) at the same deposits. The most important end use for nickel is stainless steel, representing two thirds of total consumption (71%). Nickel is also used as an alloying agent in the manufacturing of products made of ferrous and non-ferrous metals. Nickel electroplating also uses nickel (7%). This process involves covering a metal object with a thin layer of nickel as a decorative element or to provide resistance to corrosion and wear. Whereas the use of nickel in the production of nickel-cadmium batteries is well known, its use in the production of batteries for electric and hybrid vehicles is new. Electrification of the transport sector is expected to lead to a fourfold increase in global nickel demand. Interestingly, everyone has carried nickel in their pockets, as this metal is used in the multi-layer plating process for coins issued by the Royal Canadian Mint.

Exceptional resistance to elevated temperatures and corrosion have made cobalt an essential alloying element in the manufacturing of jet engine turbines and electricity production (improving combustibility and reducing fuel consumption), specialty steels for medical/scientific instruments and hard coating alloys in abrasive applications (e.g. bulldozer blades). It is also used in the manufacturing of rechargeable batteries destined for electric or hybrid vehicles as well as an array of electronic devices.

PGEs include six elements (osmium, iridium, ruthenium, rhodium, platinum, palladium) which have similar properties and belong to the transition metals group. They are sometimes referred to as platinum group metals (PGMs). PGEs have powerful catalytic properties, i.e. they can accelerate or trigger a chemical process without undergoing permanent changes or being consumed. The manufacturing of catalytic converters (used in the exhaust systems of internal combustion engine vehicles) represent the main use for these elements. They are often used as catalysts in medical materials, oil refining, glass manufacturing and several other applications. Because these precious metals are rare, durable, and have an attractive lustre, they are sometimes used in jewellery making (white gold). They are also used as investment instruments by investors.

As for copper, it is concentrated in chalcopyrite minerals (($CuFeS_2$) – Figure 2.5) and covellite (CuS) and it is very important within the context of the energy transition, namely in the electrification of transportation and the renewal energy sector (e.g. wind turbines and solar panels).

Located in the Cape Smith Belt, in Northern Quebec, in Nunavik, the Raglan Mine, which opened in 1997, is still to this day the most northern mine in Quebec. It is composed of four underground mines, Kikialik (which means "where there is nickel" in Inuktitut), Qakimajurq (which means "plentiful"), Katinniq and Mine 2, where deposits of massive and disseminated sulphides are being mined that are rich in nickel (Ni), but which also contain copper (Cu), platinum group elements (PGEs) and cobalt (Co). The Raglan mining complex is one of the most plentiful base metal mines in the world.

At the Katinniq mine, the mineralization consists of lenses of massive sulphides located at the base of komatiite flows (lava rich in magnesium, i.e. containing 20% to 30% MgO). These lenses are mainly composed of pyrrhotite ($Fe_{1-x}S$), chalcopyrite and pentlandite locally accompanied by covellite. Platinum group elements (or platinum group metals) are mostly found in minor phases in platinum group minerals, or like cobalt, incorporated into the mineral structure of abovementioned sulphide minerals. Massive sulphide zones, at the base of flows (sample on the left on Figure 2.5), range upwards into the net-texture dissemination zones in the peridotites (sample on the right, Figure 2.5). These flows form an ultramafic complex, mainly composed of peridotite (olivine-rich rock) and pyroxenite (pyroxene-rich rock), locally marked by levels of gabbros overlying sedimentary rocks.

Since the Raglan facilities are isolated from all external resources, the site has all the infrastructure of a small municipality, including a housing complex, a wastewater treatment plant, a power plant and an airport. A network of roads that are open year round connect the mining complex to warehouses and port facilities located in Deception Bay. Workers are flown in from the south of the province, but also from neighbouring Inuit villages working fly-in-fly-out type shifts (see the suggested video on the Raglan Mine in under *Mines videos* in *Section 3- Supplementary Resources*).

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CHALCOPYRITE

Figure 2.6: Sample of chalcopyrite, a brassy yellow mineral with metallic lustre, from the Rouyn-Noranda area in Abitibi, Quebec (donated by P. Mercier-Langevin).

Chalcopyrite is an iron and copper sulphide ($CuFeS_2$ – Figure 2.6). 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 contained in the "Mines and Minerals" case and the samples of nickel ore described above).

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MALACHITE AND NATIVE COPPER

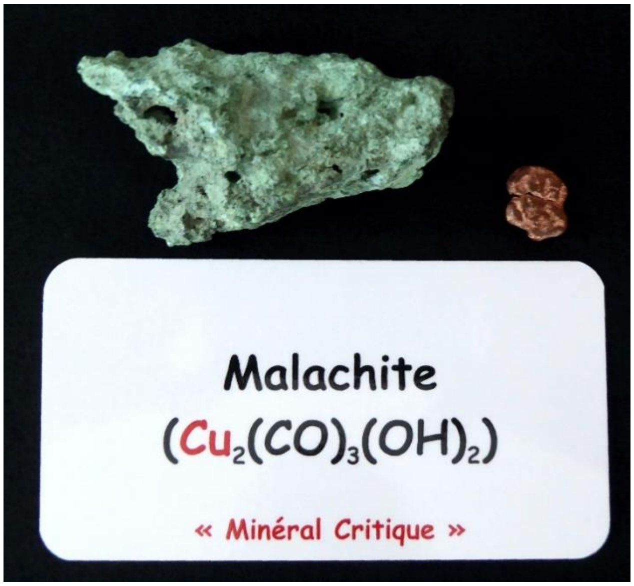

Figure 2.7: Sample of malachite from the Eastern Townships region of Quebec (donated by P. Mercier-Langevin) and a sample of native copper (GSC-Quebec collection).

Malachite ($Cu_2(CO)_3(OH)_2$ – Figure 2.7) is a hydrous copper carbonate (Cu) which is the best-known product of air weathering of copper ores and usually occurs naturally as a crust with beautiful green shades. It is composed of small acicular crystals laid out in a striped structure, often revealing zoned surfaces ranging from pale to dark green and sometimes iridescent purples. Composed of nearly 57% copper, malachite is used both as ore and an ornamental stone. It is also very popular among lithotherapy enthusiasts.

The etymology for malachite is uncertain. It may refer to its weak hardness (Greek word malakos, "soft") or its colour which is reminiscent of the leaves from the mallow plant (from the Greek word malakhê, "mallow"). Malachite has been in use since Antiquity. The Ancients ascribed curative properties to it (purgative) and used it to adorn their places of worship or people, including as an eyeshadow once pulverized into a powder. During the Middle Ages, it was supposedly good for dispelling "curses" and was used as a dye to achieve mountain green. Today, malachite is used mainly to make decorative objects, to make jewellery or as a copper ore.

Native copper is a metallic mineral that can be found in basaltic lava flows as well as in the weathered parts of copper deposits, in association with cuprite (Cu_2O), malachite and azurite ($Cu_3(CO_3)_2(OH)_2$). Native copper is found in the form of masses or deformed crystals of flattened shapes, scales, dendrites or strands. Copper is without a doubt the first metal ever used by humans, possibly due to the abundance of ore and the relative ease of the smelting process. During the time of the Romans, there were abundant deposits in Cyprus (Kypros), which explains the scientific name for copper: *cuprum*.

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EUDIALYTE

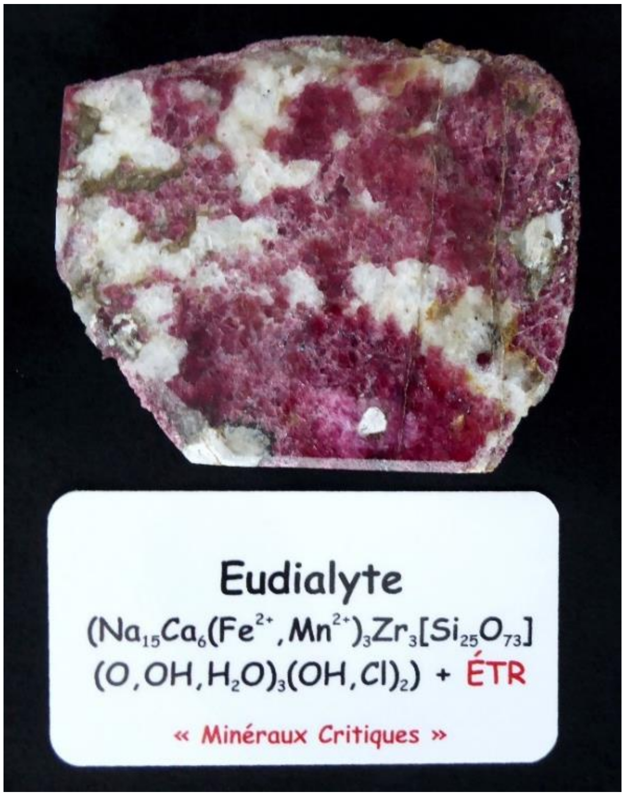

Figure 2.8: Sample of eudialyte (pink minerals) from the Kipawa deposit, located in Témiscamingue, Quebec (donated by V. Bécu and P. Mercier-Langevin). Eudialyte can contain rare earth elements, or REEs, which are essential for the manufacture of many common electronic products.

Eudialyte (Figure 2.8) 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).

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See "Section 3- Supplementary Resources" for additional information and videos on rare earths.

FLUORITE

Figure 2.9: Sample of fluorite from the Strange Lake intrusive complex, located along the Quebec-Labrador border in Nunavik, Quebec (GSC-Quebec).

Fluorite (or fluorspar – Figure 2.9) is a calcium fluoride (CaF_2) and is the main fluoride ore (F). It is a mineral with a glassy lustre, transparent to translucent and varying in colour (colourless, white, purple, yellow, blue, green) based on the chemical element inclusions contained in the mineral. Fluorite is used mainly in the production of hydrofluoric acid (HF) which is used, among other things, in the manufacturing of fluorocarbons for refrigerant gases and blowing agents in polyurethane foams, but also in the production of polymers, solvents, chemical products and lithium batteries. It is also used in the production of derived fluorinated products such as aluminum fluoride (AlF_3), which is used as an additive to lower the temperature of electrolysis baths used in aluminum production.

Fluorite is also used as a flux in the production of steel, glass, fibreglass, ceramic glazes and welding rods. While calcium fluoride is used in the manufacturing of optical instruments (microscopes, spectrographs, telescopes).

There are several types of fluorite deposits, the main ones being stratiform, lode or crack filling and associated with igneous alkaline complexes or pegmatites. More than 50% of the world's fluorine production comes from China and its exports are declining. Although there are currently no fluorite deposits being mined in Canada, certain exploration and resource definition projects are underway including a potential resumption of activities at the old St. Lawrence mine in Newfoundland as well as exploration work on the Liard Fluorspar property located in northern British Columbia. In Quebec, several deposits and occurrences have been discovered in the Grenville and Appalachian geological provinces, specifically in the Outaouais, Laurentians and North Shore regions. Fluorite is also observed at the Brisson Lake/Strange Lake intrusive complex, located on the Quebec-Labrador border, at the edge of a circular intrusion composed of peralkaline granites (rich in alkaline minerals such as aegyrine and arfvedsonite). Zirconium (Zr), yttrium (Y), niobium (Nb) and rare earth elements (REE) mineralization are associated with the pegmatitic levels of this granite complex.

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https://www.crmalliance.eu/fluorspar

GRAPHITE

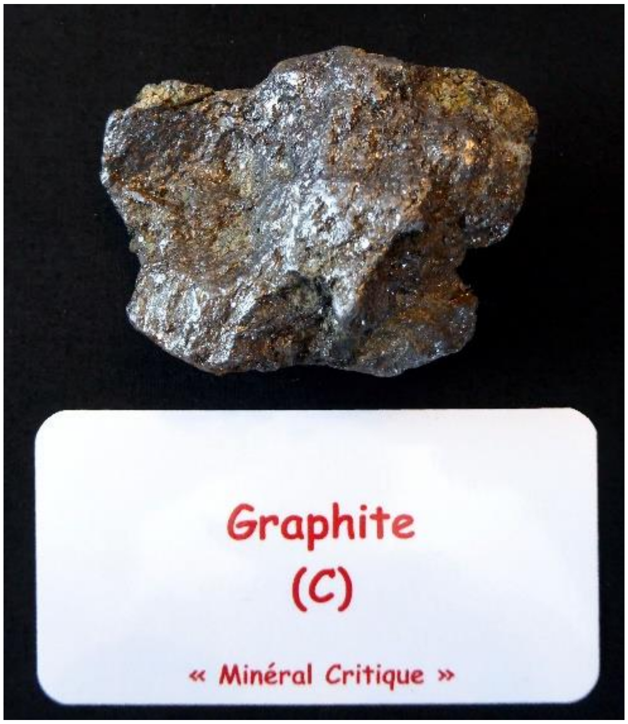


Figure 2.10: Graphite sample (GSC-Quebec collection).

Graphite (C – Figure 2.10) 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 belonging to 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://fr.canson.com/conseils-dexpert/le-crayon-mine-graphite
https://nmg.com/operations/
https://gq.mines.gouv.qc.ca/portail-substances-minerales/graphite/
For additional information regarding lithium-ion batteries, refer to “Section 3-Supplementary Resources”.

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 2.11). Here, the magma is just a vehicle transporting the diamonds quickly to the surface under high-pressure and high-temperature conditions, preventing then from transforming into graphite. (*see sample of kimberlite contained in the “Magmatic Rocks” case)

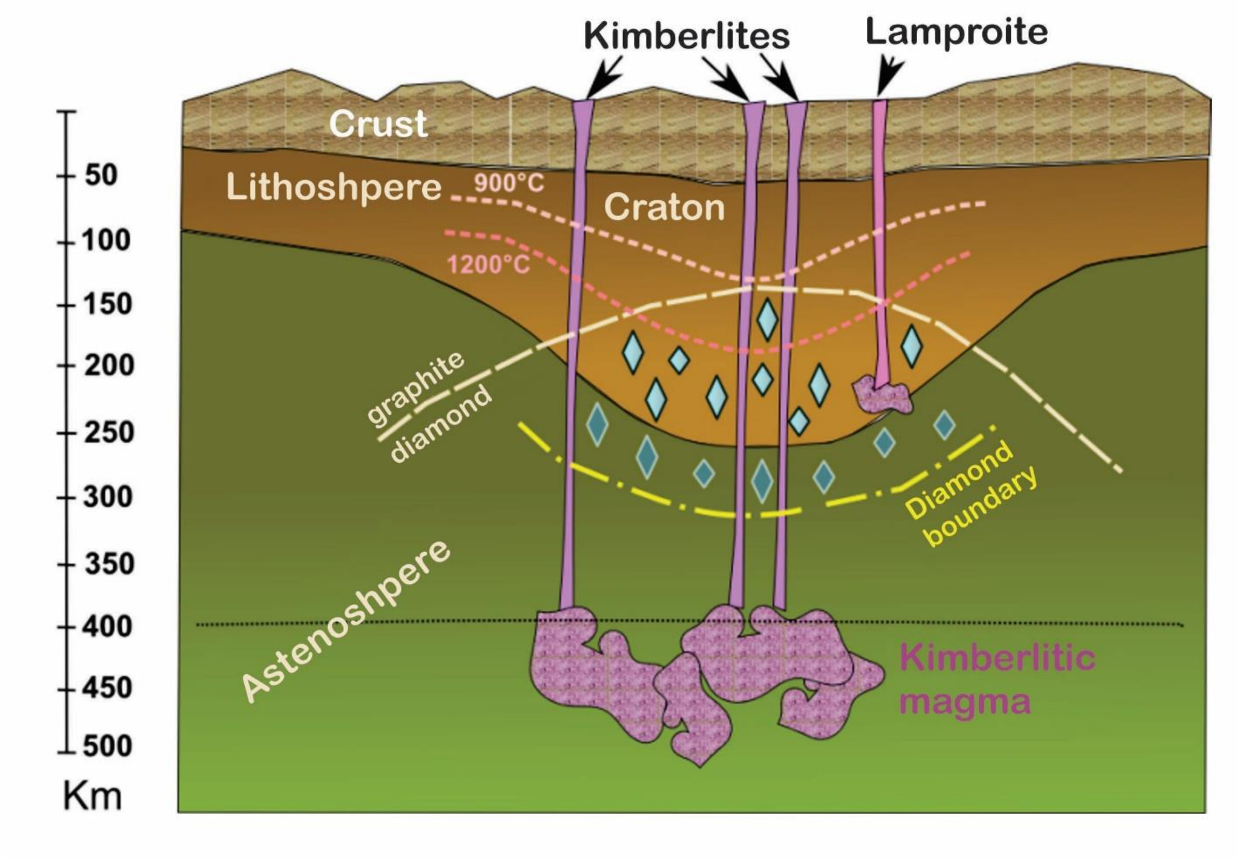


Figure 2.11: Diagram illustrating the various stability fields for graphite and diamonds as well as the mechanism for diamonds coming to rest in the continental crust when pushed up by the kimberlite magma, located at great depths in the earth's mantle. (source: https://www.pairform.fr/doc/17/138/500/web/co/grain2_1_2.html)

SPODUMENE

Figure 2.12: 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 2.12) 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 sometimes 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:
https://mern.gouv.qc.ca/mines/industrie/mineraux/mineraux-proprietes-lithium.jsp
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 3-Supplementary Resources".

MOLYBDENITE

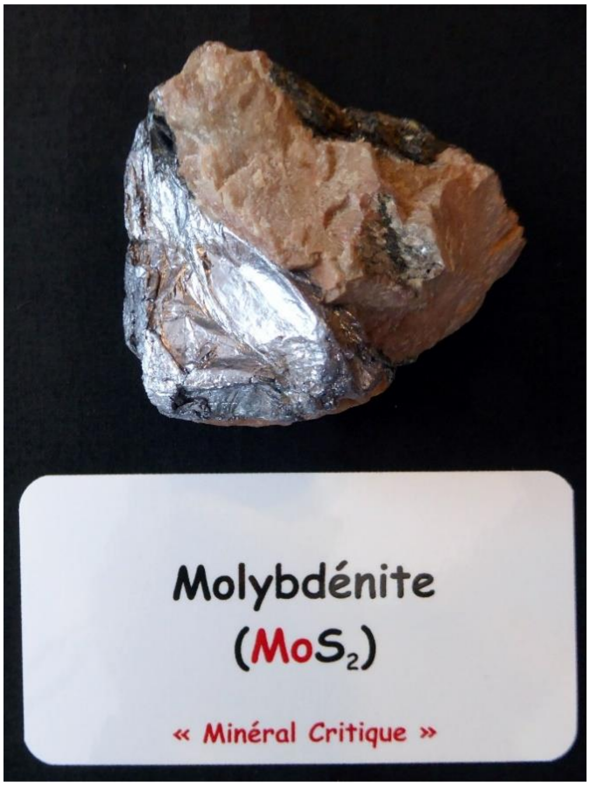


Figure 2.13: Sample of molybdenite (silver grey mineral – GSC-Quebec collection).

Molybdenite (MoS_2 – Figure 2.13) is the main ore mineral for molybdenum (Mo). The etymology of the word molybdenite comes from *molybdos*, which means lead in Greek, molybdenite being mistaken for lead originally. In Ancient Greece, this term encompassed not only lead and molybdenite, but also analogous minerals such as galena (PbS), graphite (C) and certain elements containing antimony (Sb). Finally, in 1778, Swedish chemist Scheel separated molybdenite from other minerals with the same name.

Molybdenum is a silver grey metallic element that has a particularly elevated melting point (2610°C). It is an important element in iron and steel alloys and in speciality alloys. Commonly used as a refractory metal (thermoresistant), molybdenum is also used in the composition of catalysts, dyes and pigments. In the steel industry, molybdenum adds hardness, strength, corrosion resistance and increases weldability. As for molybdenite, it is used as a solid lubricant and serves as an additive in greases and oils.

In Canada, molybdenum is mined in British Columbia as a sub-product in a few mines that operate porphyry type mines for copper-molybdenum-gold. Mineralized chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), pyrite (FeS_2), molybdenite (MoS_2), chalcocite (Cu_2S), covellite (CuS), sphalerite (ZnS), galena (PbS), and native copper in these deposits are mainly encased in veins and stockworks that cut across polyphased intrusions of compositions varying from granodiorite to quartz diorite, porphyritic to granodiorite quartz monzonite and tonalite. Production of this commodity has dropped considerably over the last few years and, with an annual production of 170 metric tons of molybdenum in 2021, Canada ranked 9th among international producers. Larger producers of molybdenum include China (130 000 tons), Chile (51 000 tons) and the US (48 000 tons).

Sources:
https://www.thecanadianencyclopedia.ca/en/article/molybdenum
https://minfile.gov.bc.ca/searchresults.aspx?23=890&27=Any&t=1
https://investingnews.com/daily/resource-investing/industrial-metals-investing/molybdenum-investing/top-molybdenum-producers/
Kourimsky, J. and Tvrz, F. 1977. Encyclopédie des minéraux: Gründ, Paris, 352 p.

PYROCHLORE

Figure 2.14: Sample of pyrochlore (small black minerals) from the Niobec Mine located in Saint-Honoré, Quebec (donated by P. Mercier-Langevin).

Pyrochlore ($(Na, Ca)_2Nb_2O_6(OH,F)$ – Figure 2.14) is a complex oxide mineral composed of niobium (Nb), sodium (Na) and calcium (Ca) which forms brown and black glassy crystals, generally octahedral, but sometimes appearing in irregular masses. Pyrochlore is the main mineral mined for niobium.

Niobium is resistant to many chemical products and is easily malleable even at low temperatures. Mainly used as a steel alloy agent (more than 90% of the market), niobium makes it possible to reduce the weight of steel while making it more resistant to corrosion. This results in notable construction cost savings by allowing for the construction of larger, thinner and lighter structures that use less steel in buildings, bridges or reinforced concrete. The transport sector is becoming more and more interested in niobium, because by reducing the weight of vehicles, GHGs are also reduced leading to lower fuel consumption. Niobium is also used as a superconductor and reacts well to temperatures as low as absolute zero (-273°C), making it an interesting elements for particle accelerators, magnetic imaging devices, rockets and satellites (Apollo 11 was made from 60% steel and niobium).

In Canada, niobium is mined at the Niobec mine, located in Saint-Honoré, near the City of Saguenay, Quebec. This mine is one of only three niobium mines in the world, the other two being located in Brazil. It is also the only underground mine. The mineralization consists of pyrochlore, a niobium-bearing bipyramidal mineral, and secondarily columbite ($Fe^{2+}Nb_2O_6$), disseminated through a ring-shaped, quasi-circular host rock of magmatic origin, composed of more than 50% carbonates (e.g. calcite, dolomite), known as the Saint-Honoré carbonatite* complex. Once extracted, the pyrochlore ore is sent to a concentrator where, following a multi-step treatment, a concentrate composed of 58% niobium pentoxide (Nb_2O_5) is obtained. Each ton of ore (1000 kg) provides on average 3.4 kg of niobium pentoxide. The ferroniobium (FeNb) concentrate, as used in the industry, is then converted onsite through an aluminothermic reaction, a pyrometallurgical process used in metal production. After a cooling period, the ferroniobium is crushed into the dimensions required by each steel mill, packed in containers of 10 to 1500 kg and shipped around the world. (*see sample contained in the “Magmatic Rocks” case)

Sources:
https://www.magrispm.com/niobec
SIGÉOM, 2021. Quebec’s reference geomining information system, Name of the entity: Niobec mine; Ministère des Ressources naturelles et des Forêts du Québec.
Côté, T., Fradette, N., and Lévesque, R., Module 3: Les cailloux, des matériaux très modernes. Geology and Geological Engineering Department, Université Laval, Quebec City, 12 p.

TITANOMAGNETITE

Figure 2.15: Sample of titanomagnetite (metallic grey minerals) from the Lac Doré intrusive suite in Chibougamau, Quebec (donated by P. Mercier-Langevin).

Vanadium (V) is a white, slivery, hard, ductile and corrosion-resistant metal. It is a good conductor of heat and electricity. It occurs naturally in more than 60 different minerals, and, due to its nature as a trace element, it is mainly extracted from concentrates of magnetite, an iron oxide ($Fe^{2+}Fe^{3+}{}_2O_4$) or concentrates of titanomagnetite, a iron-titanium oxide ($FeV_{3-x}Ti_xO_4$ – Figure 2.15), which are known to be highly magnetic.

Between 80% and 90% of vanadium is used in alloys to make high strength steel. These steels are used for a variety of purposes such as buildings, bridges, oil pipelines, gas pipelines and ships. Vanadium is used in steel for its strength, toughness and resistance to heat and wear. In addition to significantly strengthening steel alloys, vanadium also reduces corrosion and oxidation processes.

Vanadium is also used in the manufacture of vanadium redox-flow batteries (VRB). These are chemically and structurally different from lithium batteries. They last ten times longer, can be charge and discharge at the same time, and are capable of instantly releasing electricity. VRBs can power anything, from a simple house to power grids where they can stabilize energy flows from wind turbines and solar panels, ensuring a continuous supply of energy. In addition to VRBs, lithium-vanadium-phosphate batteries provide more energy for longer periods of time and charge faster than lithium-cobalt batteries.

Vanadiferous magnetites occur mainly in layered igneous rocks, mainly in South Africa, and in sandstone uranium deposits in Russia, China and the USA. It is also recovered from Venezuelan crude oil, where it can be found in small quantities. Although often mined as a by-product, vanadium can account for the main commodity such as in the example of the Lac Doré advanced exploration project (VanadiumCorp Resource Inc.) located in Chibougamau, Quebec. Here, the vanadium mineralization of economic interest is associated with massive to disseminated beds of titanomagnetite hosted in horizons ranging in composition from from anorthrosite to pyroxenite to more or less anorthositic gabbros belonging to an important stratiform intrusion identified as the Lac Doré Intrusive Suite. With mineralized zones that can be traced over a distance of approximately 3 km and a thickness that varies between 200 and 300 m, the Lac Doré project constitutes one of the most important vanadium resources in North America.

Sources:
https://mern.gouv.qc.ca/mines/industrie/metaux/metaux-proprietes-vanadium.jsp
https://gq.mines.gouv.qc.ca/lexique-stratigraphique/province-du-superieur/suite-intrusive-du-lac-dore_en/
https://mineralseducationcoalition.org/elements/vanadium/
https://www.crmalliance.eu/vanadium

ILMENITE

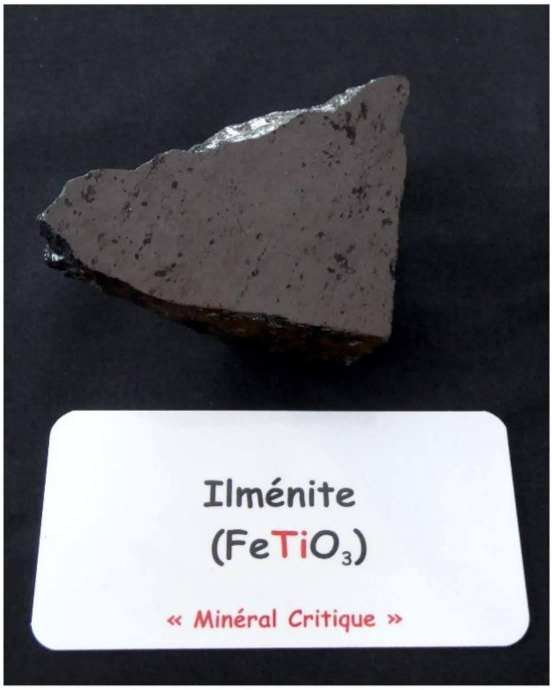


Figure 2.16: Sample of ilmenite from an old mining sites in the Saint-Urbain sector, in the Charlevoix region of Quebec (donated by P. Mercier-Langevin).

Taking its name from the Titans of Greek mythology, titanium (Ti) is a hard, shiny and white metal. It is very resistant to corrosion and is generally not affected by air, water, acids or bases. Titanium is very common in Earth's crust, being the ninth most abundant element. It can also be found in meteorites, the sun and the moon. The spectra from titanium oxides are used by astronomers to identify cold red dwarf stars. Titanium is mainly obtained from minerals such as rutile (TiO_2) and ilmenite ($FeTiO_3$ – Figure 2.16). It is mined in Australia, Sierra Leone, South Africa, Russia and Japan.

Titanium has many uses, namely in chemical production and the creation of light and solid alloys. Titanium is as solid as steel, but 45% lighter. Its high melting point is useful in high-temperature applications where weight is important, namely in engines and other parts for aircraft and space craft. Titanium is resistant to corrosion caused by sea water, making it popular in the manufacturing of equipment that is constantly exposed to the sea. The former Soviet Union constructed the hulls for several of its submarines using titanium, making them very solid and very expensive. Titanium oxide is used as a dye in several white paints and as a yellow food additive. It also blocks ultraviolet rays and is often used in sunscreen lotions. Titanium is also used in fireworks because of the colours it can produce when ignited.

Quebec is the only ilmenite producer in North America with the Lac Tio mine, located north of Havre-Saint-Pierre in the Côte-Nord region. The company Rio Tinto Fer and Titane operates one of the largest deposits of ilmenite in the world, encased in an anorthositic complex, composed of magmatic plutonic rock composed of plagioclases*. Other examples of similar mineralization have been found in the province, namely in the Saint-Urbain sector where several small-scale productions dating back to the 20^{th} century have been inventoried. Ilmenite is also a common mineral on the moon's surface and it is quite likely that any future colony there will use titanium as a main construction material. Ilmenite is also thought by some to be a potential source for oxygen production on lunar soil. (*see sample of anorthosite contained in the "Magmatic Rocks" case)

Sources:
https://mineralseducationcoalition.org/elements/titanium/
https://gq.mines.gouv.qc.ca/portail-substances-minerales/
https://www.space.com/esa-oxygen-from-lunar-regolith-demonstration.html

SPHALERITE

Figure 2.17: Sample of sphalerite (ZnS) from the Chisel North mine, located in Snow Lake, Manitoba (donated by P. Mercier-Langevin).

Sphalerite (Figure 2.17), 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 all 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 the "Mines and Minerals" case)

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/zinc-facts/20534
Côté, T., Fradette, N., and Lévesque, R., Module 3: Les cailloux, des matériaux très modernes. Geology and Geological Engineering Department, Université Laval, Quebec City, 12 p.

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

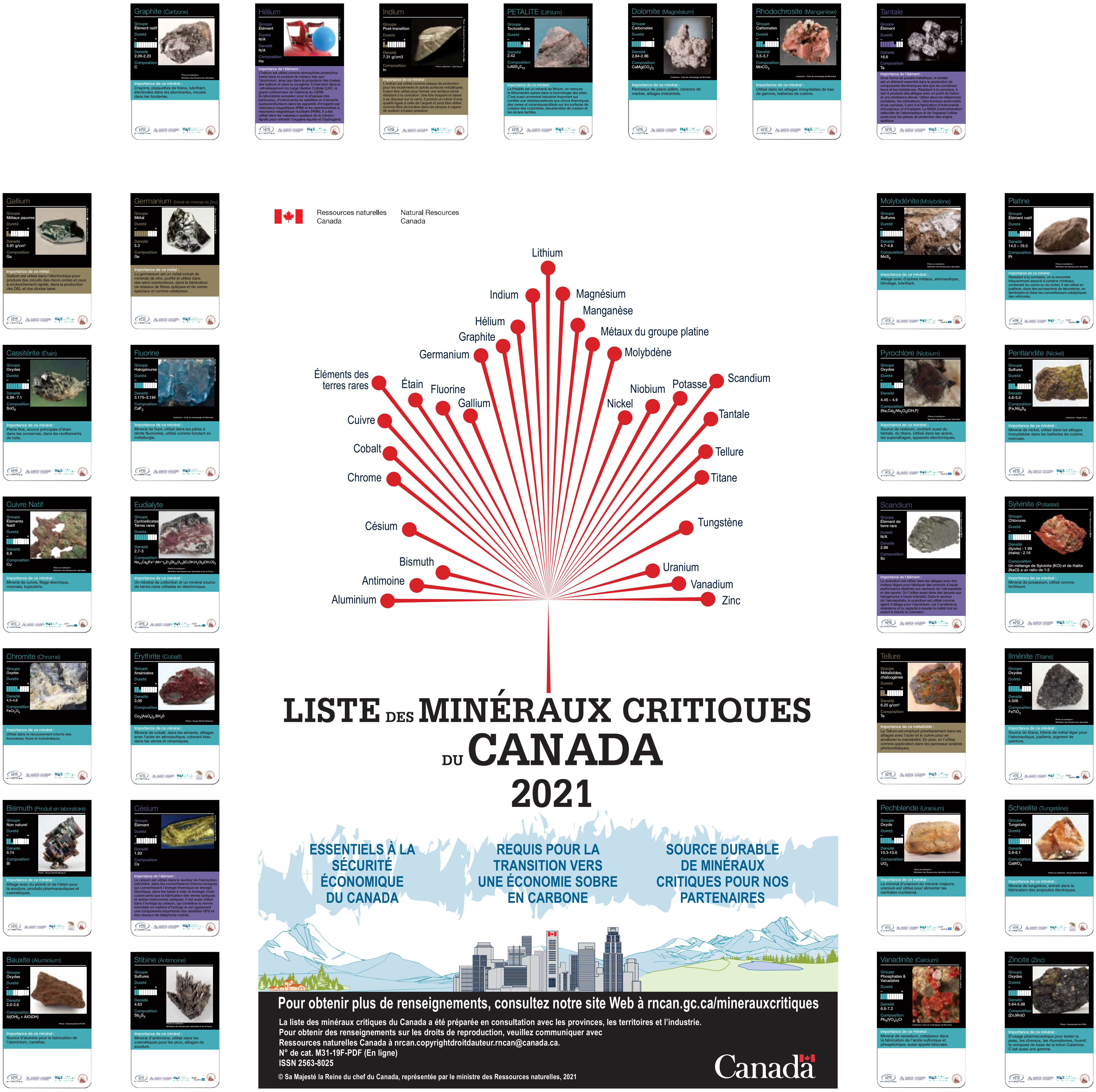
CIRCUIT BOARDS / CIRCUITS IMPRIMÉS

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:



Graphite (Carbone)
Hélium
Indium
PETALITE (Lithium)
Dolomite (Magnésium)
Rhodochrosite (Manganèse)
Tantale
Gallium
Germanium
Molybdénite (Molybdène)
Platine
Cassitérite (Étain)
Fluorine
Pyrochlore (Niobium)
Pentlandite (Nickel)
Cuivre Natif
Eudialyte
Scandium
Sylvinite (Potasse)
Chromite (Chrome)
Erythrite (Cobalt)
Tellure
Ilménite (Titane)
Bismuth (Produit en laboratoire)
Césium
Pechblende (Uranium)
Scheelite (Tungstène)
Bauxite (Aluminium)
Stibine (Antimoine)
Vanadinite (Vanadium)
Zincite (Zinc)
Ressources naturelles Canada
Natural Resources Canada
Lithium
Indium
Magnésium
Manganèse
Hélium
Graphite
Métaux du groupe platine
Germanium
Molybdène
Éléments des terres rares
Étain
Fluorine
Gallium
Niobium
Potasse
Scandium
Nickel
Cuivre
Tantale
Cobalt
Tellure
Chrome
Titane
Césium
Tungstène
Bismuth
Uranium
Antimoine
Vanadium
Aluminium
Zinc
LISTE DES MINÉRAUX CRITIQUES DU CANADA
2021
ESSENTIELS À LA SÉCURITÉ ÉCONOMIQUE DU CANADA
REQUIS POUR LA TRANSITION VERS UNE ÉCONOMIE SOBRE EN CARBONE
SOURCE DURABLE DE MINÉRAUX CRITIQUES POUR NOS PARTENAIRES
Pour obtenir plus de renseignements, consultez notre site Web à rncan.gc.ca/minerauxcritiques
La liste des minéraux critiques du Canada a été préparée en consultation avec les provinces, les territoires et l'industrie.
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Canada

Section 3 : Supplementary Resources

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)	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)
Ministère des Ressources naturelles et des Forêts	Fascinantes terres rares	https://mern.gouv.qc.ca/mines/trousse-educative/conferences/
Wavrant et al.	Projet terres rares au Québec (MB 2017-17)	https://sigeom.mines.gouv.qc.ca/signet/classes/I1102_examine?l=F
Bureau de Recherches Géologiques et Minières (BRGM)	Ressources minérales : les terres rares	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 (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 on 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	Reporting 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
Videos mines:		
Minalliance	L'exploitation minière à ciel ouvert	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 mine, an underground mine.
Mines QC	Nous sommes descendus à 3 km de profondeur dans le sous-sol québécois	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	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 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 mine, Eeyou Istchee Baie-James – virtual underground tour	Eleonore – virtual underground tour, duration: 6:10 minutes (2015): https://youtu.be/F_ssMQQpdtw

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