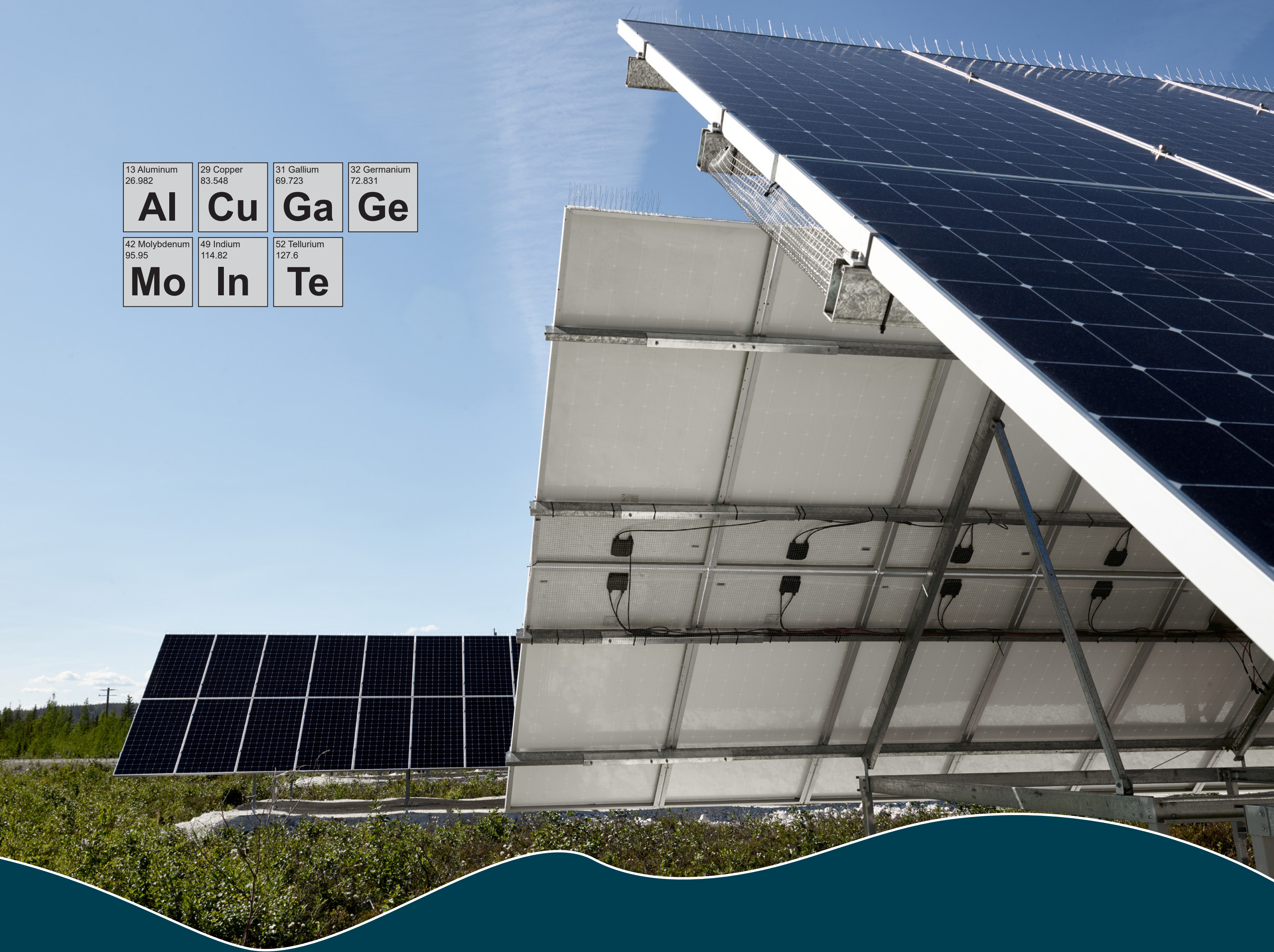

YGS Miscellaneous Report 23

Yukon critical minerals inventory 2021

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Yukon

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Front cover: Solar array in Old Crow, Yukon. Photo courtesy of Solvest Inc.

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Overview of critical minerals

Introduction

Geological resources have played an important role throughout human history, and as technology has advanced, our need for raw materials has grown. We are now at the front end of a transition in which renewable energy will replace fossil fuels. The Geological Survey of Norway characterized this transition as the "Green Shift" (Løvø, 2016), and compared it to society's transition from the Stone Age to the Bronze Age 5000 years ago. In recent history, technological advances have driven increases in both the volume and the types of mineral commodities that society needs. Figure 1 is a schematic illustration of the link between evolving technology over the last three centuries and the raw materials we have mined to support this evolution. Many of the recently-added commodities in the graphic support renewable energy; they are part of a suite of commodities known as critical minerals.

Critical minerals are becoming an increasingly important part of international conversations about clean energy, and in the last decade many countries have been actively defining lists of critical minerals. These minerals not only underpin the transition to "green" energy, but they are considered to be essential for the economy and defence. Most countries include vulnerability to supply disruptions as a defining criteria, because demand for these commodities is growing internationally. Different countries have variously termed these commodities "critical metals", "critical raw materials", "critical minerals" and "strategic metals".

This report is intended as a general reference document on Yukon's critical mineral endowment and potential. It provides some background on critical minerals, and for clarity it includes a number of definitions, as the terms used to describe these commodities are somewhat fluid. The document also provides

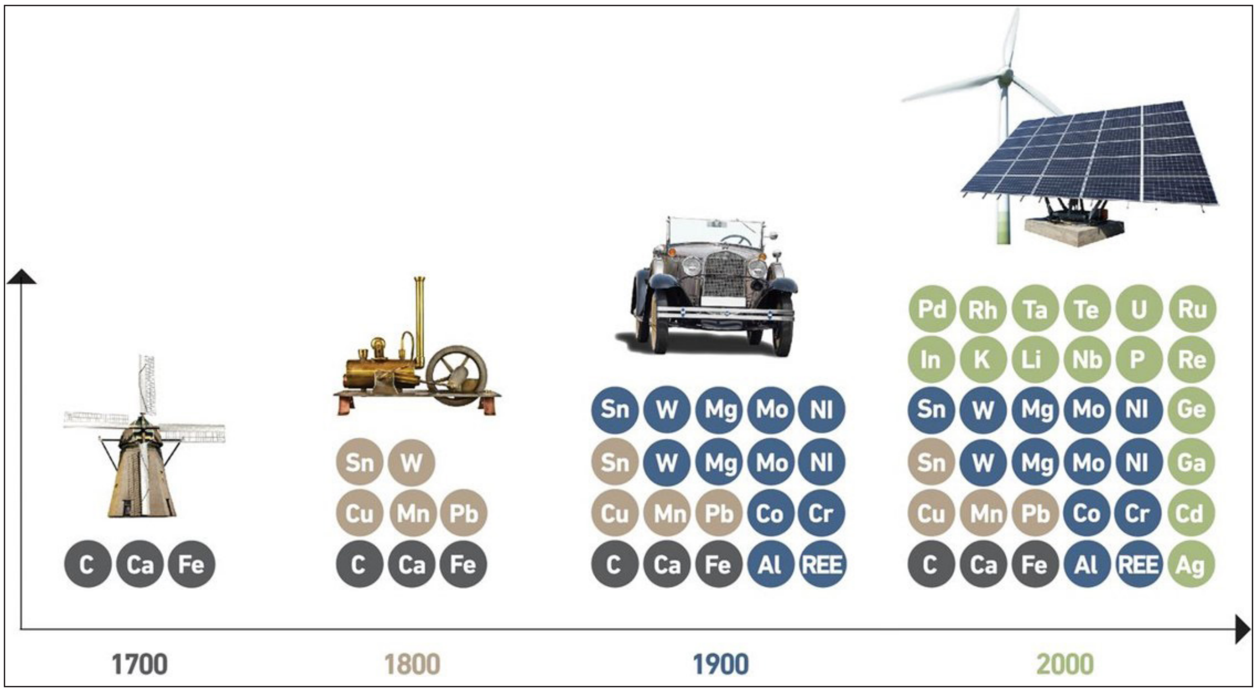


Figure 1. *Illustration showing sample technological milestones since the 1700s and the corresponding mineral resources needed for their development. Reproduced from Løvø, 2016. Abbreviations: C–carbon; Ca–calcium; Fe–iron; Sn–tin; W–tungsten; Cu–copper; Mn–manganese; Pb–lead; Mg–manganese; Mo–molybdenum; Ni–Nickel; Co–cobalt; Cr–chromium; Al–aluminum; REE–Rare Earth Elements; Rh–rhodium; Ta–tantalum; Te–tellurium; U–uranium; Ru–ruthenium; In–indium, K–potassium; Li–lithium; Nd–neodymium; P–phosphorus; Re–rhenium; Ge–germanium; Ga–gallium; Cd–cadmium; Ag–silver. Note: there is not a one-to-one correspondence between Norway's list of "green" metals and Canada's Critical Minerals list.*

a snapshot of Canada's (and Yukon's) position as a supplier of critical minerals and highlights potential opportunities for Yukon. The bulk of the report, presented in Part 2, consists of a series of critical mineral data sheets, describing each of the critical minerals that are on Canada's list. The data sheets provide some basic facts about each commodity, as well as information on Yukon's endowment of each critical mineral.

Background

In 2020, Canada and the United States signed a Joint Action Plan on Critical Minerals Collaboration (NRCan, 2020). Under the agreement, they committed to increase production of critical minerals and develop a North American supply chain. Upon signing the agreement, Canada began developing its own list of critical minerals in consultation with provincial and territorial governments. In defining its list, Canada considered the following criteria (NRCan, 2021a):

- critical minerals are minerals that are essential to Canada's economic security;
- they are required to support Canada's transition to a low-carbon economy; and
- they can be sustainably supplied to Canada's trade partners.

The Government of Canada announced its official critical minerals list in March, 2021, at the Prospectors and Developers Association of Canada's annual convention (NRCan, 2021b). Canada's list, consisting of 31 minerals, is presented in Table 1.

It is important to note that different countries' critical minerals lists vary as a reflection of both the commodities needed to advance their economic priorities, and their mineral endowment, which influences the security of their supply chain (Table 2). Over time, it is expected that these lists will be adjusted to reflect advances in technology and changes in global supply.

The sectors that rely on critical minerals include the aerospace, transportation, agriculture, manufacturing, electronics and medical industries. Demand for most critical minerals is projected to increase as the world transitions to a low-carbon future. The pledge by many countries to have 100% electric vehicles on their roads by 2050 is one of the factors driving this demand. In addition to the expected growth in demand, international trade agreements are increasingly targeting raw materials that are mined while adhering to high environmental and social standards. For example, in February, 2021, President Joe Biden and Prime Minister Justin Trudeau pledged to work together to build a supply chain that would make Canada and the United

Table 1. *Canada's Critical Minerals list (NRCan, 2021a).*

Critical Minerals – Canada			
aluminum	gallium	molybdenum	tellurium
antimony	germanium	nickel	tin
bismuth	graphite	niobium	titanium
cesium	helium	platinum group metals[1]	tungsten
chromium	indium	potash	uranium
cobalt	lithium	rare earth elements[2]	vanadium
copper	magnesium	scandium	zinc
fluorspar	manganese	tantalum	

[1] platinum, palladium, iridium, osmium, rhodium, ruthenium.
[2] rare earth elements - lanthanum, cerium praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium.

States global leaders in the development and production of batteries for electric vehicles and energy storage (Government of Canada, 2021).

Currently, Canada is a major global supplier of critical minerals and a leading supplier to the United States for 13 of their 35 critical minerals (NRCan, 2020): cesium, graphite, indium, niobium, rubidium, tantalum, vanadium, uranium, potash, titanium concentrate, tellurium, tungsten and magnesium. Supply/demand projections present opportunities for further growth in the critical minerals space. While Canada's global position is strong, Yukon's contributions to the global supply chain

Table 2. *Comparison of critical mineral lists for Canada (CA), United States (USA), European Union (EU), Australia (Aus) and Japan (JP). Sources: NRCan (2021a), US Department of the Interior (2018), European Commission (2020), Australian Government (2019).*

Critical mineral	CA	USA	EU	Aus	JP
aluminum	x	x			
antimony	x	x	x	x	x
arsenic		x			
barite		x	x		
bauxite			x		
beryllium		x	x	x	x
bismuth	x	x	x	x	
borate			x		
cadmium					
chromium	x	x		x	x
cesium	x	x			
cobalt	x	x	x	x	x
coking coal			x		
copper	x				x
fluorspar	x	x	x		x
gallium	x	x	x	x	x
germanium	x	x	x	x	x
gold					x
graphite	x	x	x	x	x
hafnium		x	x	x	
helium	x	x		x	
indium	x	x	x	x	x
lead					x
lithium	x	x	x	x	x
magnesium	x	x	x	x	x
manganese	x	x		x	x
molybdenum	x				x
natural rubber			x		
nickel	x				x
niobium	x	x	x	x	x
platinum group metals	x	x	x	x	x
phosphate rock			x		
phosphorus			x		x
potash	x	x			
rare earth elements	x	x	x	x	x
rhenium		x		x	x
rubidium		x			
scandium	x	x	x	x	
selenium					
strontium		x	x		x
silicon metal			x		
silver					x
tantalum	x	x	x	x	x
tellurium	x	x			
thallium					
thorium					
tin	x	x			x
titanium	x	x	x	x	x
tungsten	x	x	x	x	x
uranium	x	x			
vanadium	x	x	x	x	x
zinc	x				x
zirconium		x		x	x

are very modest. In 2020, Yukon's Minto Mine produced 8089 tonnes of copper (Government of Yukon, pers. comm.), compared to Canada's total estimated production of 475 898 tonnes for the same period (NRCan, 2021c). The Keno Mine produces a small amount of zinc and a very small amount of indium as a byproduct of its ore, although it does not get credit for indium and therefore does not track or report on production.

Although Yukon's output of critical minerals is presently low, the territory hosts several significant deposits and many underexplored occurrences of critical minerals. As a starting point for considering how Yukon might benefit from global interest in critical minerals, this document presents an inventory of critical minerals in the territory and provides a brief overview of occurrences documented in the Yukon MINFILE database (https://data.geology.gov.yk.ca/Occurrences/). The information provided includes the use(s) of each critical mineral, information on global production and processing, and brief descriptions of the geological settings in which each is found.

Although Yukon has not yet advanced a strategic plan for managing its critical minerals, the vision outlined in the territory's "Our Clean Future" strategy lays the groundwork for a Critical Minerals Strategy. Our Clean Future identifies four goals, three of which call for investments in clean energy (Government of Yukon, 2020):

- reduce Yukon's greenhouse gas emissions;
- ensure Yukoners have access to reliable, affordable and renewable energy; and
- build a green economy.

The information compiled in this report is intended to provide a high level overview of the potential opportunities that exist for Yukon in critical mineral space, and if warranted, could provide a framework to support the development of a critical minerals strategy for the territory.

Definitions

The terms "Critical Minerals", "Strategic Metals" and "Battery Metals" are commonly used interchangeably, and their use can be confusing as there is overlap between the definitions of the three groups of commodities. The three terms are defined below.

Critical Minerals

Critical minerals are metals, semi-metals and non-metals that are considered essential for the economic well-being of the world's major and emerging economies, and for which no substitutes exist. Critical minerals are needed to produce renewable energy and are used in high-tech applications such as mobile phones and computers. Critical minerals also include minerals used for defence purposes.

Due to growing demand for renewable energy and high-tech products, a shortage of some critical minerals is anticipated. Shortages may be due to depleted geological resources, or may be the result of geopolitical issues.

Strategic Metals

Like critical minerals, strategic metals are metals required for national defence, energy and high-tech industries. However, unlike critical minerals, strategic metals are not produced in significant quantities domestically and no reliable supply chain exists. Their distribution is therefore strictly managed.

Battery Metals

The term battery metals refers to a suite of metals that are used in batteries for a wide range of uses, including energy storage and electric vehicles. Modern battery technology, including rechargeable and deep-cycle batteries, is rapidly changing, and the demand for battery metals is evolving and increasing. Meeting international commitments for greenhouse gas reductions will require large quantities of battery metals such as cobalt, graphite, lithium, manganese, nickel, zinc and vanadium.

Economics of critical minerals

As with other mineral commodities, critical minerals are affected by fluctuations in global prices, changes in supply and demand, disruptions such as labour strife and political conflicts, changing technologies, availability of substitutes and social/environmental concerns.

For countries that hold a virtual monopoly on a resource, prices are vulnerable to changes in supply. For example, China, the world's largest producer of tungsten, flooded the market with tungsten in the early 2000s, causing prices to fall and leading to the closure of several tungsten mines in other countries (Monet, 2012). The drop in value also triggered a sharp decline in tungsten exploration spending. A decade later, China began restricting exports of domestically-produced tungsten and importing the metal from other countries, creating a global shortage and leading to a major increase in price (ibid.).

Critical minerals lists are not static and are revised on occasion to reflect fluctuating needs, new technologies and changing political climate. For instance, new processing technologies may make sub-economic deposits profitable, leading to enhanced supply. Substitutes for certain materials may be developed and worked into the manufacturing process, reducing demand for some commodities. Additionally, environmental and health considerations may trigger the phasing out of certain elements in the manufacturing process.

Global critical mineral production

Global production of different critical minerals varies widely based on both geologic resources and market demand. Annual production of minerals such as copper and zinc is measured in millions of tonnes, whereas that of less common minerals such as indium and PGEs is measured in thousands of ounces. The data sheets presented in this report identify the most significant producers of each of the critical minerals on Canada's list. Many critical minerals are relatively minor constituents of ore deposits and do not, by themselves, occur in economic quantities, and so they are produced as byproducts.

In recent years, the principle of zero waste has triggered the mining industry to examine waste products and find uses for residual materials. Beyond efforts to reduce mine waste, recycling is playing an increasingly important role in supplying certain commodities; particularly as known mineral resources are depleted. Building recycling into the manufacturing process will not only reduce the dependence on mined metals, but it will help reduce waste disposal costs.

Critical mineral production and processing in Canada

Mining is a major economic driver in Canada; it contributed $109B in 2019 and employed one in 26 Canadians (Mining Association of Canada, 2020). Among countries that produce critical minerals, Canada is a major contributor of potash, cobalt, graphite, indium, nickel, niobium, platinum group metals, titanium, copper, zinc, aluminum and uranium. As noted previously, Yukon produces a modest share of Canada's copper and zinc supply and a minor amount of indium.

Several new mineral processing facilities are being developed in Canada that will expand our role in the supply of critical minerals. A rare earth element processing facility and a lithium-ion battery manufacturing plant are being built in Quebec. North American Helium completed building Canada's largest helium purification plant in Saskatchewan in 2021, bringing the number of helium facilities in the province to three (Rattray, T., 2021). Saskatchewan Research Council and the Government of Saskatchewan are building a rare earth element processing facility in Saskatoon. To boost Canada's role further, the Government of Canada has dedicated funds toward establishing a Critical Battery Minerals Centre of Excellence (Jarratt, 2021). This Centre is mandated to implement the Canada-U.S. Joint Action Plan on Critical Minerals cooperation. The Government of Canada has also committed money, over a three year period, for federal research and development toward critical battery mineral processing and refining.

Critical minerals in Yukon

Yukon hosts a number of deposits containing critical minerals, including primary deposits of copper, zinc, molybdenum, tungsten, tin, nickel and platinum group elements (Fig. 2). The most advanced projects with a likelihood of being developed in the near future contain copper, zinc, platinum group elements ± nickel or tungsten as their primary metal.

Yukon is endowed with several porphyry copper deposits, including those at the currently operating Minto Mine and the Casino deposit (10.6 billion pounds of copper: Casselman, 2021), as well as a number of other copper porphyry deposits in the Dawson Range (*e.g.*, Carmacks Copper, Nucleus, Revenue; see Fig. 2).

Yukon is also rich in zinc, having both sediment-hosted and volcanic-hosted deposits. Sediment-hosted deposits include the Macmillan Pass deposits (Tom and Jason), the Selwyn deposits and the Faro deposits (Fig. 2). The most advanced volcanic-hosted zinc property in Yukon is Kudz Ze Kayah, which hosts the ABM, GP4F and Krakatoa deposits (Fig. 2). Collectively these deposits contain about 2.9 billion pounds of zinc (Casselman, 2021).

Most of the above-mentioned copper and zinc deposits have had one or more Preliminary Economic Assessments completed, some have completed pre-feasibility studies, and a few have feasibility studies completed. One project is advancing through the assessment and permitting process (Kudz Ze Kayah).

Other significant deposits of critical minerals in Yukon include the Mactung and Logtung tungsten deposits, both of which are ranked among the world's ten largest (Werner *et al.*, 2014); as well as the Nickel Shäw nickel-copper-cobalt-PGE deposit (Fig. 2).

In addition to measured resources of critical minerals in Yukon, many occurrences of these minerals have been documented but have not been advanced to a stage where a resource has been defined. Figure 3 shows the locations of drilled occurrences of critical minerals. These occurrences represent potential investment opportunities if factors such as global demand, road access, power and other infrastructure are met.

Of the 31 critical minerals on Canada's list, six (aluminum, cesium, graphite, helium, potash and scandium) have not been documented in Yukon, although prospective geology for four of these commodities does occur in the territory. Graphite has been documented in minor amounts locally (*e.g.*, along faults and shear zones, in certain metamorphic rocks, and in coal-bearing sedimentary rocks), although no known economic concentrations have been discovered. Scandium occurs in ultramafic rocks and in tungsten-tin hydrothermal settings. Helium is found in association with natural gas and is produced from gas wells. Sedimentary basins in Yukon have been assessed for their oil and gas potential, but not for their helium potential. Given that prospective geology for these commodities occurs in Yukon, the potential for these critical minerals cannot be ruled out. New, targeted geoscience studies could help answer the question of whether these commodities occur and are viable exploration targets.

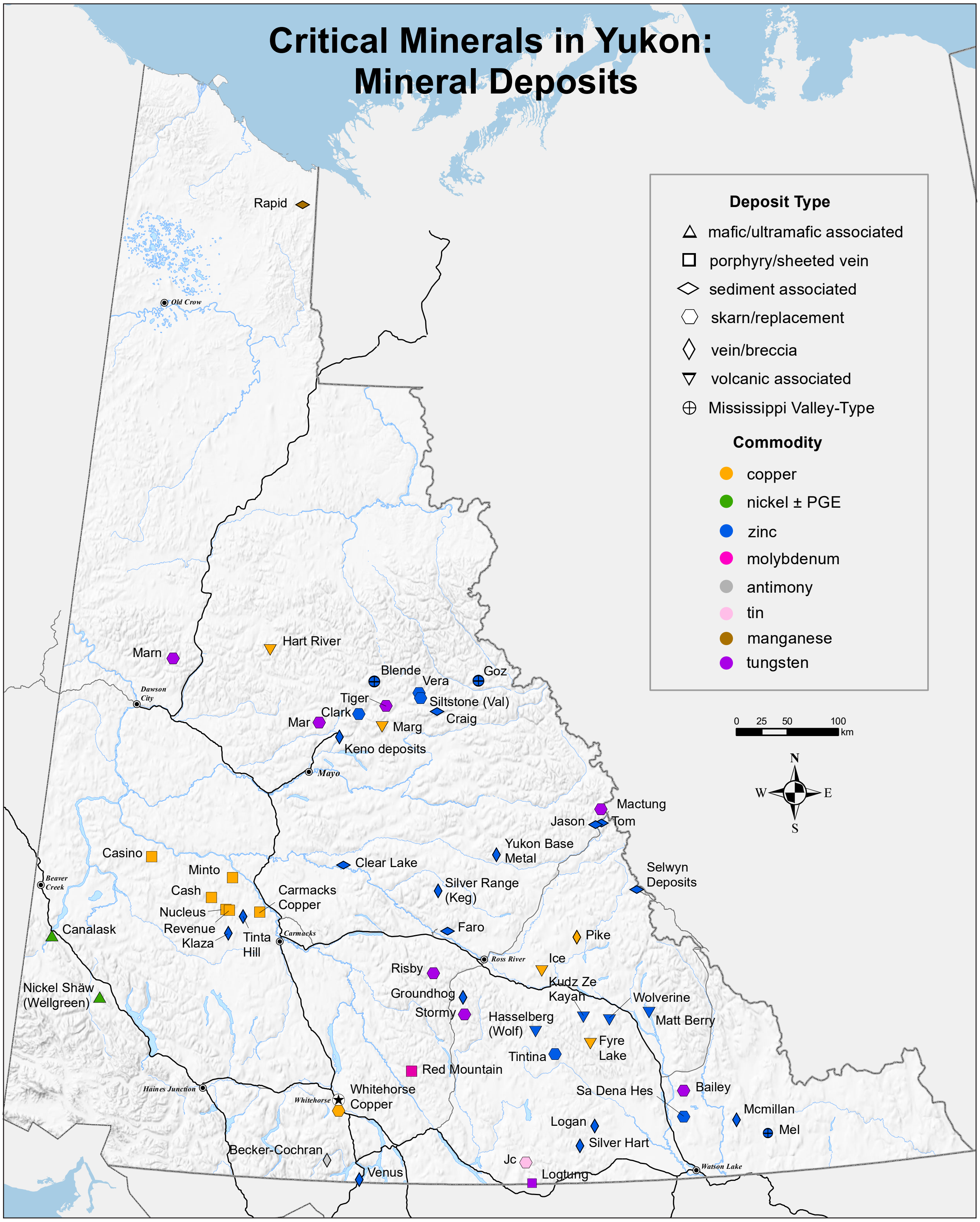


Figure 2. Map showing locations of critical mineral deposits with documented resources in Yukon. Note: the map symbols represent only the primary commodity, although in many cases, a deposit contains more than one critical mineral (e.g., Nickel Shäw is primarily a nickel + PGE deposit, but it contains copper and cobalt resources as well).

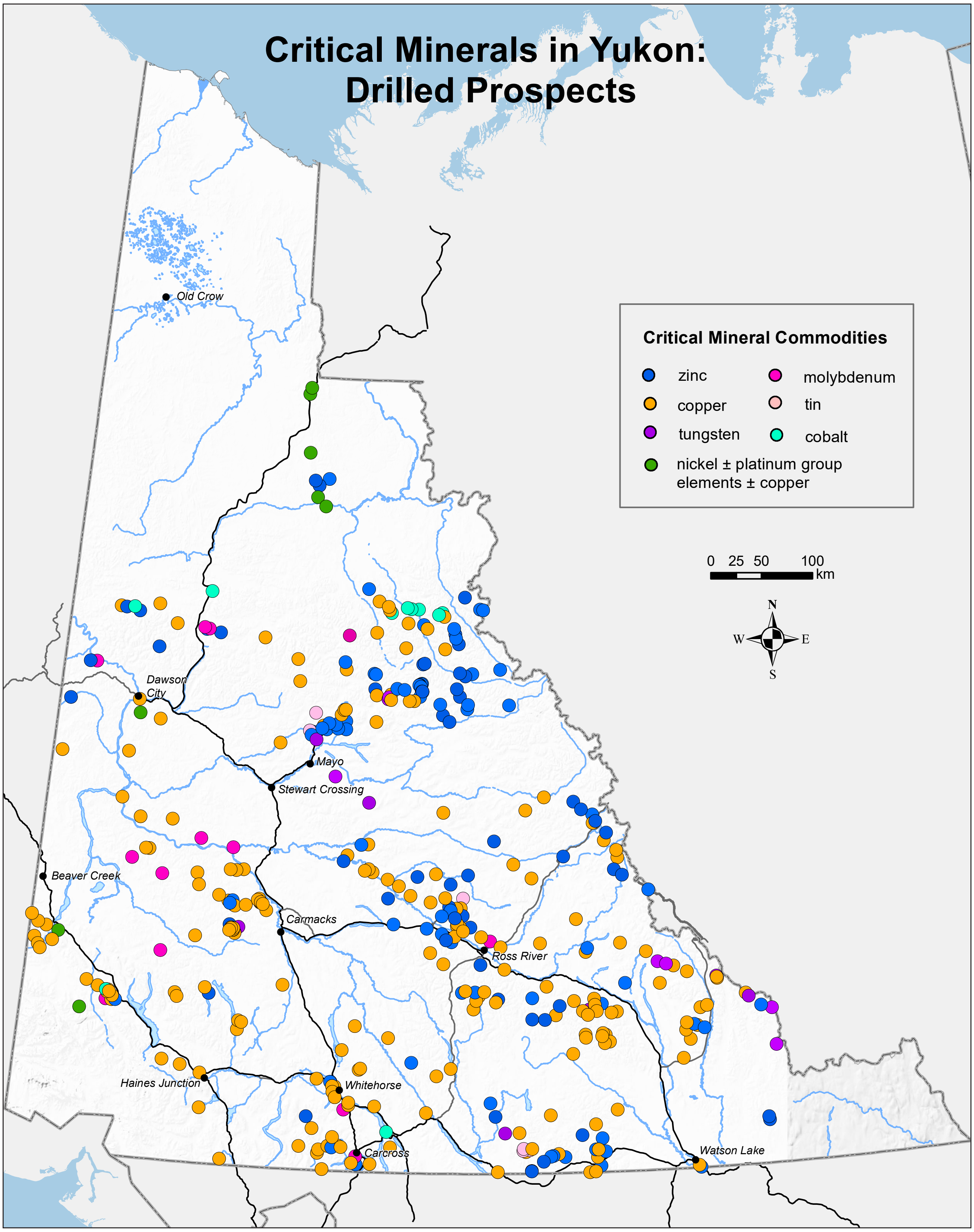


Figure 3. *Map showing locations of drilled critical mineral occurrences in Yukon. Note: the map symbols represent only the primary commodity, although in many cases, a deposit contains more than one commodity.*

Yukon critical mineral data sheets

This part of the report presents data sheets for Canada's critical minerals, most of which are known to occur in Yukon. The data sheets describe each critical mineral and provide general information such as its common mineral form(s), uses, global production and price graph. Price graphs are included for critical minerals that have defined resources. The data sheets also describe the geologic setting in which each commodity occurs, both globally and in Yukon. Accompanying maps show occurrences cited in the data tables as labelled symbols. The maps also depict known occurrences in MINFILE for a given commodity as unlabelled dots.

The data sheets are presented in three sections:

1. critical minerals for which resources have been reported in Yukon. the data sheets in this section include resource values;
2. critical minerals for which there are documented occurrences in Yukon but no defined resources; and
3. critical minerals that are on Canada's list but are not currently known to occur in Yukon.

Definitions and abbreviations

Definitions for some of the language used in the critical mineral data sheets are presented here. The intent is to provide clarity for readers unfamiliar with mining-related terms.

The data sheets reference deposit types. Generally the deposit type is fully spelled out in the tables, although abbreviations are used for three common deposit types: Iron Oxide Copper Gold (IOCG); Mississippi Valley-type (MVT); and Volcanogenic Massive Sulphide (VMS).

Mineral Deposit

A mineral deposit is a natural concentration of minerals—*i.e.*, mineral occurrence—defined in three dimensions for which a defined resource and/or reserve has been calculated. The critical mineral deposit information presented in the data sheets that follow is derived primarily from Yukon Geological Survey's most recent Mineral Deposits Summary publication (Casselman, 2021).

Mineral Resources and Reserves

Reporting of mineral resources and reserves is federally regulated and provides a standard for assessing the value of a mineral deposit. In Canada, public disclosure of mineral resources and reserves is regulated under National Instrument 43-101. A similar reporting standard exists in Australia under their Joint Ore Reserves Committee (JORC) code.

In the critical mineral data sheets presented in this section, the reported mineral resource and reserve values are NI 43-101 compliant unless otherwise indicated. Some reported values pre-date the implementation of NI 43-101 (these are referred to as historical resources, and may lack the rigour of their more modern counterparts); a few values are compliant with the standards set out in the JORC code.

By definition, resources have a reasonable likelihood of being economically extracted. There are three classifications of resources, in order of decreasing confidence (CIM Standing Committee on Reserve Definitions, 2014): measured, indicated and inferred, abbreviated as M, I & I in the data sheets.

Reserves are resources that are considered to be economically viable at the time of determination

Resources are reported in the data sheets by mass, as contained metals. Values are based on the units reported on company websites at the time of writing. Abbreviations used in the data sheets are presented in Table 3.

All known deposits of critical minerals in Yukon are documented in the data sheets. Unless otherwise indicated, the reported resources are derived from Casselman (2021).

Table 3. Common abbreviations used in the data sheets.

Unit	Abbreviation	Unit	Abbreviation
tonne	t	ounces	oz
million tonnes	Mt	grams	g
billion tonnes	Bt	kilograms	kg
thousand pounds	klb	billion cubic metres	BCM
million pounds	Mlb		
billion pounds	Blb		

Mineral Occurrence

A mineral occurrence is a documented mineral discovery that is either observable physically (e.g., fluorite in a vein) or has returned anomalous assays for the element of interest. Information on critical mineral occurrences in the data sheets are sourced from Yukon's MINFILE database.

Yukon MINFILE

Yukon MINFILE (https://data.geology.gov.yk.ca/Occurrences/) is a database of mineral occurrences, including deposits, that documents information such as location, geology, mineralization, work history, deposit type, etc. At the time of writing, not all data from assessment reports and corporate websites has been captured in MINFILE, so the numbers of critical mineral occurrences reported may be underestimated.

Assay

An assay analysis is a quantitative measure of selected elements in a rock. Assay results are typically reported in weight percent (%), grams per tonne (g/t), parts per million (ppm) or parts per billion (ppb).

Alloy

An alloy is a material made of two or more metals, or of metal combined with one or more non-metallic elements. Alloys generally have properties that differ from pure metal (e.g., stainless steel, an iron and chromium alloy, is rust-resistant).

Platinum Group Metals (PGM)/Platinum Group Elements (PGE)

This group of precious metals has similar physical and chemical properties, and they occur together in certain mineral deposits. Although they comprise a number of elements, they are cited on Canada's list as a group. In this report, they are treated as individual elements. The group comprises the following elements: platinum, palladium, ruthenium, rhodium, osmium and iridium.

Rare Earth Elements (REE)/Rare Earth Metals (REM)

This group of 15 elements is referred to as the lanthanide series in the periodic table of elements (Appendix 1). Rare earth elements are divided into light and heavy REEs based on their atomic weight. The light REEs are lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium and gadolinium. The heavy REEs are terbium, dysprosium, holmium, erbium and thulium (NRCan, 2021f). Yttrium and lanthanum, while not strictly rare earth elements, are included with the group because they occur with the REEs in nature and have similar properties. They are cited on Canada's list as a single entry. In this report, they are presented as a group, but there is also information provided on individual elements.

Chemical Elements

The critical mineral data sheets contain abbreviations for a number of chemical elements. Table 4 presents the abbreviations

Table 4. Chemical symbols and corresponding names for chemical elements.

Ag = Silver	Ga = Gallium	Ni = Nickel	Ta = Tantalum
Al = Aluminum	Gd = Gadolinium	Os = Osmium	Tb = Terbium
Au = Gold	Ge = Germanium	P = Phosphorus	Te = Tellurium
Bi = Bismuth	He = Helium	Pb = Lead	Th = Thorium
Ce = Cerium	Ho = Holmium	Pd = Palladium	Ti = Titanium
Co = Cobalt	In = Indium	Pm = Promethium	Tm = Thulium
Cr = Chromium	Ir = Iridium	Pr = Praseodymium	U = Uranium
Cs = Cesium	La = Lanthanum	Pt = Platinum	V = Vanadium
Cu = Copper	Li = Lithium	Re = Rhenium	W = Tungsten
Dy = Dysprosium	Mg = Magnesium	Rh = Rhodium	Y = Yttrium
Er = Erbium	Mn = Manganese	Ru = Ruthenium	Yb = Ytterbium
Eu = Europium	Mo = Molybdenum	Sb = Antimony	Zn = Zinc
F = Fluorine	Nb = Niobium	Sc = Scandium	
Fe = Iron	Nd = Neodymium	Sn = Tin	

cited in the data sheets and the full names of the elements.

Data sheets: Critical mineral deposits in Yukon

The first set of critical mineral data sheets include those for which documented resources have been reported. Yukon hosts deposits of twelve of Canada's critical minerals, of which eight form significant primary deposits. The data sheets are ordered using a set of criteria that includes the number and size of deposits, their value, their status (e.g., actively being advanced), and whether they are primary or secondary ore. The primary deposits are listed first in the following order: copper, zinc, nickel, PGMs, cobalt, tungsten, tin and molybdenum. These are followed by deposits where the critical mineral is considered secondary or the deposit is inactive and is expected to remain so: antimony, germanium, indium and manganese.

The critical mineral deposit data sheets include graphs showing global mine production and price for the period 2000 to 2020. The data, which are sourced from the US Geological Survey (USGS, 2021), are included because they illustrate recent market trends for each commodity and may be useful for identifying opportunities for investment. It is important to note that in addition to the deposits presented in the Critical Mineral Deposits data sheets, there are numerous mineral occurrences of each of these commodities.

Data sheets: Critical mineral occurrences in Yukon

The second set of critical mineral data sheets present critical minerals that have been documented as mineral occurrences and captured in the Yukon MINFILE database. Twelve of the minerals on Canada's list fit this category. The data sheets are arranged in alphabetical order by critical mineral: bismuth, chromium, fluorspar, gallium, lithium, magnesium, niobium, REEs, tantalum, tellurium, titanium, uranium and vanadium.

For brevity, only a few selected occurrences and sample assay data are presented in the data sheets; readers are referred to the Yukon MINFILE database to view additional occurrence data.

Data sheets: Critical minerals with no documented occurrences in Yukon

Of the thirty-one critical minerals on Canada's list, six have not been documented in the territory: aluminum, cesium, graphite, helium, potash and scandium. Data sheets on each of these minerals are included (in alphabetical order), primarily to inform discussions around their potential, but also to enable a comparison of Canada's critical minerals list to Yukon's inventory.

Summary

The shift away from a carbon-based economy is underpinning the search for certain critical minerals, particularly, the battery metals. Several factors will influence how quickly this shift will occur, but countries are advancing strategies to ensure a secure supply of these commodities.

Yukon is well-endowed in copper, nickel, tungsten and zinc; and has documented occurrences of all but six of the critical minerals. Many of the critical mineral occurrences in the territory have seen limited exploration, and as a result there are limited data in Yukon's MINFILE database. Given the Government of Canada's commitment to investing in critical minerals and the goals of Yukon's "Our Clean Future" strategy, the territory may see increased investment in these commodities.

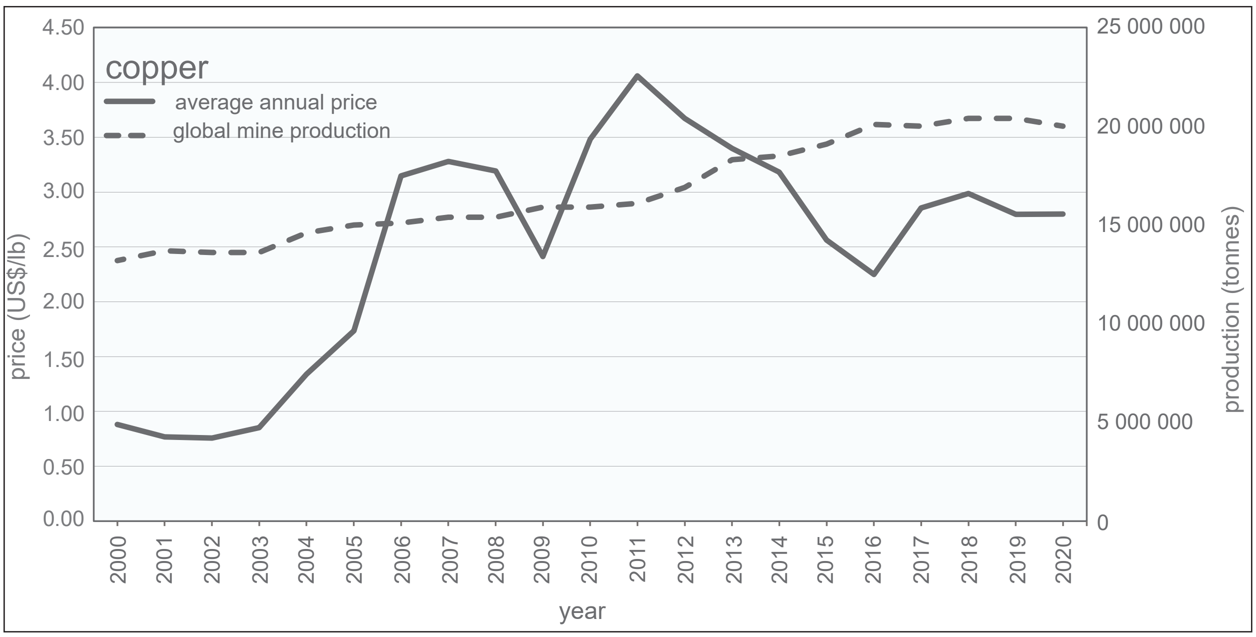
Acknowledgements

Scott Casselman provided valuable input on the scope for this report and created the price graphs presented in the data sheets. Bailey Staffen created the maps. Karen MacFarlane edited and managed the layout of this publication.

Data sheets for critical mineral deposits in Yukon

Copper

Description	soft metal usually found in association with other elements; good electrical conductor with tensile strength, corrosion resistance, low thermal expansion and ductility
Source minerals	chalcopyrite, bornite, azurite, malachite, chalcocite
Primary use	electrical wire and cables
Secondary uses	plumbing, industrial machinery, electronics
Mine production	largest producer is Chile (5.79 Mt in 2019; 28% of world production); other producers include Peru (12%), China (8%), United States (6%) and Democratic Republic of the Congo (6%); Canada accounts for 3% of world production (USGS, 2021)
Supply/demand outlook	electric vehicles contain more than three times as much copper as conventional cars; world demand for copper is expected to result in future supply shortfalls (Goldman Sachs, 2021)
Recovery	no significant challenges processing copper oxide or copper sulphide ores
Recycling	recycling copper less energy intensive than processing from ore; ~32% of copper is recycled (International Copper Study Group, 2020). China is world's largest refiner; much scrap comes from other countries (Everstream Analytics, 2021)



Average annual copper price and global mine production from 2000 to 2020.

Copper

Global geological setting: Copper mineralization occurs in various geological settings including VMS, porphyry, IOCG, stratiform redbed, orthomagmatic, vein, skarn, exhalative and MVT deposits. The largest deposit types are porphyries.

Yukon geological setting: In Yukon, copper occurs in VMS, porphyry, IOCG, orthomagmatic, vein, skarn and exhalative settings.

Yukon occurrences: Yukon is well-endowed with copper. There are more than 1000 occurrences containing copper; 31 of these occurrences are deposits with defined resources. Yukon deposits with defined resources for copper are listed below and illustrated on Figure 4.

Name MINFILE #	Deposit Type	Resource
Carmacks Copper 115I 008 115I 103 115I 129 115I 130 115I 131	calc-alkalic porphyry	572 Mlb Cu (M,I&I; 2016) + Au, Ag
Cash 115I 037	calc-alkalic porphyry	136 Mlb Cu (historical calculation; 1975) + Mo
Casino 115J 028	calc-alkalic porphyry	10.86 Blb Cu (M,I&I; 2020) + Mo, Au, Ag
Fyre Lake 105G 034	VMS (Besshi-type)	379.0 Mlb Cu (I&I; 2018) + Au, Zn
GP4F 105G 143	VMS (Kuroko-type)	7.5 Mlb Cu (I&I; 2016) + Au, Ag, Pb, Zn
Hart River 116A 009	VMS (Besshi-type)	16.9 Mlb Cu (historical calculation; 1969) + Zn, Pb, Ag, Au
Ice 105G 118	VMS (Cyprus-type)	148.8 Mlb Cu (historical calculation; 2002)
Kudz Ze Kayah 105G 117 105G 154	VMS (Kuroko-type)	379 Mlb Cu (I&I; 2016; JORC-code compliant) + Zn, Pb, Au, Ag
Marg 106D 009	VMS (Kuroko-type)	224.4 Mlb Cu (I&I; 2016; JORC-code compliant) + Zn, Pb, Ag, Au
Marn 116B 147	skarn	5.0 Mlb Cu (historical calculation; 1986) + Au, Ag, W
Minto 115I 021 115I 022	calc-alkalic porphyry	693 Mlb Cu (M,I&I; 2012) + Au, Ag
Nickel Shäw (Wellgreen) 115G 024	ultramafic-associated	1.47 Blb Cu (M,I&I; 2014) + Au, Ni, Co, Pt, Pd
Nucleus 115I 107	calc-alkalic porphyry	53 Mlb Cu (I&I; 2020) + Au, Ag
Pike 105J 003	orogenic	3.3 Mlb Cu (historical calculation; 1981) + Ag

Name MINFILE #	Deposit Type	Resource
Revenue 115I 042	calc-alkalic porphyry	103 Mlb Cu (I&I; 2020) + Mo, Au, Ag, W
Silver Range (Keg) 105K 078	polymetallic vein	131 Mlb Cu (inferred; 2013) + Ag, Pb, Zn, In, Sn, Cd
Tinta Hill 115I 058	epithermal	9.0 Mlb Cu (inferred; 2020)
Whitehorse Copper 105D 211 105D 214 105D 215 105D 217 105D 218 105D 230 105D 233	skarn	64 Mlb Cu (historical calculation; 1984) + Mo, Au, Ag
Wolverine 105G 072	VMS (Kuroko-type)	160.2 Mlb Cu (M,I&I; 2007) + Au, Ag, Pb, Zn

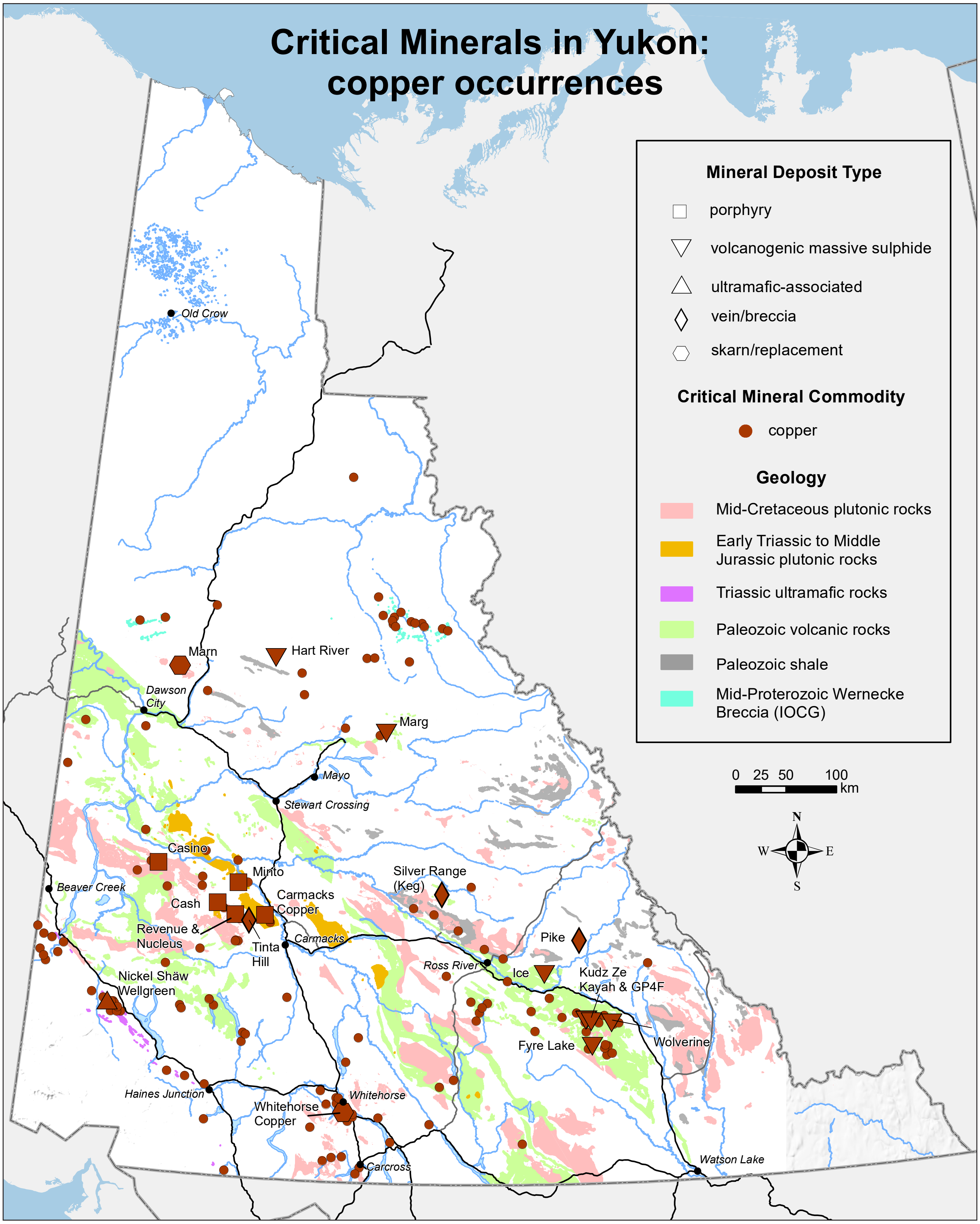
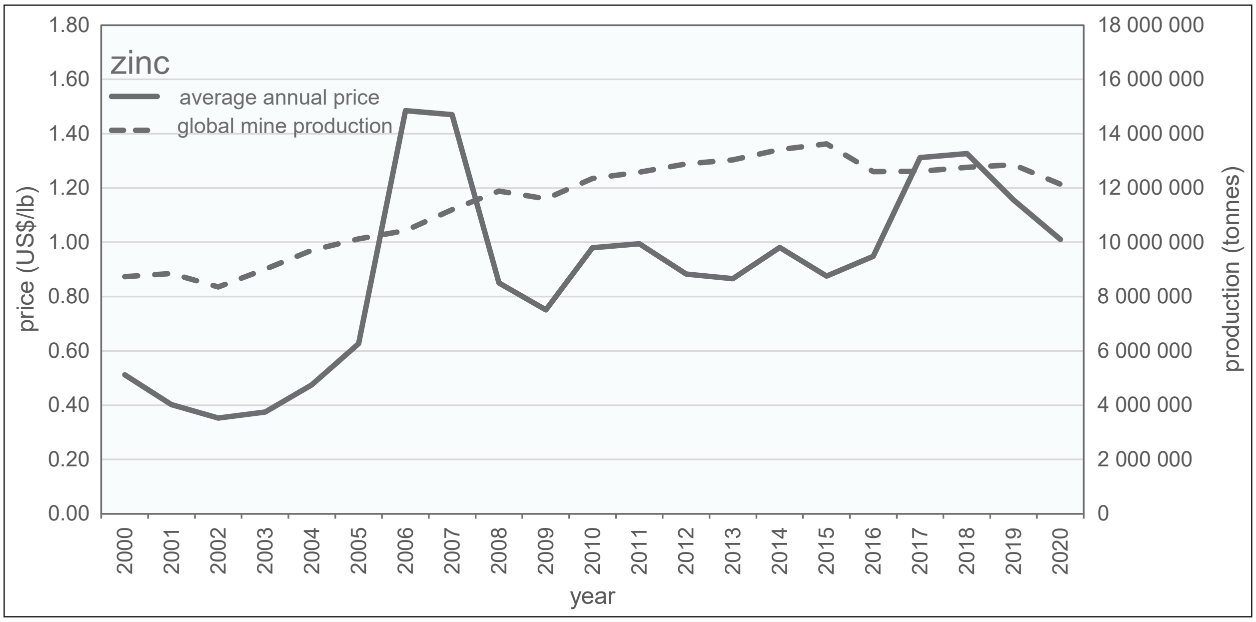


Figure 4. *Map showing the distribution of copper occurrences in Yukon. Large symbols are deposits (i.e., occurrences with defined resources) listed on the data sheet; small circular symbols are occurrences without defined resources.*

Zinc

Description	silver-grey metal with relatively low melting and boiling points; commonly found combined with other elements; moderately reactive
Source minerals	sphalerite, zincite, franklinite, smithsonite
Primary use	galvanization (anti-corrosion agent)
Secondary uses	alloys (e.g., with copper to form brass); replacement for lead in weights; zinc oxide batteries
Mine production	largest producer is China (4.2 Mt in 2019; 33% of world production; other producers include Peru (11%) and Australia (10%); Canada accounted for 3% of world production (336 000 t) in 2019 (USGS, 2021)
Supply/demand outlook	world reserves estimated at 250 Mt (USGS, 2021). Forecasts show reduced demand in near term due to oversupply (Mining.com, 2020)
Recovery	no significant challenges processing zinc ore. Canada imports concentrate for processing and exports zinc metal (NRCan, 2021d)
Recycling	recycling accounted for ~10% of world zinc production in 2019 (NRCan, 2021d)



Average annual zinc price and global mine production from 2000 to 2020.

Global geological setting: Zinc occurs in sedimentary exhalative, black shale, MVT, VMS, vein, manto and skarn deposits.

Yukon geological setting: In Yukon, zinc occurs in the following settings: sedimentary exhalative, MVT, high-temperature carbonate replacement (manto), VMS, lead-zinc veins, skarns and hyper-enriched black shale deposits.

Yukon Occurrences: Yukon is well-endowed in zinc. There are more than 850 occurrences containing zinc, including 46 deposits with defined resources for zinc. Yukon deposits with defined resources for zinc are listed below and illustrated on Figure 5.

Name MINFILE #	Deposit Type	Resource
Blende 106D 064 106D 107	MVT	1.621 Blb Zn (I&I; 2018) + Ag, Pb
Clark 106D 011	manto	33.2 Mlb Zn (historical calculation; 1975) + Ag, Pb
Clear Lake 105L 045	sedimentary exhalative	1.3 Blb Zn (inferred; 2010) + Ag, Pb
Craig 106C 073	MVT	260 Mlb Zn (historical calculation; 2002) + Ag, Pb
Faro deposits 105K 101 105K 046 105K 055 105K 056	sedimentary exhalative	4.7 Blb Zn (historical, 1983, 1997) + Ag, Pb, Au
Goz 106C 020	MVT	650.9 Mlb Zn (historical calculation; 1989)
Groundhog 105F 029	polymetallic vein	17.8 Mlb Zn (historical calculation; 1988) + Ag, Pb
Keno Hill deposits 105M 082 105M 083 105M 084 105M 085 105M 086 105M 087 105M 134	orogenic	591.8 Mlb Zn (I&I; 2020) + Ag, Pb, Au
Klaza 115I 067 115I 150	low sulphidation epithermal	181.3 Mlb Zn (I&I; 2020) + Au, Ag, Pb
Kudz Ze Kayah & GP4F 105G 117 105G 143 105G 154 105G 155	VMS (Kuroko-type)	2.9 Blb Zn (I&I; 2016; JORC-code compliant) + Cu, Pb, Au, Ag
Logan 105B 099	orogenic	1.47 Blb Zn (inferred; 2004) + Ag

Name MINFILE #	Deposit Type	Resource
MacMillan Pass (Tom & Jason) 105O 001 105O 019	sedimentary exhalative	6.7 Blb Zn (I&I; 2018) + Ag, Pb
Marg 106D 009	VMS (Kuroko-type)	591 Mlb Zn (I&I; 2016) + Cu, Pb, Ag, Au
Matt Berry 105H 021	VMS (Kuroko-type)	54 Mlb Zn (historical calculation; 1983) + Ag, Pb
McMillan 095D 006	manto	216.3 Mlb Zn (historical calculation; 1991) + Ag, Pb
Mel 095D 005	MVT	757.8 Mlb Zn (inferred; 2017) + Pb, Ba
Sa Dena Hes (Mt. Hundere) 105A 012 105A 013	skarn/manto	502 Mlb Zn (indicated; 2003) + Pb (in reclamation)
Selwyn deposits 105I 012 105I 032 105I 037 105I 053 105I 066 105I 067 105I 068 105I 069	sedimentary exhalative	38.6 Blb Zn (I&I; 2008, 2009, 2012) + Pb
Siltstone (Val) 106C 135	manto	3.2 Mlb Zn (historical calculation; 1981) + Ag, Pb
Silver Hart 105B 021	polymetallic vein	14 Mlb Zn (inferred; 2010) + Ag, Pb
Silver Range (Keg) 105K 078	skarn/polymetallic vein	674.9 Mlb Zn (inferred; 2013) + Ag, Cu, Pb, Sn, In, Cd
Tinta Hill 115I 058	low sulphidation epithermal	62 Mlb Zn (I&I; 2020) + Au, Ag, Cu, Pb
Tintina 105G 006	manto	20 Mlb Zn (historical calculation; year unknown) + Ag, Pb
Vera 106C 083	manto	30 Mlb Zn (historical calculation; 1981) + Ag, Pb
Yukon Base Metal (Andrew, Darin, Darcy) 105K 004 105K 033 105K 089	polymetallic vein	2.0 Blb Zn (M,I&I; 2012, JORC-code compliant) + Pb

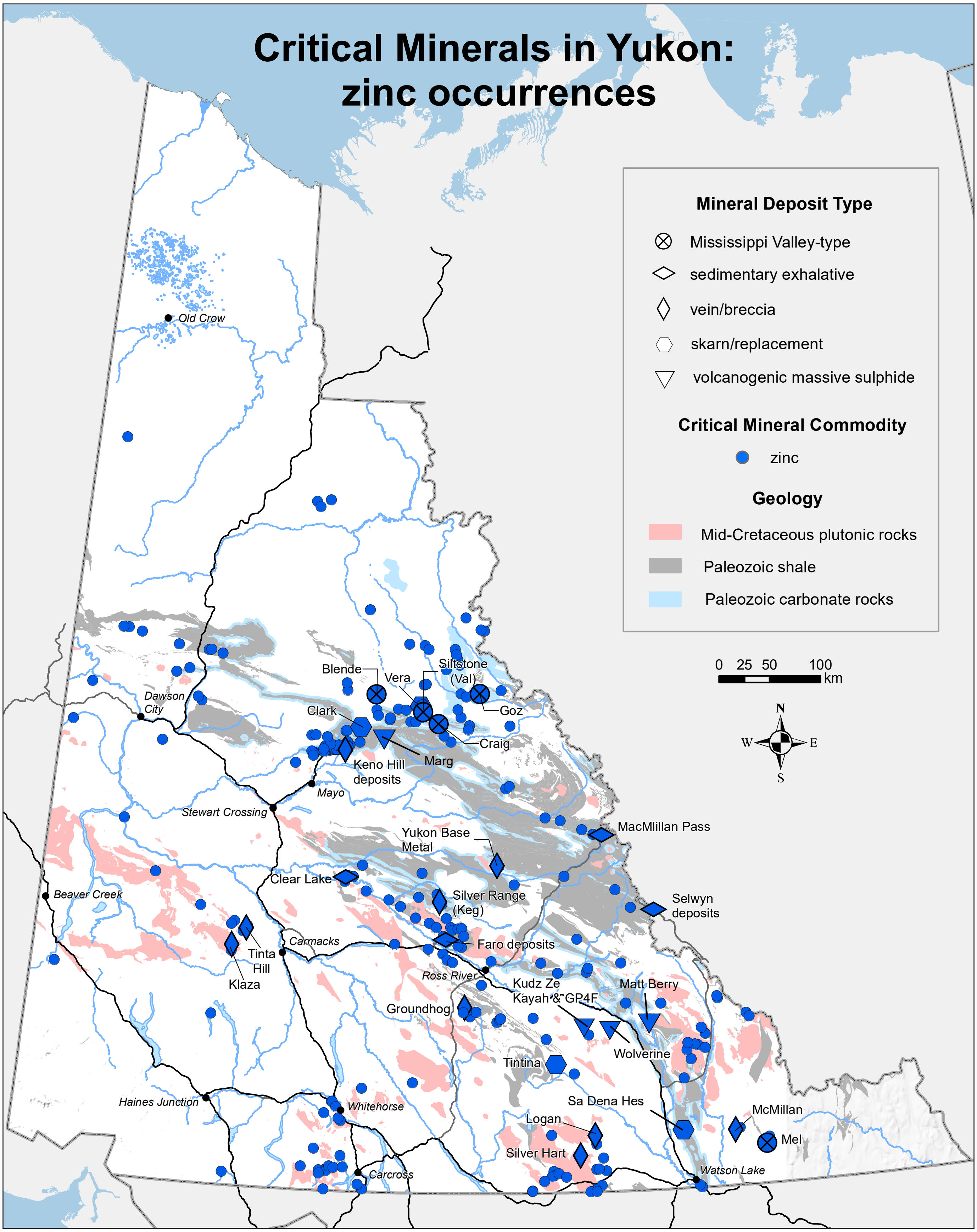
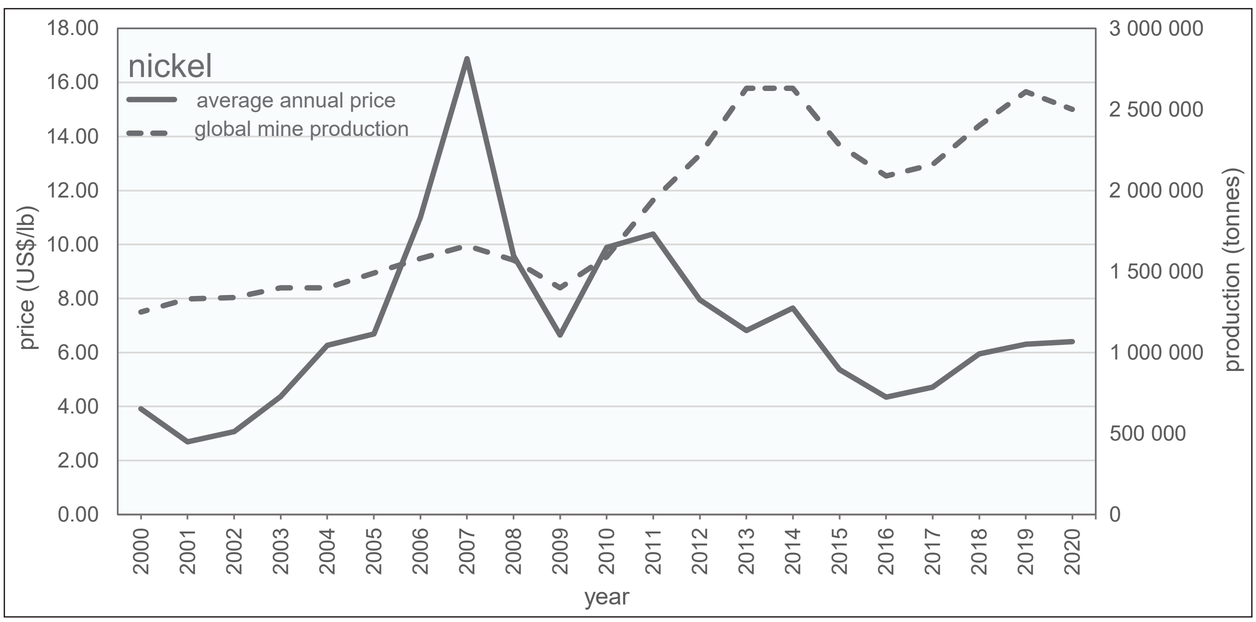


Figure 5. *Map showing the distribution of zinc occurrences in Yukon. Large symbols are deposits (i.e., occurrences with defined resources) listed on the data sheet; small circular symbols are occurrences without defined resources.*

Nickel

Description	silver-white metal with good corrosion resistance, toughness and strength at high and low temperatures; ferromagnetic (forms magnets or is attracted to magnets); important battery metal
Source minerals	pentlandite, nickeliferous limonite, garnierite
Primary use	stainless steel and other alloys (nickel content <99.8%)
Secondary uses	electronics and rechargeable batteries; nickel content >99.8% for nickel-manganese cobalt batteries
Mine production	largest producer is Indonesia (853 000 t in 2019; 33% of world production; other producers include the Philippines (12%), Russia (11%), New Caledonia (8%) and Canada (7%); ~60% of world resources hosted in laterites (iron and aluminum rich deposits formed in tropical areas; USGS, 2021)
Supply/demand outlook	land-based resources (averaging 0.5% nickel or greater) contain at least 270 Mt of nickel (USGS, 2021). Battery manufacturers are replacing cobalt with nickel, leading to increased demand (Christian, 2021)
Recovery	laterite deposits more energy intensive to process than sulphide deposits (USGS, 2021); sulphide ore has well-established smelting and refining processes, so most nickel is produced from sulphide deposits
Recycling	recycling accounted for ~68% of nickel produced in 2010 (Nickel Institute, 2021)



Average annual nickel price and global mine production from 2000 to 2020.

Global geological setting: The two main deposit types for nickel are laterite and magmatic sulphide deposits. Laterites form in wet tropical environments through weathering of nickel-rich ultramafic rocks. Magmatic sulphide (mafic or ultramafic) deposits are found throughout the world. The Sudbury Igneous Complex is the second largest nickel sulphide deposit in the world. Extensive nickel resources are also found in manganese crusts and nodules on the ocean floor (USGS, 2021).

Yukon geological setting: Nickel occurs in the Kluane Ultramafic complex, along with PGMs, copper and gold. It also occurs in the hyper-enriched black shales of the Canol Formation and in serpentinized peridotites of the Cache Creek terrane as disseminated awaruite, a naturally occurring stainless steel (nickel-iron) alloy.

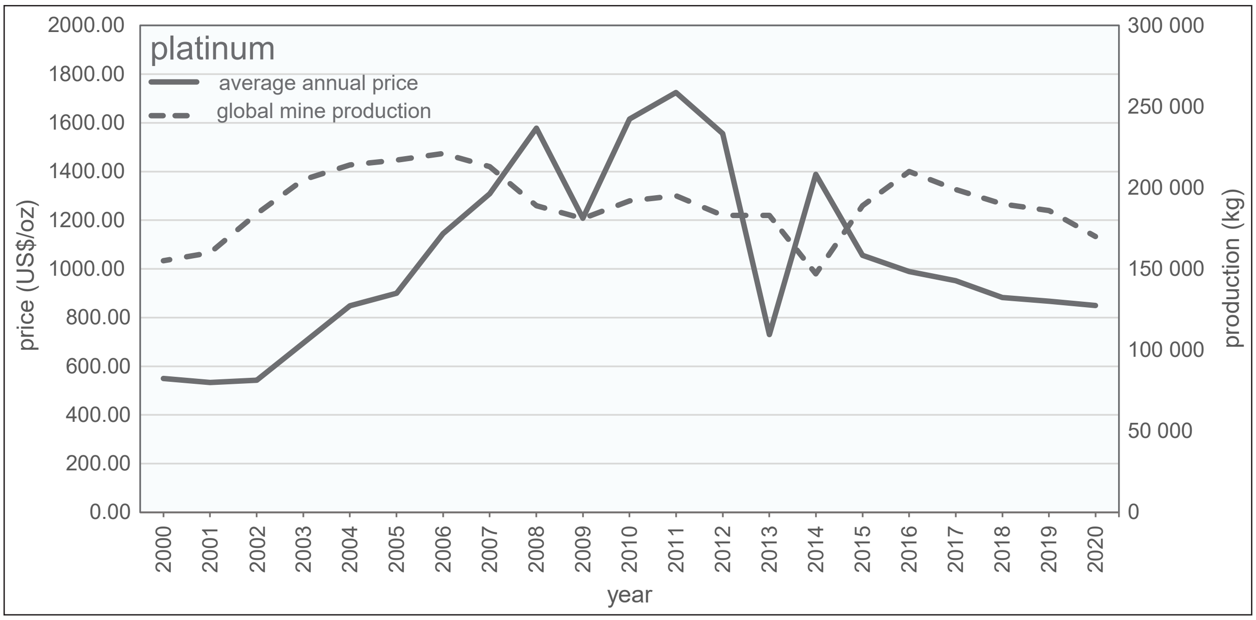
Yukon occurrences: There are more than 80 occurrences containing nickel, including two deposits with defined resources for nickel. Yukon deposits with defined resources for nickel are listed below and illustrated on Figure 6.

Name MINFILE #	Deposit Type	Resource
Canalask 115F 045	ultramafic-associated	10.5 Mlb Ni (historical calculation; 1968)
Nickel Shäw (Wellgreen) 115G 024	ultramafic-associated	2.6 Blb Ni (M,I&I; 2014) + Au, Cu, Co, Pt, Pd

Platinum Group Metals (PGM: platinum, palladium, iridium, osmium, rhodium and ruthenium)

Platinum

Description	silver metal; dense, highly unreactive, corrosion-resistant, ductile
Source	free metal platinum or alloyed; in sulfides, arsenides, tellurides and antimonides
Primary use	catalytic converters in combustion-engines
Secondary uses	electrodes and electronics; dentistry; jewelry; as a store of investment similar to gold or silver
Mine production	largest producer is South Africa (133 000 kg in 2019; 72% of world production; other producers include Russia (13%) and Zimbabwe (7%); Canada and the United States are minor producers; (USGS, 2021)
Supply/demand outlook	prices declining since 2011 due to reduction in diesel engine production (The Economist, 2018). Demand outlook uncertain
Recovery	refining PGMs is laborious and costly
Recycling	recycling accounts for ~30% of world supply; primarily from catalytic converters (NRCan, 2021e). ~120 000 kg of combined palladium and platinum recycled in 2018 (USGS, 2019)

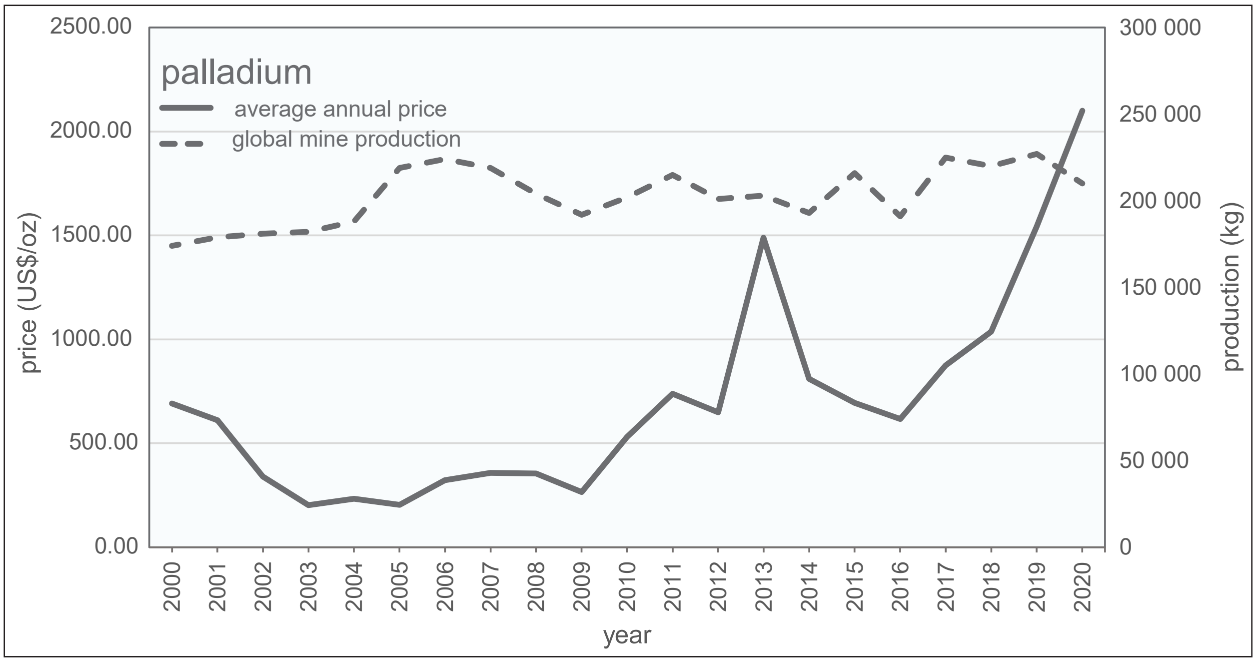


Average platinum price and global mine production from 2000 to 2020.

PGM

Palladium

Description	non-tarnishing silver metal; soft, ductile, melting point and density lowest of the PGMs
Source	free metal or alloyed with gold or other platinum group metals
Primary use	catalytic converters in combustion engines (accounts for nearly two-thirds of world production)
Secondary uses	electronics, dentistry, medicine, jewelry and chemical applications; store of investment, similar to gold or silver; used as a catalyst for hydrogen-oxygen reaction in fuel cells
Mine production	largest producer is Russia (91 t in 2019; 43% of world production; other producers include South Africa (33%), Canada (10%), United States (7%) and Zimbabwe (6%; USGS, 2021)
Supply/demand outlook	anticipate decreasing demand due to decline in production of combustion engines
Recycling	~120 000 kg of combined palladium and platinum recycled in 2018. Most recycled palladium is from catalytic converters (USGS, 2019)



Average annual palladium price and global mine production from 2000 to 2020.

PGM

Iridium

Description	silver corrosion-resistant metal; hard, brittle and very dense; high melting point; rare
Source	iridium metal or in natural alloys
Primary use	hardening agent in platinum-iridium alloys
Secondary uses	jewelry, catalysts, electrical contacts, high-temperature spark plugs
Mine production	largest producer is South Africa (80–85% of the world's iridium; Hobson, 2021). Byproduct of platinum and palladium ore. In 2020, world production was ~237,000 oz (USGS, 2021)
Supply/demand outlook	demand is growing; used to split water into hydrogen and oxygen for use in hydrogen fuel cells (Creamer, 2020)
Recycling	minor; accounts for a small proportion of the metal produced each year (Hilton, 2021)

Osmium

Description	silver metal; hard, brittle; densest of all naturally occurring elements; considered the rarest precious metal
Source	alloy or trace element in platinum ores
Primary use	alloys for instruments, needles and electrical contacts
Secondary uses	catalyst in the chemical industry
Mine production	major world producers are Russia, Canada and South Africa (Heraeus, 2021)
Supply/demand outlook	price has been steady for decades; no change in supply/demand anticipated; rare metal; difficult to work with; limited use (Bell, 2019)
Recycling	minor; small portion of osmium is recycled worldwide each year, e.g., osmium-iridium alloy waste (Umicore, 2021)

Rhodium

Description	silver metal; very reflective; highly resistant to corrosion
Source	free metal rhodium or alloyed with other platinum group metals
Primary use	catalytic converters in combustion engines
Secondary uses	finish for jewelry, mirrors, search lights; in electric connections and alloyed with platinum for aircraft turbine engines; used in the manufacture of nitric acid
Mine production	byproduct of platinum/palladium or nickel ores. Largest producer in 2020 was South Africa (450,000 oz; 77% of world production; Statista, 2021a)
Supply/demand outlook	anticipate decreasing demand due to decline in production of combustion engines
Recycling	high recycling rate; most is from catalytic converters (Manhattan Gold & Silver, 2011)

Ruthenium

Description	silver metal; resistant to most chemicals; rare
Source	minor component of platinum ores
Primary use	hardens platinum and palladium to make wear-resistant components
Secondary uses	added to gold jewelry to increase its durability
Mine production	largest producers are South Africa, Russia and Zimbabwe; world supply of ruthenium in 2017 was 6.1 Moz (Cowley, 2018)
Supply/demand outlook	use in electrochemistry, aerospace, electronics and semi-conductors expected to drive demand moving forward (MarketResearch.biz, 2021)
Recycling	recycled from spent catalysts, scrap, chemicals and machine parts (Colonial Metals Inc., 2018)

Global geological setting: Platinum group metals (PGM) occur primarily in mafic and ultramafic complexes or in placer settings associated with those complexes. The world's largest source of palladium is the Bushveld layered ultramafic complex in South Africa. Turkey has the world's largest known reserve of osmium at 115 000 tonnes. Other major PGM complexes are the Noril'sk-Talnakh deposits in Russia and the Stillwater deposits in Montana, United States. In Canada, most PGMs are mined as a byproduct of nickel mining in the Sudbury Basin of Ontario.

Yukon geological setting: PGM occurrences are dominantly associated with the Kluane Ultramafic belt. Other occurrences are associated with Slide Mountain ultramafic rocks, ultramafic rocks of the Cache Creek terrane, the hyper-enriched shales of the Canol Formation and skarn of the Whitehorse Copper Belt.

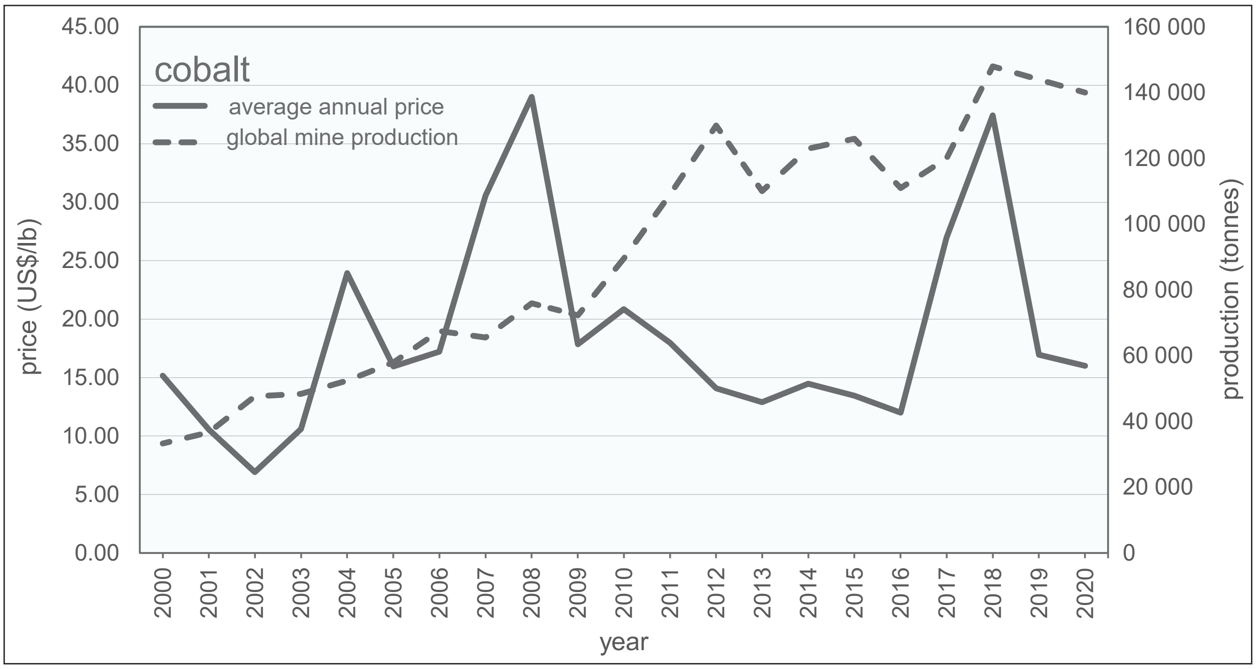
Yukon occurrences: There are more than 40 occurrences with associated PGMs in Yukon, including one deposit with a defined resource. The belt of ultramafic rocks that hosts the deposit has potential for other deposits. The Yukon deposit containing PGMs is listed below and illustrated on Figure 6.

Name MINFILE #	Deposit Type	Resource
Nickel Shäw (Wellgreen) 115G 024	ultramafic-associated	3.5 Moz Pt and 3.6 Moz Pd (M,I&I; 2014) + Au, Ni, Cu, Co

PGM

Cobalt

Description	hard silver-grey metal; commonly found in combined form with nickel and copper
Source minerals	cobaltite, erythrite
Primary use	batteries, e.g., lithium-ion
Secondary uses	high-strength superalloys
Mine production	largest producer is Democratic Republic of the Congo (100 000 t in 2019; 69% of world production); other producers include Russia (4%), Australia (4%) and the Philippines (4%; USGS, 2021)
Supply/demand outlook	demand is expected to increase as more electric vehicles are produced (Daly, 2019). Supply-chain uncertainties and human rights issues with cobalt mining in the DRC causing manufacturers to seek alternatives to cobalt in batteries (Airhart, 2018). China controls majority of the world's refined cobalt through investment in Democratic Republic of the Congo mines (Global Energy Metals Corp., 2021)
Recovery	byproduct of copper and nickel ores; no significant challenges to processing cobalt
Recycling	minor recycling (less than 5%) from spent lithium-ion batteries containing cobalt (Church and Wunnenberg, 2019); recycling expected to increase with growth in battery supply chain



Average annual cobalt price and global mine production from 2000 to 2020.

Global geological setting: Iron oxide copper-gold deposits, sediment-hosted stratiform copper-cobalt deposits (e.g., Zambian Copperbelt), vein deposits and laterite deposits.

Yukon geological setting: Cobalt occurs as cobaltite/erythrite in magmatic nickel-copper sulphide, iron-oxide copper gold (Wernecke Breccia) and VMS deposits.

Yukon occurrences: There are no known primary deposits of cobalt in Yukon, but cobalt does occur in significant quantities in the Fyre Lake and Nickel Shäw deposits. There are more than 60 mineral occurrences containing cobalt. Yukon deposits with defined resources for cobalt are listed below and are illustrated on Figure 6.

Name MINFILE #	Deposit Type	Resource
Fyre Lake 105G 034	VMS (Besshi)	18.7 Mlb Co (I&I; 2017) + Cu, Au, Zn*
Nickel Shäw (Wellgreen) 115G 024	ultramafic-associated	145 Mlb Co (M,I&I; 2018) + Ni, Cu, Pt, Pd, Au

*Note: this is an older resource. The updated resource (2018) does not have a resource estimate for cobalt.

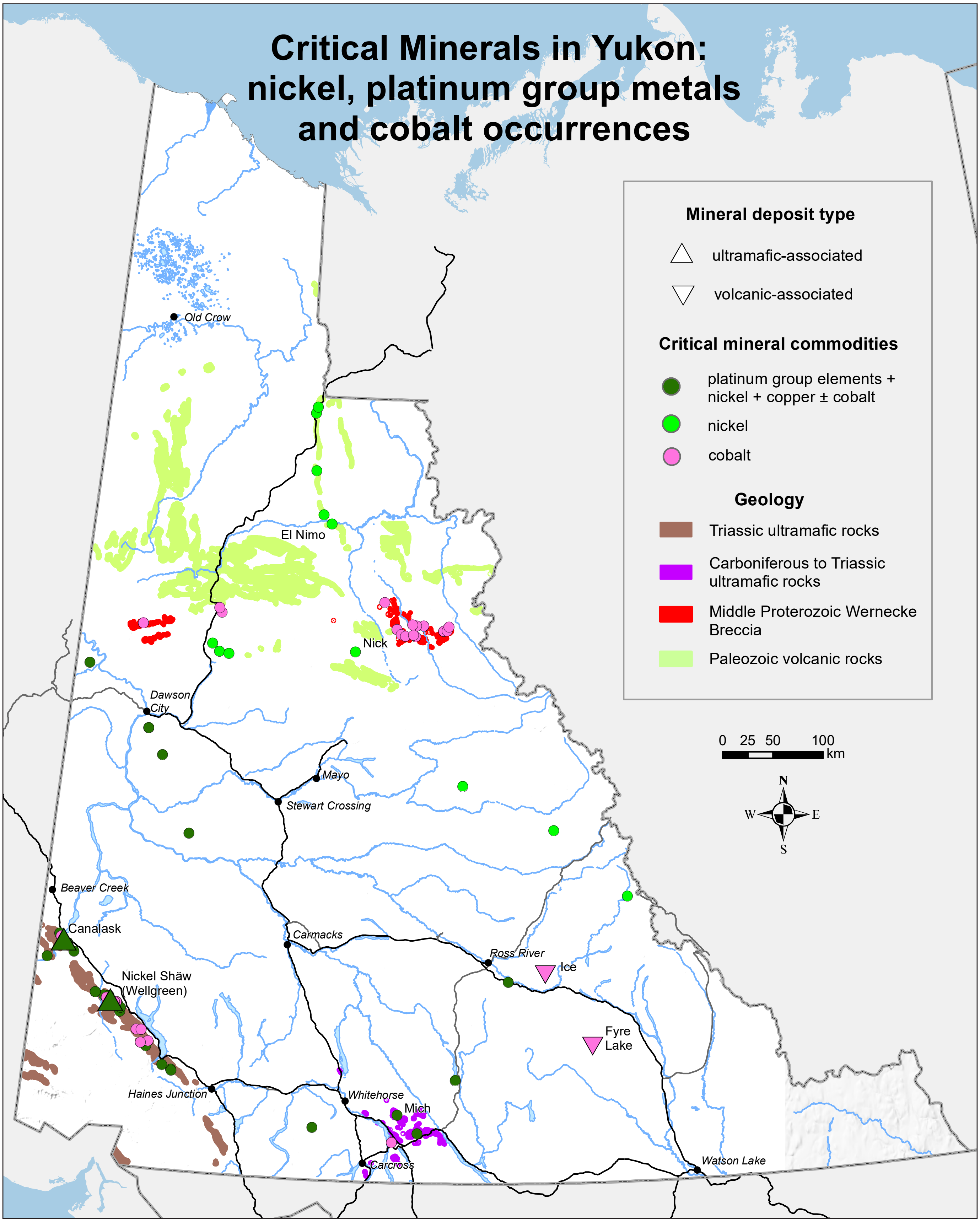
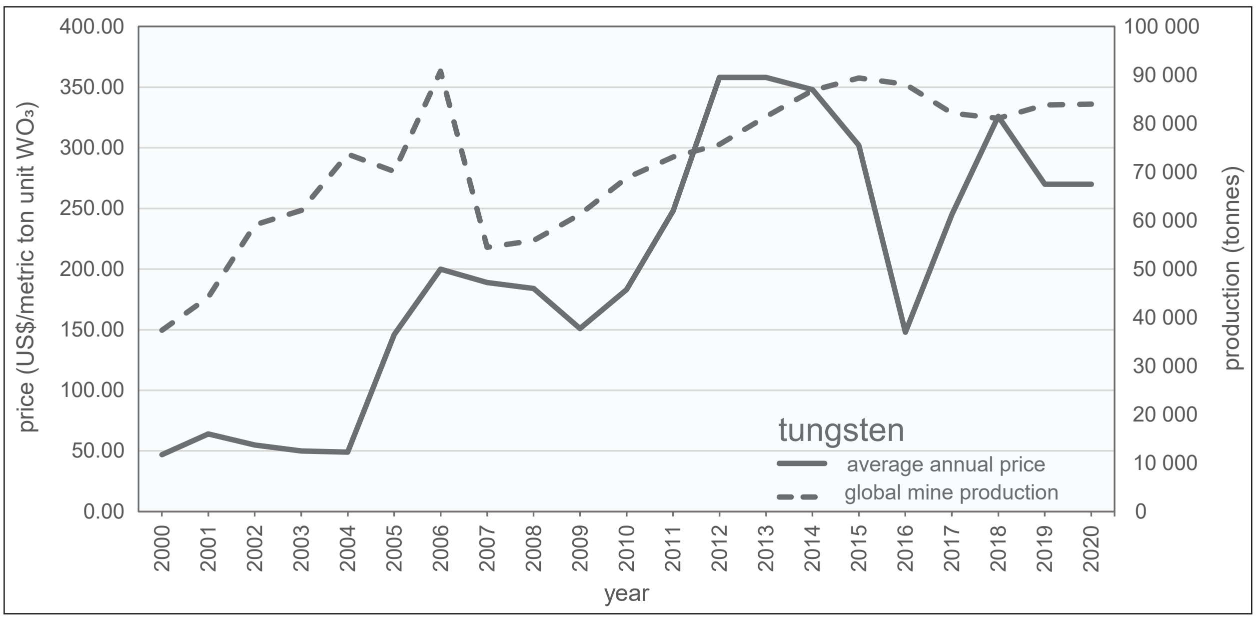


Figure 6. Map showing the distribution of nickel, PGM and cobalt occurrences in Yukon. Large symbols are deposits (i.e., occurrences with defined resources) listed on the data sheet; small circular symbols are occurrences without defined resources.

Tungsten

Description	dense, hard, corrosion-resistant steel-grey metal with high thermal and electrical conductivity; found in combination with other elements in nature; highest melting point of all metals
Source minerals	scheelite, wolframite, ferberite
Primary use	cemented carbides (e.g., tungsten carbide for drilling, boring and cutting tools) and alloys
Secondary uses	electrodes, wires, and other components for electrical, electronic and welding applications
Mine production	largest producer is China (69 000 t in 2019; 82% of world production); other producers include Vietnam (5%), Russia (3%) and Mongolia (2%; USGS, 2021)
Supply/demand outlook	world reserves estimated at 3.2 Mt, near-term supply deficiencies not anticipated (USGS, 2021). China has limited mining and export licenses in recent years and has imposed production quotas
Recovery	well-established processing with no significant challenges
Recycling	~30% of tungsten scrap recycled each year; most scrap is richer in tungsten than ore concentrates (Metalpedia, 2021)



Average annual tungsten price and global mine production from 2000 to 2020.

Tungsten

Global geological setting: More than 40% of the world's tungsten reserves are bound up in tungsten skarns (Foucad, *et al.*, 2020). Most mine production is from vein, skarn, porphyry and stratabound deposits. Minor production is from pegmatite, breccia, disseminated and placer deposits (Werner *et al.*, 2014).

Yukon geological setting: Main tungsten minerals in Yukon are scheelite ($CaWO_4$, calcium tungstate) and wolframite ($(Fe,Mn)WO_4$). Yukon's tungsten deposits are predominantly scheelite-bearing skarns developed at contacts between mid-Cretaceous felsic plutons and Paleozoic limestone. Other deposit types include porphyries developed in Cretaceous intrusions and minor vein occurrences.

Yukon tungsten occurrences: Yukon is well-endowed in tungsten. There are approximately 200 mineral occurrences containing tungsten, including nine occurrences with defined resources. Yukon deposits with defined resources for tungsten are listed below and are illustrated on Figure 7.

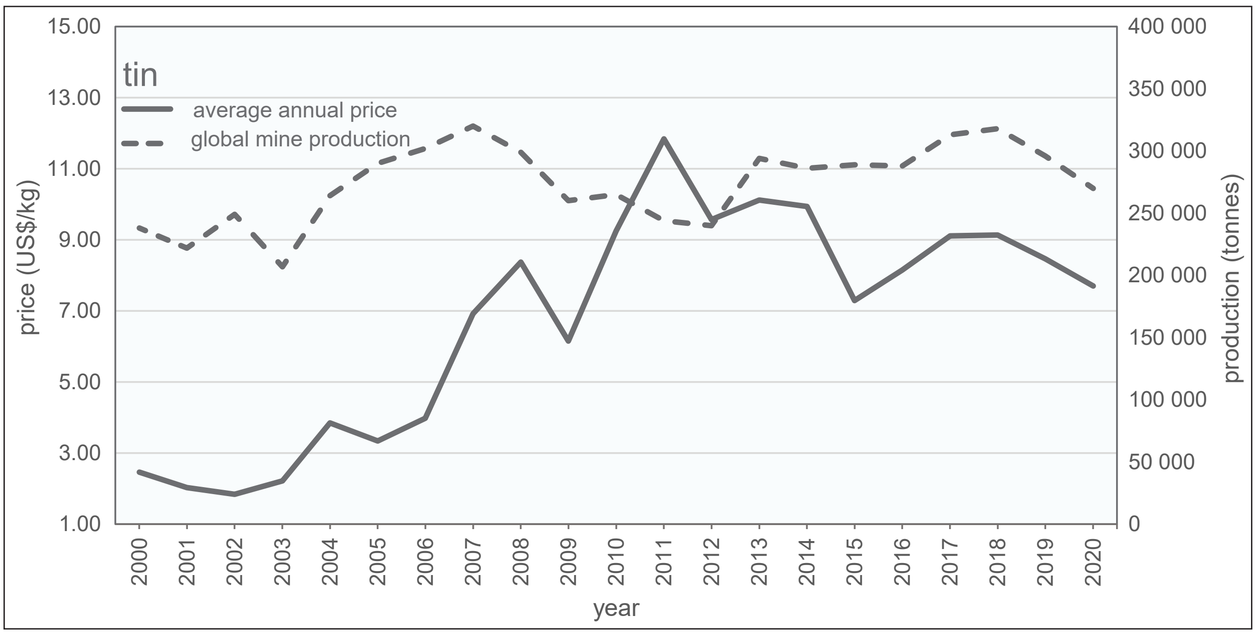
Name MINFILE #	Deposit Type	Resource[1]
Bailey 105A 017	skarn/replacement	8.8 Mlb WO_3 (historical calculation; 1988)
Logtung 105B 039	porphyry	893.2 Mlb WO_3 (M,I&I; 2009) + Mo
Mactung 105O 002	skarn/replacement	844.7 Mlb WO_3 (I&I; 2009)
Mar (Ray Gulch) 106D 027	skarn/replacement	95.4 Mlb WO_3 (I&I; 2008)
Marn 116B 147	skarn/replacement	551 klb W (historical calculation; 1986)
Revenue 115I 042	porphyry	4.95 Mlb W (I&I; 2020) + Cu, Mo, Au, Ag
Risby 105F 034	skarn/replacement	89.4 Mlb WO_3 (inferred; 2009)
Stormy 105F 011	skarn/replacement	353 klb WO_3 (historical calculation; 1959) + Mo
Tiger 106D 098	carbonate replacement deposit	2.2 Mlb W (M,I&I; 2020) + Au

[1]Tungsten resources are generally expressed in units of WO_3, tungsten trioxide.

Tungsten

Tin

Description	soft, pliable metal; occurs as oxide and sulphide compounds; does not occur in native form
Source mineral	cassiterite
Primary use	tin/lead solder; tablet computers; smart phones and other electronics
Secondary uses	tin plating of steel in tin cans; alloys (e.g., pewter and bronze); pottery glazes
Mine production	largest producer is China (84 500 t in 2019; 29% of world production); other producers include Indonesia (26%), Burma (14%), Peru (7%) and Bolivia (6%; USGS, 2021)
Supply/demand outlook	world resources are extensive. Near-term supply deficiencies not anticipated (USGS, 2021)
Recovery	ores tend to have low concentrations of tin (typically <1% Sn)
Recycling	~16 000 t of tin was recycled in 2020 (USGS, 2021)



Average annual tin price and global mine production from 2000 to 2020.

Tin

Global geological setting: Tin deposits are formed as part of magmatic-hydrothermal systems related to late granite phases (Lehmann, 2020). Most of the world's supply of tin comes from placer mining of cassiterite. Placer mining accounts for about 70% of the world output of cassiterite concentrates (USGS, 2012).

Yukon geological setting: Tin deposits in Yukon are related to felsic magmatic-hydrothermal systems, particularly late phases such as pegmatites. Wood tin (cassiterite) is found in placer deposits, but not in high enough concentrations to be economic.

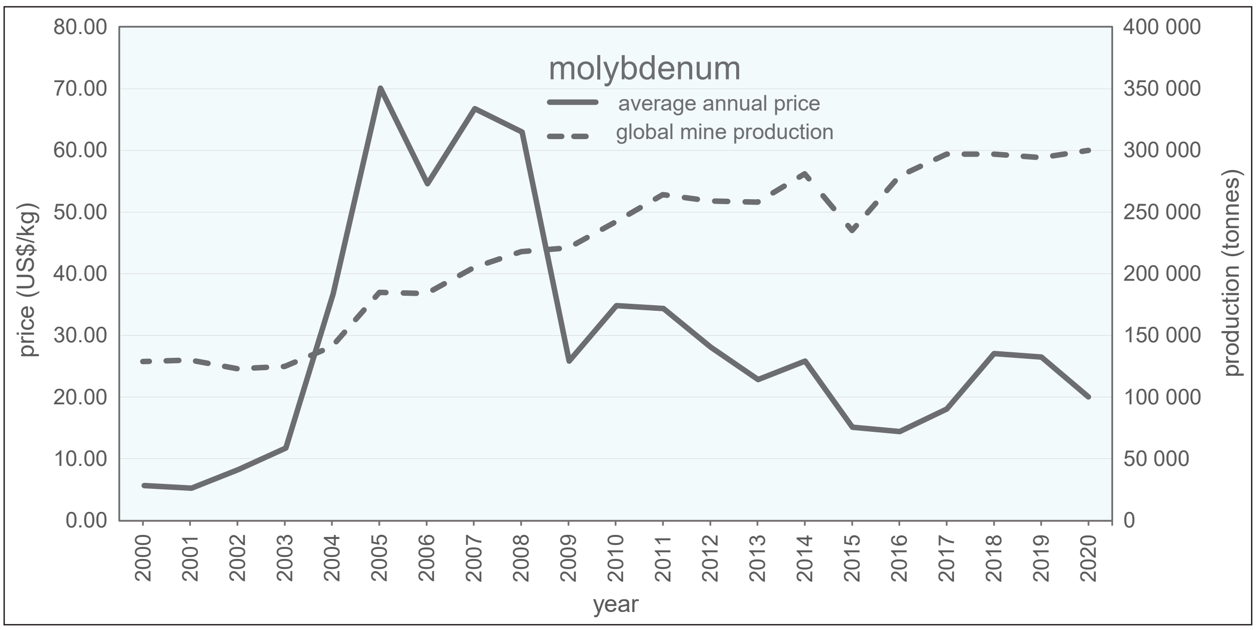
Yukon occurrences: There are more than 100 occurrences containing tin, including two occurrences with defined resources. Yukon deposits with defined resources for tin are listed below and are illustrated on Figure 7.

Name MINFILE	Deposit Type	Resource
Jaycee (JC) 105B 040	skarn	13.5 Mlb Sn (historical calculation; 1981)
Silver Range (Keg) 105K 078	vein/breccia	23.3 Mlb Sn (inferred; 2013) + Ag, Cu, Pb, In, Zn

Tin

Molybdenum

Description	silver, ductile metal; very high melting point; high resistance to corrosion; not found as a free metal in nature, but forms compounds
Source mineral	molybdenite
Primary use	in alloys to increase strength, hardness, electrical conductivity and corrosion resistance
Secondary uses	high temperature lubricant; in catalysts; pigments in ceramics; adhesives
Mine production	largest producer is China (130 000 t in 2019; 44% of world production); other producers include Chile (19%) United States (15%), Peru (10%) and Mexico (6%; USGS, 2021)
Supply/demand outlook	world resources estimated at 18 Mt; near-term supply deficiencies not anticipated (USGS, 2021)
Recovery	mineable ore grades range from 0.01 to 0.25% Mo (International Molybdenum Association, 2021)
Recycling	recycled from catalysts and scrap metal; up to ~30% of the world supply of molybdenum is recycled (USGS, 2021)



Molybdenum Price versus Annual Production from 2000 to 2020.

Molybdenum

Global geological setting: The dominant type of molybdenum deposits that are mined are porphyries (± copper ± tungsten ± gold).

Yukon geological setting: Molybdenum occurs in porphyry molybdenum (± copper ± tungsten ± gold), skarn and hyper-enriched black shale deposits

Yukon Occurrences: There are more than 2000 mineral occurrences containing molybdenum, including seven occurrences with defined resources. Yukon deposits with defined resources for molybdenum are listed below and are illustrated on Figure 7.

Name MINFILE #	Deposit Type	Resource
Cash 115I 037	calc-alkalic porphyry	8.8 Mlb Mo (historical calculation, 1975) + Cu
Casino 115J 028	calc-alkalic porphyry	1.1 Blb Mo (M,I&I; 2020) + Cu, Ag, Au
Logtung 105B 039	calc-alkalic porphyry	251.6 Mlb Mo (M,I&I; 2009) + WO_3
Red Mountain 105C 009	calc-alkalic porphyry	689.6 Mlb Mo (historical calculation; 1995)
Revenue 115I 042	calc-alkalic porphyry	9.57 Mlb Mo (I&I; 2020) + Au, Ag, Cu, W
Stormy 105F 011	skarn	246 klb Mo (historical calculation, 1959) + WO_3
Whitehorse Copper Belt 105D 218 105D 230	skarn	1.3 Mlb Mo (historical calculation, 1984) + Cu, Au, Ag

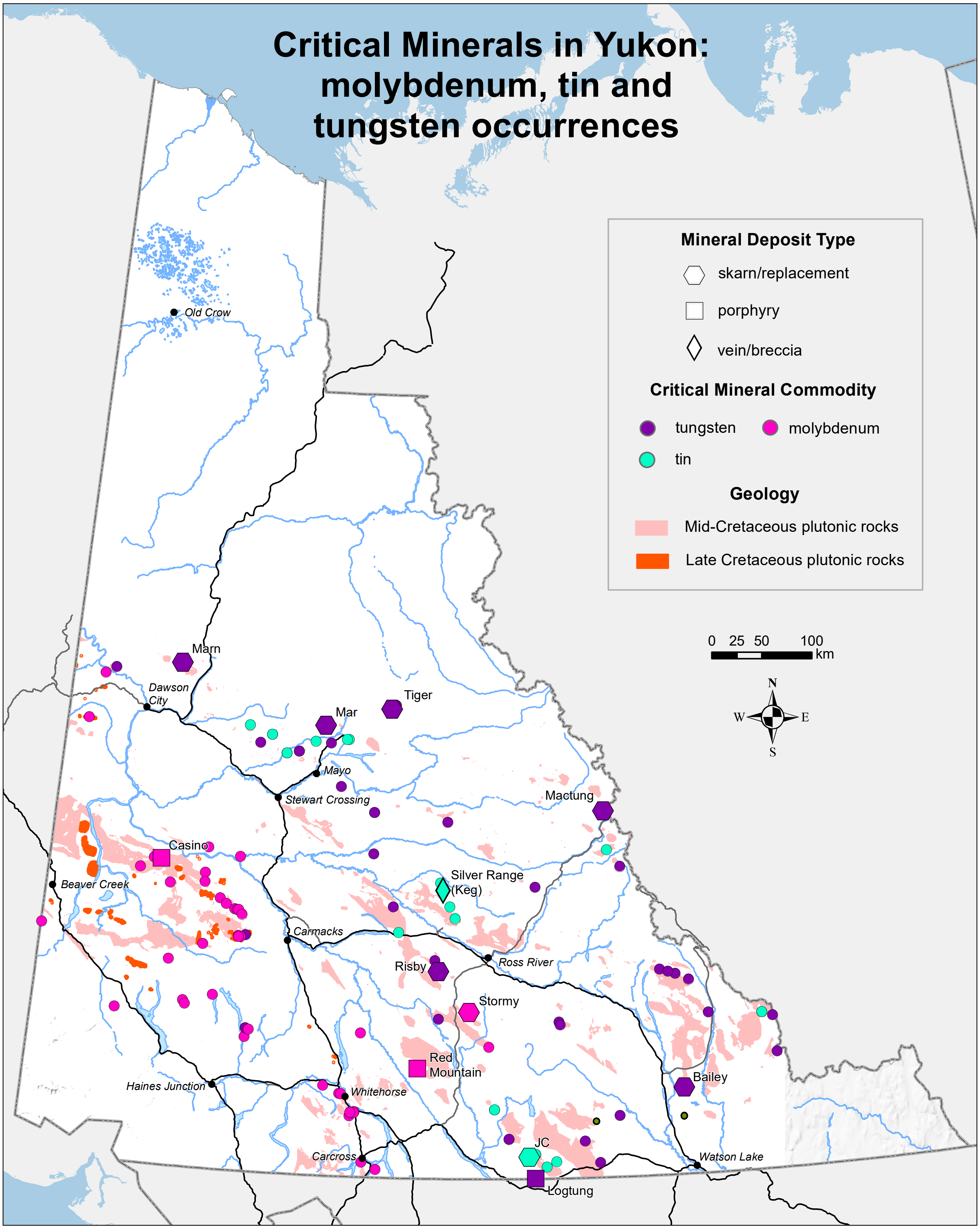
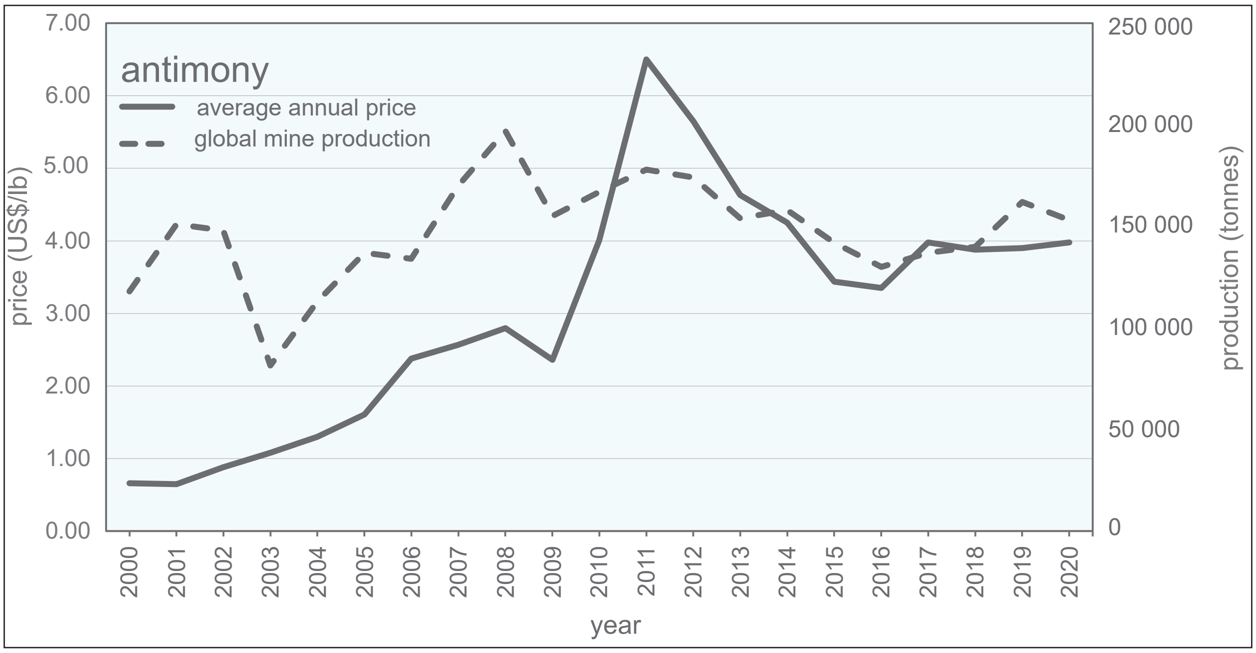


Figure 6. *Map showing the distribution of molybdenum, tin and tungsten occurrences in Yukon. Large symbols are deposits (i.e., occurrences with defined resources) listed on the data sheet; small circular symbols are occurrences without defined resources.*

Antimony

Description	metalloid; brittle; poor conductor of heat and electricity; rarely found in its elemental form in nature; occurs in over 100 different minerals
Source mineral	most common mineral form is stibnite, which accounts for all of its commercial production
Primary use	flame retardant additive for plastic, rubber and fibre compounds
Secondary uses	hardener for electrodes in lead-acid batteries; in lead alloys used for solders, bullets, bearings; additive in glass for optical uses
Mine production	largest producer is China (89 000 t in 2019; 55% of world production); other producing nations include Russia (19%), Tajikistan (17%), Burma (4%) and Bolivia (2%; USGS, 2021). There are no producing mines in the United States or the European Union; Canada has one producing mine in Newfoundland
Supply/demand outlook	recently-imposed environmental standards and controls on over-production are expected to result in reduced production in China (USGS, 2019)
Recovery	generally a byproduct of gold, copper and lead ores; commonly not recovered during processing
Recycling	low recycling rate; most is from antimonial lead in lead-acid batteries (Perpetua Resources, 2021)



Antimony Price versus Annual Production from 2000 to 2020.

Antimony

Global geological setting: Approximately 80% of the world's antimony is produced from two types of deposits: carbonate replacement deposits and gold-antimony epithermal deposits (Guberman, 2015). The largest deposit of antimony in the world is the Xikuangshan Mine in China, a sedimentary-hosted deposit (Hu *et al*., 1996).

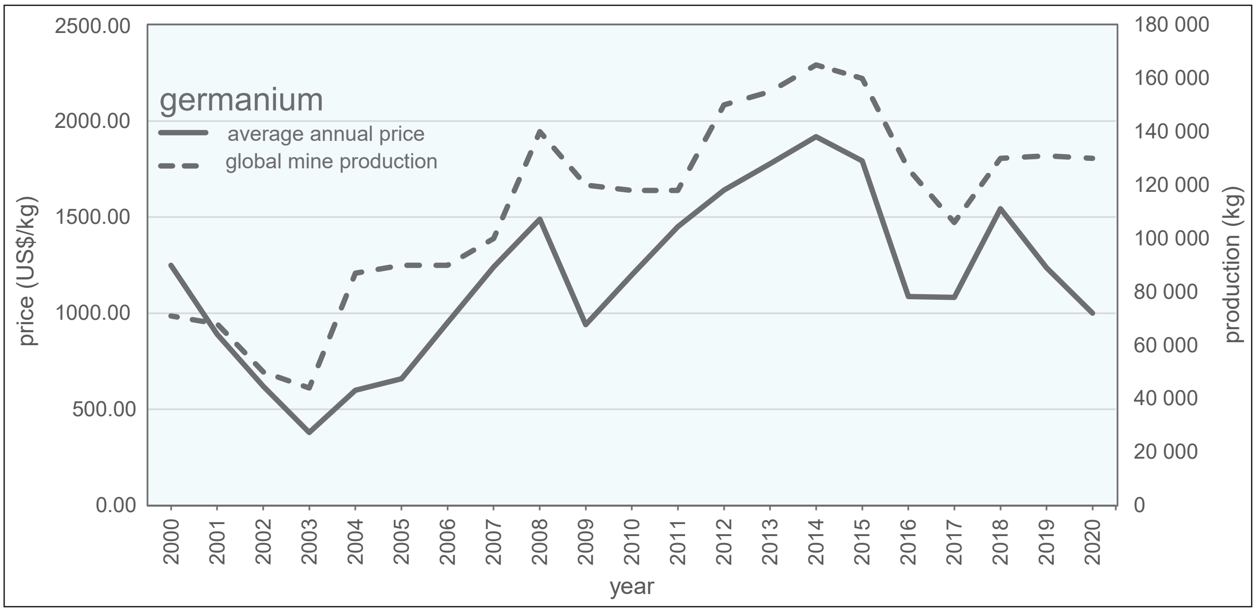
Yukon geological setting: Antimony in Yukon predominantly occurs as an accessory metalloid in epithermal, intrusion-related, orogenic and Carlin-style systems ranging in age from Early Cretaceous to Eocene. Intrusion-related systems are typified by a suite of pathfinders that include antimony. The main antimony-bearing mineral in these settings is stibnite.

Yukon Occurrences: There is one primary antimony deposit in Yukon with a defined resource, but there are more than 100 mineral occurrences that contain antimony. The Yukon deposit with a defined resource for antimony is listed below and is illustrated on Figure 8.

Name MINFILE #	Deposit Type	Resource
Becker-Cochran 105D 027	epithermal	11.2 Mlb Sb (historical calculation, 1974)

Germanium

Description	carbon group metalloid (semi-metal); found in nature combined with other elements
Source minerals	most commonly found in sphalerite
Primary use	semi-conductors
Secondary uses	fibre-optic systems; light-emitting diodes; solar cells, infrared night vision systems, polymerization catalysts
Mine production	largest producer is China (85 700 kg; 65% of world production); other producers include Russia (4%), Belgium, Canada, Germany, Japan and Ukraine (USGS, 2021). Produced as byproduct of zinc ore from Red Dog Mine in Alaska (104–249 ppm Ge; Pat Shanks, 2017)
Supply/demand outlook	demand expected to continue for use in 5G telecommunications and infrared technology (Argus Media, 2021)
Recovery	byproduct in coal and zinc ores; generally recovered at smelters due to low concentration (USGS, 2021)
Recycling	difficult to recycle; ~30% of germanium is produced from recycled materials worldwide (USGS, 2021)



Germanium Price versus Annual Production from 2000 to 2020.

Global geological setting: Germanium is most commonly found in small amounts in sphalerite, a zinc sulphide. It is less commonly associated with silver, lead and copper ores. Germanium can occur in various deposit styles: sedimentary exhalative, carbonate replacement, volcanogenic massive sulphide, porphyry, vein-stockwork and Kipushi-type (Pat Shanks, 2017).

Yukon geological setting: Germanium occurs in minor quantities in the sphalerite of MVT deposits. It may also occur in the sphalerite of sedimentary exhalative deposits.

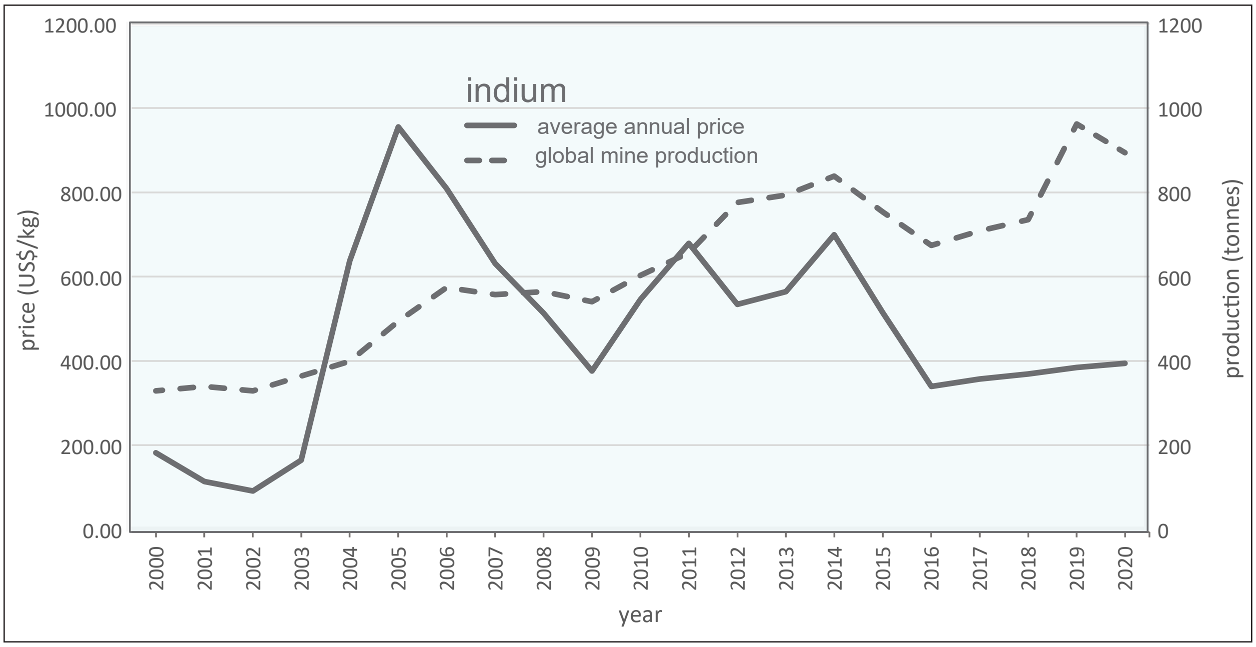
Yukon occurrences: There are only two occurrences containing germanium, but there is potential for more since most companies have not historically assayed for it. The Yukon deposit with a defined resource for germanium is listed below and is illustrated on Figure 8.

Name MINFILE #	Deposit Type	Resource
Yukon Base Metal Project (Andrew) 105K 089	vein/replacement	193 klb Ge (M,I&I; 2008; JORC-code compliant) + Zn, Pb*

*Note: this is an older resource. The updated resource (2012) does not have a resource estimate for germanium.

Indium

Description	very soft metal; low melting point; stable in water and air; conducts electricity; bonds strongly to glass
Source minerals	sphalerite and tin minerals
Primary use	coatings of indium tin oxide on glass for liquid crystal displays (LCD) and light emitting diodes (LED) in televisions; cell phones and other electronic devices
Secondary uses	semiconductors, alloys and solders; infrared lasers for transmitting data through fibre optic lines
Mine production	largest producer is China (485 t in 2019; 55% of world production); other producers include Korea (23%), Japan (7%) and Canada (6%; USGS, 2021). Teck Resources Ltd. produces indium as part of the zinc smelting process (Teck, 2021)
Supply/demand outlook	limited market; not traded on world metal exchanges. Near-term supply deficiencies not anticipated (Stevenson, 2019)
Recovery	byproduct of lead and zinc ores; recovery generally subeconomic (USGS, 2021). ~25% of mined indium is refined into metal; most refineries not capable of recovering indium (Tolcin, 2018)
Recycling	recycling currently not economic; efficiency could be improved to reduce waste (Hilton, 2019)



Indium Price versus Annual Production from 2000 to 2020.

Indium

Global geological setting: Indium may occur in the following settings: VMS, polymetallic vein, epithermal, sedimentary exhalative, porphyry and skarn deposits. Indium occurs predominantly in zinc deposits, but can also occur in copper, tin, silver and polymetallic ores (Lokanc *et al.*, 2015). Most production comes from VMS and polymetallic vein deposits.

Yukon geological setting: Indium might potentially be found associated with lead-zinc veins and skarns, copper-molybdenum porphyries and VMS occurrences.

Yukon occurrences: There is only one deposit containing indium in Yukon: the Silver Range (Keg). Very few companies report indium assays for their prospects, although it is expected that at least some zinc deposits might have elevated levels of indium. The Keno Hill ores contain indium which is recovered at the smelter in Trail; however, the company does not receive a credit for it (pers. comm., Alexco, 2020) and therefore there is no available data on the indium resource. The Yukon deposit with a defined resource for indium is listed below and is illustrated on Figure 8.

Name MINFILE #	Deposit Type	Resource
Silver Range Project (Keg) 105K 078	polymetallic vein	506 klb In (inferred; 2013) + Ag, Pb, Zn, Cu, Sn, Cd

Manganese

Description	hard silver metal; paramagnetic (weakly attracted to the poles of a magnet); brittle; commonly found combined with iron in minerals. Improves strength and wear resistance of alloys
Source minerals	pyrolusite, romanechite, manganite, hausmannite, rhodochrosite, rhodonite
Primary use	steel and aluminum production
Secondary uses	dry cell batteries; fertilizers and animal feed
Mine production	largest producer is South Africa (5.8 Mt in 2019; 30% of world production in 2019); other producers include Australia (16%), Gabon (12.8%), Brazil (8.9%) and Ghana (7.9%; USGS, 2021)
Supply/demand outlook	worldwide reserves estimated at 1.3 Bt (USGS, 2021); near-term supply deficiencies not anticipated
Recovery	mined as a primary ore. Key processing challenge is economical recovery of coarse manganese at grades acceptable to the steel industry (Michaud, 2021b)
Recycling	negligible; recovered along with iron from steel slag (USGS, 2021)

Manganese Price versus Annual Production from 2000 to 2020.

Global geological setting: The main global source of manganese is in sedimentary rocks where accumulations of manganese minerals occur in shallow marine sediments via precipitation from seawater or low-temperature hydrothermal activity (Khan et *al*., 2020).

Yukon geological setting: Manganese is accumulated in phosphate and iron-rich shales in a restricted marine basin setting in northernmost Yukon. In southern Yukon, manganese-rich skarn lenses occur within quartzite of the early Paleozoic Snowcap assemblage of Yukon Tanana terrane. The manganese likely formed as a stratiform synsedimentary deposit, which was later metamorphosed.

Yukon occurrences: Yukon has more than ten mineral occurrences containing manganese, including one occurrence with a defined resource. The Yukon deposit with a defined resource for manganese is listed below and is illustrated on Figure 8.

Name MINFILE #	Deposit Type	Resource
Rapid 117A 027	sedimentary	1.35 Bt MnO (historical calculation; 1984) + Fe, P

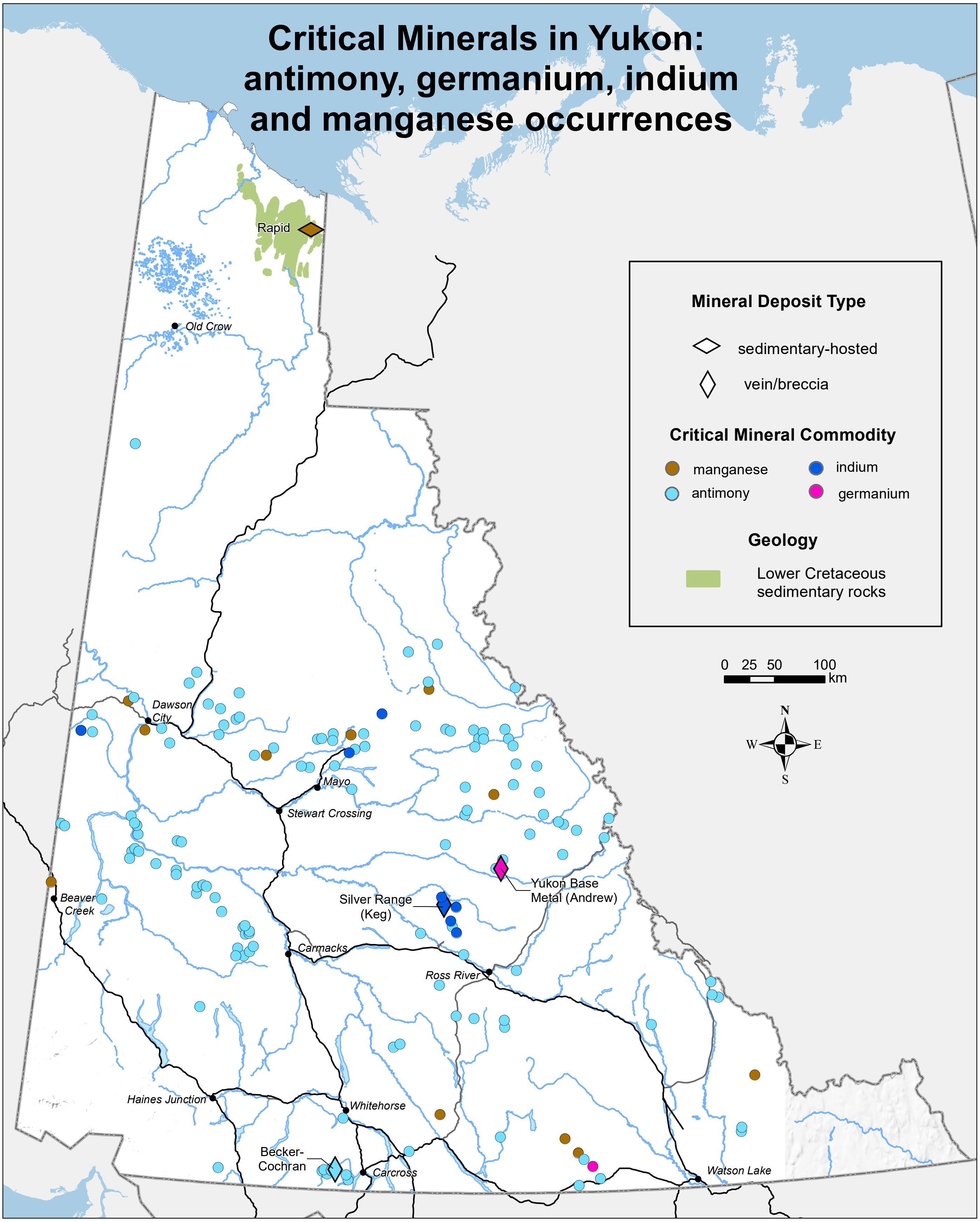


Figure 7. *Map showing the distribution of antimony, germanium, indium and manganese occurrences in Yukon. Large symbols are deposits (i.e., occurrences with defined resources) listed on the data sheet; small circular symbols are occurrences without defined resources.*

Data sheets for critical mineral occurrences in Yukon

Bismuth

Description	brittle metal with one of the lowest thermal conductivities; high resistivity; low toxicity; expands as it solidifies, which lends itself to use in alloys
Source minerals	bismuthinite and bismite are the most important ores
Primary use	metal alloys, including solders
Secondary uses	pharmaceuticals (e.g., pepto bismol); pigments and cosmetics; replacement for lead in shotgun shot, fishing sinkers, glazes, etc.
Mine production	largest producer is China (16 000 t in 2019; 76% of world production). Laos accounted for 14% of world production, followed by production in South Korea, Japan, Mexico, Kazakhstan, and other countries (USGS, 2021)
Supply/demand outlook	prices expected to rise as bismuth replaces lead in electronics and is used in superconductive materials, catalysts and nuclear fuel (Merchant Research & Consulting Ltd., 2021)
Processing	typically obtained as a byproduct in refining lead, copper, tin, silver and gold ores; high bismuth in copper concentrates (>200 ppm) can incur smelter penalties, but recovering the bismuth from the concentrate can be costly (USGS, 2021)
Recycling	United States produces small amounts of bismuth through recycling (USGS, 2021)

Global geological setting: Bismuth occurs as a secondary metal in skarn, intrusion-related gold, Carlin-type, epithermal, orogenic, polymetallic vein, base-metal rich porphyries and VMS deposits.

Yukon geological setting: Bismuth commonly occurs as a secondary metal in intrusion-related, skarn and orogenic systems predominantly in the form of bismuthinite (B_2S_3, bismuth trisulphide). Bismuth-bearing minerals occur in veins and fractures, along with quartz and other sulphide minerals. The mid-Cretaceous Tombstone-Tungsten plutonic suite is enriched in bismuth, a pathfinder for gold in those mineralizing systems.

Yukon occurrences: There are more than 60 occurrences containing bismuth. Selected Yukon occurrences containing bismuth are listed below and illustrated on Figure 9.

Name MINFILE #	Description
Black Jack 105H 028	a 2 m wide chip sample 2279 ppm Bi + Zn, Au
Blue Line 105G 120	arsenopyrite-chalcopyrite bearing quartz vein float assayed 912 ppm Bi + Ag, Au, As
Kathy 106D 083	veinlet material assayed up to 5530 ppm Bi + Au, Sb

Chromium

Description	hard, brittle metal that resists tarnishing
Source mineral	chromite ($FeCr_2O_4$), the only economically significant chromium mineral
Primary use	in alloys, primarily as ferro-chromium in stainless steel production
Secondary uses	green pigment in glassmaking; in glazes for ceramics; in wood preservatives and in the tanning industry
Mine production	largest producer is South Africa (15 395 Mt in 2019; 37% of world production); second largest producer is Turkey (22%), followed by Kazakhstan, India, Finland and other countries (USGS, 2021)
Supply/demand outlook	world resources (>12 Bt of shipping-grade chromite) are expected to supply chromium needs for centuries (USGS, 2021)
Recovery	no significant processing challenges for extracting chromium from ores
Recycling	steel and superalloys are recycled for their chromium and nickel content (911Metallurgist, 2018)

Global geological setting: Chromite forms as a result of magmatic differentiation of basaltic magma and is hosted in ultramafic rocks such as serpentinized peridotite, residual mantle harzburgite and cumulate dunite.

Yukon geological setting: There are no significant deposits of chromite in Yukon; however, occurrences have been documented in ultramafic rocks of the Cache Creek terrane and in rocks of the Pyroxenite Creek plutonic suite, where it occurs as an accessory mineral in narrow seams. Additionally, it has potential to occur in ultramafic rocks of the Slide Mountain terrane.

Yukon occurrences: There are more than 10 occurrences containing chromium. Selected Yukon occurrences containing chromium are listed below and illustrated on Figure 9.

Name MINFILE #	Description
Dalayee 105C 028	grab sample assayed 49.4% chromite
Lavalee 105D 070	grab samples assayed from 458 to 1714 ppm chromium
Michie 105D 071	a chromite-magnetite lens 3.7 m thick assayed 39.4% chromium oxide
Pyroxene 115O 116	pyroxene grab sample assayed 2050 ppm chromium
Squanga 105C 012	a 1 m chip sample assayed 33.5% chromium oxide
Stride 115A 037	a float sample from the base of the sill assayed 19.8% chromium

Fluorspar (Fluorite ore)

Description	mineral with the chemical formula CaF_2 (calcium fluoride); referred to as fluorspar when it occurs in economic quantities
Primary use	manufacturing of hydrofluoric acid (HF) used in laboratories and to process aluminum and uranium ores
Secondary uses	flux in steel production (lower grade fluorite); hydrofluoric acid is used to prepare silicon wafers for use in semiconductors microscopes and telescope glass
Mine production	largest producer is China (4.3 Mt in 2019; 58% of world production); minor producers are Mexico (16%) and Mongolia (9.6%; USGS, 2021)
Supply/demand outlook	world reserves are estimated at 320 Mt, more than enough to maintain yearly production of 7.46 Mt (USGS, 2021)
Recovery	fluorspar ore may contain metal sulphides that must be separated to meet standards for "acid grade fluorspar" (Michaud, 2021b)
Recycling	aluminum producers recycle hydrofluoric acid and fluorides from smelting operations (USGS, 2021)

Global geological setting: Fluorite is found in felsic igneous rocks, particularly in late-crystallizing pegmatites. It can be found in quartz-calcite vein deposits associated with sphalerite, galena and barite. Phosphate rock can also have large quantities of fluorine.

Yukon geological setting: Fluorite is found in pegmatites, greisens, veins, skarns, Carlin-style deposits and MVT deposits in Yukon, but there are no fluorite deposits with calculated resources. Potential exists for high levels of fluorine in the phosphate-rich sedimentary rocks of the Blow River area and the Crest iron deposit.

Yukon occurrences: There are more than 15 mineral occurrences containing fluorite. Selected Yukon occurrences containing fluorite are listed below and illustrated on Figure 9.

Name MINFILE #	Description
Chzerpnough 105F 071	fluorite and sulphides with bedded barite in pyritic, brecciated felsic volcanic rocks
Fiddler 105B 004	fluorite, scheelite and sulphides in quartz veins that cut phyllite and limestone near an intrusive contact
Logtung 105B 039	fluorite, wolframite, tourmaline and beryl in a quartz vein cutting quartz monzonite
Mars 105E 002	fluorite, scheelite and sulphide minerals in brecciated and altered rock
Nokluit 105E 080	fluorite and rare earth minerals in skarns peripheral to a syenite stock cutting carbonate rocks
Unexpected 116B 006	veinlets and disseminated fluorite in a porphyry stock

Gallium

Description	rare soft metal; relatively low melting point (29.76° Celsius); one of the few elements that expands when it cools from a liquid to a solid; does not occur as native metal
Source minerals	bauxite, sphalerite and coal may contain recoverable amounts of gallium
Primary use	semiconductors, electronics, light-emitting diodes (LEDs)
Secondary uses	thermometers (as a non-toxic alternative to mercury), barometers and pharmaceuticals; in alloys (forms alloys with low melting points)
Mine production	largest producer is China (338 000 kg in 2019; 97% of world production), mostly from its aluminum refineries; other minor producers include Russia, Japan and Korea (USGS, 2021)
Supply/demand outlook	demand is expected to grow. Used in wireless communication, semiconductors and in 5G networks (USGS, 2021)
Recovery	byproduct of processing bauxite and zinc ores; less than 10% of the gallium in bauxite and zinc ores is recovered; most smelters do not have a gallium-dedicated circuit (USGS, 2021)
Recycling	minor; recovered from new scrap in Canada, China, Germany, Japan, Slovakia and the United States (USGS, 2021)

Global geological setting: Gallium occurs as a minor metal in bauxite ores. It also occurs in zinc-rich sediment-hosted deposits such as MVT and VMS, where it substitutes for zinc in the crystal structure of sphalerite (Foley *et al.*, 2017).

Yukon geological setting: Gallium occurs in trace amounts in zinc ores. It is present in small amounts in MVT deposits. It also occurs in association with magnetite and hematite in the Whitehorse Copper Belt skarn deposits.

Yukon occurrences: There are less than 10 occurrences containing gallium. Selected Yukon occurrences containing gallium are listed below and illustrated on Figure 9.

Name MINFILE #	Description
Arctic Chief 105D 209	grab sample of magnetite assayed 0.06% gallium
Discovery 106C 103	grab sample assayed 124 ppm gallium
Michelle 116A 016	drillhole MCH-08-20 intersected 9.40 m of 870 ppm gallium + Zn, Pb, Ag

Lithium

Description	the lightest metal; highly reactive and flammable; does not occur in its elemental form in nature
Source minerals	lepidolite, spodumene
Primary use	rechargeable batteries for electric vehicles; electronic devices such as mobile phones and laptops
Secondary uses	heat-resistant glass and ceramics; lubricants and in flux additives for steel, iron and aluminum production
Mine production	largest producer is Australia (45 000 t in 2019; 52% of world production); other major producers include Chile (22%), China (14%) and Argentina (7%; USGS, 2021)
Supply/demand outlook	use in electric vehicle (EV) batteries is a key price driver; lithium demand is expected to increase as more EVs enter the market
Recovery	mined from hard-rock ores or obtained via evaporation pond from brines (Bradley *et al.*, 2017); processing uses large amounts of water and energy. Electric vehicles (EVs) require high-purity lithium (Berry, 2021)
Recycling	recycling lithium-ion batteries is costly; ~5% of lithium-ion batteries are recycled (Woollacott, 2021)

Global geological setting: Lithium is obtained from oilfield, salar and geothermal brines, lithium clays and pegmatites; the salar brines are found in salt-rich lakes such as the Salar de Atacama in Chile (Bradley, *et al.*, 2017).

Yukon geological setting: Lithium occurs with rare earth elements in alkalic intrusive systems.

Yukon Occurrences: One mineral occurrence has documented lithium. The Yukon occurrence containing lithium is listed below and illustrated on Figure 9.

Name MINFILE #	Description
Trench 11-06 095C 075	trench sample assayed 404 ppm lithium

Lithium

Magnesium

Description	lightweight, chemically reactive silvery metal
Sources	ocean water, salt lake brines, dolomite, serpentine, magnesite
Primary use	as alloys in products to reduce weight: aircraft components, portable power tools and electronics
Secondary uses	added to molten iron and steel to remove sulfur; used in flares and fireworks
Mine production	largest producer of magnesium oxide is China (19 Mt in 2019; 70% of world production); other producers are Brazil, Russia and Turkey, at almost 6% each. China also dominates world production of magnesium metal, accounting for 87% of world production (970 000 t; USGS, 2021)
Supply/demand outlook	lightweight metal replacement for steel and aluminum, demand is expected to remain high into the future
Recovery	production in China is mainly accomplished by low-cost thermal processing of dolomite ore, but it is more polluting than the electrolytic processing method that occurs in most other countries (Roskill, 2021)
Recycling	over 80 000 t of magnesium scrap was recycled in 2020 (USGS, 2021). Recycling magnesium alloys only takes 5% of the energy of that required to produce primary magnesium alloys (International Magnesium Association, 2021)

Global geological setting: Magnesium can be obtained from ocean water, salt lake brines, dolomite, serpentine, magnesite and other magnesium minerals. In 2020, construction was started on a magnesium production plant that will extract magnesium from serpentine tailings in Asbestos, Quebec (Alliance Magnesium, 2020).

Yukon geological setting: Potential sources of magnesium in Yukon are serpentinized ultramafic rocks and dolomite rock, which are widespread throughout Yukon. Magnesium has never been a focus of exploration in Yukon due to its low price and the distance to the nearest processing facilities for magnesium ore.

Yukon occurrences: There are three occurrences containing magnesium. Yukon occurrences containing magnesium are listed below and illustrated on Figure 9.

Name MINFILE #	Description
Clinton Creek 116C 025	serpentinized ultramafic rocks have high values for magnesium
Wels Nickel 115J 042	soil samples have values up to 10.5% Mg
Mex (Linda) 115G 110	soil sampling returned values up to 13.6% Mg

Niobium

Description	silvery metal; high melting point; corrosion resistance and extreme heat resistance
Source mineral	columbite, pyrochlore
Primary use	in alloys to increase their strength, e.g., jet engines, building beams and oil and gas pipelines
Secondary uses	in superconducting magnets for particle accelerators and MRI scanners; in corrective lenses
Mine production	largest producer is Brazil (88 900 t in 2019; 92% of world production); Canada is the second largest producer at 7% (USGS, 2021)
Supply/demand outlook	world resources of niobium are estimated at greater than 17 Mt, more than enough to supply projected world needs (USGS, 2021)
Recovery	niobium processing can be challenging because the minerals aren't easily separated from other minerals (USGS, 2021)
Recycling	recycling levels are estimated at up to 20% of consumption (USGS, 2021). Better sorting of steel scrap in terms of niobium content would improve recycling results (Globe Metal, 2021)

Global geological setting: Most of the world's identified resources of niobium occur as pyrochlore in carbonatite deposits (USGS, 2021).

Yukon geological setting: Niobium is found in the few alkalic-intrusion-related rare earth occurrences in Yukon, as an accessory element.

Yukon occurrences: Two occurrences contain niobium. Yukon occurrences containing niobium are listed below and illustrated on Figure 9.

Name MINFILE #	Description
Bandito 095C 076	altered syenite assayed up to 0.24% niobium
Fin Zone 105F 143	mafic dike samples assayed up to 0.36% niobium

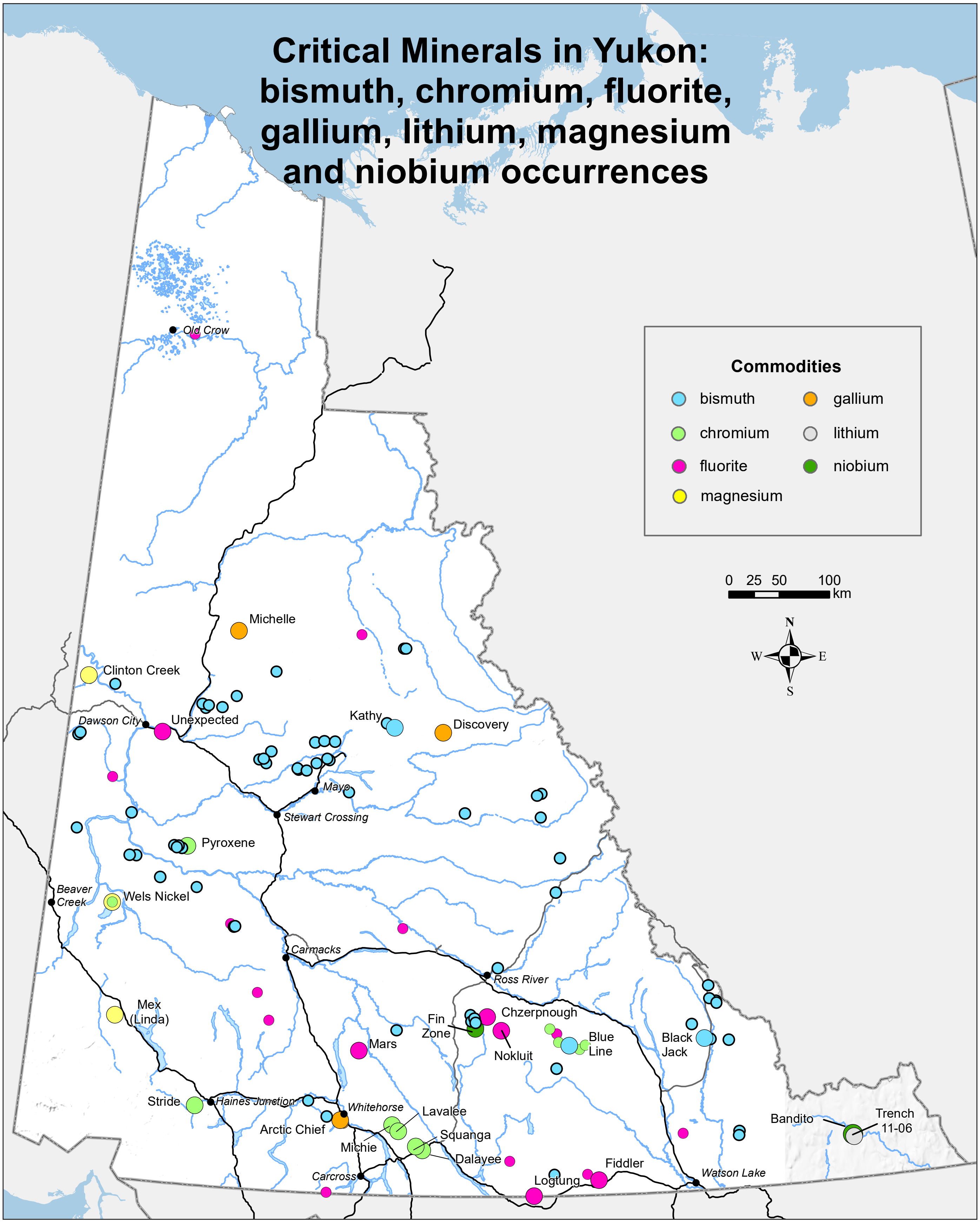


Figure 9. *Map showing the distribution of bismuth, chromium, fluorspar, gallium, lithium, magnesium and niobium occurrences in Yukon. Large symbols are listed on the data sheet.*

Bi, Cr, F, Ga, Li, Mg, Nb

Rare Earth Elements (REEs)

Despite their name, most rare earth elements are relatively abundant in the earth's crust. In the periodic table of elements they are grouped together as lanthanides. For application purposes, they are divided into light and heavy elements (NRCan, 2021f).

- Light REEs (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium and gadolinium)
- Heavy REEs (terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium and yttrium). Yttrium is not actually a rare earth element, but it is commonly included with them because it has similar characteristics and occurs with them in ore deposits
- Note: the division between light and heavy rare earth elements is based on atomic mass. As one moves from left to right on the periodic table, atomic mass increases.

Rare earth elements are found in various minerals, but only three are typically mined for their rare earth content: bastnasite, monazite and laterite clays.

Light Rare Earth Element	Characteristics	Uses
lanthanum	soft, silvery metal; tarnishes quickly in air	catalysts, batteries, glass production, lamps, ignition elements, electron cathodes
cerium	soft, ductile, silvery metal; tarnishes quickly in air	catalysts, glass polishers, steel, alloys, ceramics, phosphor* applications
praseodymium	soft, silvery metal; malleable, ductile; valued for its magnetic, electrical, chemical and optical properties	strong magnets; aircraft engines
neodymium	hard, slightly malleable metal; silvery; tarnishes easily	strong magnets; lasers, speakers
promethium	rare, radioactive	research
samarium	moderately hard, silvery metal; slowly oxidizes in air	strong magnets; cancer treatments
europium	very soft, ductile, silvery metal; most reactive lanthanide	LCD displays; phosphor* applications
gadolinium	silvery metal; ductile, slightly malleable; tarnishes slowly	MRIs; alloys, shielding in nuclear reactors; phosphor* applications
terbium	soft, silvery metal; malleable, ductile	LCD displays; metal alloys

*phosphors are luminescent materials

Heavy Rare Earth Element	Characteristics	Uses
yttrium	silvery transition metal, similar to rare earth metals	LCD displays, LED lights, phosphor* applications
dysprosium	silvery, soft metal; high magnetic strength; tarnishes slowly in moist air	computer hard drives; transducers
holmium	silvery, soft, malleable metal; reactive; highest magnetic strength of any element	strong magnets; cubic zirconia
erbium	silvery, malleable, soft metal; does not oxidize readily compared to other rare earth elements	optical fibres, lasers; glass colouring
thulium	soft, silvery metal; malleable, ductile; slowly tarnishes in air	portable x-ray machines
ytterbium	soft, malleable, ductile metal; silvery; oxidizes slowly in air	nuclear medicine; stainless steel
lutetium	silvery metal; hard, dense; resists corrosion in dry air, but not moist air	catalysts; petroleum refining

*phosphors are luminescent materials

Mine production	largest producer of heavy REEs is China (132 000 t in 2019; 70% of world production); remaining 30% of REEs supplied by Australia, United States, Myanmar, Russia and India (USGS, 2021). Canada's sole rare earth mine is in the Northwest Territories and began production in 2021
Supply/demand outlook	light REEs are produced worldwide and are in surplus supply; heavy REEs are in limited supply. World reserves of rare earths are estimated at 120 Mt rare earth oxide; China represents 37% of this reserve, (USGS, 2021)
Recovery	mineral processing is challenging because it requires sequential separation of multiple elements. Since no two REE deposits are alike, there is no standard process for extracting REE minerals. Many REE deposits also contain thorium, which requires special handling when mining and processing (Long *et al.*, 2010)
Recycling	~1% of rare earth elements are recycled (Jowitt *et al.*, 2018)

Global geological setting: Alkaline igneous rocks, carbonatites, placer deposits (especially monazite), laterite/residual deposits, pegmatites and IOCG deposits.

Yukon geological setting: In Yukon, peralkaline intrusive rocks are hosts for rare earth elements. This includes plutonic suites ranging in age from Neoproterozoic to Eocene. Although British Columbia has REE occurrences that are hosted in carbonatites, no known carbonatites have been mapped in Yukon.

Yukon occurrences: There are more than 10 occurrences containing rare earth elements. Selected occurrences containing rare earth elements are listed below and illustrated on Figure 10.

Name MINFILE #	Description
Bandito 095C 051	trenching exposed areas with more than 2% rare earth oxides
Garnet Greisen 105F 141	greisen grab samples have assayed up to 1.24% total rare earth oxides
Nokluit 105F 080	a chip sample contained 1.2% rare earth oxides across 10 m

Tantalum

Description	hard, ductile silvery metal; resistant to corrosion; high conductivities of electricity and heat; forms strong alloys that have higher melting points
Source minerals	tantalite is the most significant ore mineral
Primary use	electronic components in devices such as cell phones
Secondary uses	in equipment for handling corrosive materials; in alloys, e.g., for the aerospace industry
Mine production	largest producer is Democratic Republic of the Congo (580 t in 2019; 31% of world production); other major producers are Brazil (23%), Rwanda (18%) and Nigeria (9%; USGS, 2021)
Supply/demand outlook	world reserves are estimated at over 140 000 t. Most of the identified world resources of tantalum are in Australia and Brazil, and are considered adequate to supply future needs (USGS, 2021)
Recovery	no significant challenges in processing tantalum. A significant amount of tantalum is obtained commercially as a byproduct of tin extraction
Recycling	In 2014, 35% of world production of tantalum was recycled (Globe Metal, 2015).

Global geological setting: Tantalum is rarely found in its native state in nature. It occurs mainly in the mineral columbite-tantalite. Tantalite is found as an accessory mineral in alkalic intrusive systems and carbonatites.

Yukon geological setting: Tantalum is associated with alkalic intrusive systems.

Yukon occurrences: The only occurrence containing tantalum in Yukon is listed below and illustrated on Figure 10.

Name MINFILE #	Description
Electricity 105B 126	a megaporphyry pod returned high values for tantalum, niobium, thorium and rare earth elements

Tellurium

Description	brittle, silvery semi-metal (metalloid)
Source minerals	occurs in telluride and sulphide minerals
Primary use	solar cells, thermoelectric devices; various alloys (steel, copper, lead, etc.)
Secondary uses	vulcanization of rubber; photoreceptors and thermoelectric devices; pigment in glass and ceramics
Mine production	largest producer is China (325 t in 2019; 63% of world production); other main producers are Japan (10%), Sweden (8%) and Canada (8%; USGS, 2021)
Supply/demand outlook	majority extracted during electrolytic copper refining, with lesser amounts from lead refineries and smelting of bismuth, copper and lead-zinc ores. USGS estimates world reserves at 31 000 t, more than enough to serve world needs in the near future (USGS, 2021)
Recovery	byproduct from processing copper, iron and other base-metal ore bodies, it is not necessarily recovered at the smelter
Recycling	minor; small amount has been recovered from old paper copiers and cadmium-tellurium solar cells (USGS, 2021)

Global geological setting: Tellurium occurs as an accessory semi-metal in bismuth, copper and lead-zinc ores (Goldfarb, 2015).

Yukon geological setting: Tellurium is a pathfinder element for intrusion-related gold occurrences.

Yukon occurrences: There are less than ten occurrences containing tellurium. Selected Yukon occurrences containing tellurium are listed below and illustrated on Figure 10.

Name MINFILE #	Description
Connaught 115N 179	gold-silver mineralized vein assayed 17.75 ppm tellurium
Mt. Sheldon 105J 008	quartz-veined megacrystic granite assayed 0.55 ppm tellurium

Titanium

Description	lightweight, hard, strong metal; corrosion resistant
Source minerals	rutile, ilmenite, leucoxene
Primary use	white pigment in paint, plastics and paper
Secondary uses	lightweight alloying agent with other metals used in the aerospace industry; in structures exposed to seawater; surgical applications (*e.g.*, hip joint replacements)
Mine production	largest producer is China (2.3 Mt in 2019; 27% of world production); South Africa accounted for 13% of world production and there are many other smaller producers (USGS, 2021)
Supply/demand outlook	consumption of titanium is primarily tied to TiO_2 pigments which has consistent growth in demand. World resources are more than 1.8 Bt, enough to service the world's needs well into the future (USGS, 2021)
Recovery	no significant challenges to processing, except in the case of titanium for pigments where trace contaminants can compromise the pigment production process (Woodruff, 2017)
Recycling	titanium that is contaminated by iron can't be recycled for pigments, instead, it is melted and used in steel production (Takeda *et al.*, 2020)

Global geological setting: The two main minerals containing titanium are rutile and ilmenite. Titanium ore is mainly mined from magmatic deposits (anorthosite, gabbro and norite) and heavy-mineral shoreline, dune and placer deposits.

Yukon geological setting: Titanium occurs in accessory minerals in magmatic systems and also accumulates in placer deposits. There are no known economic accumulations of titanium minerals in Yukon.

Yukon Occurrences: The one occurrence containing titanium in Yukon is listed below and illustrated on Figure 10.

Name MINFILE #	Description
Shell Creek 116C 029	iron formation grab sample assayed 0.21% TiO_2 + Fe, silica

Uranium

Description	silvery-grey, weakly radioactive metal; malleable, strongly electropositive (loses electrons and forms positive ions in chemical reactions) and a poor conductor of electricity
Source minerals	uraninite (pitchblende), carnotite, torbernite, brannerite
Primary use	fuel in nuclear reactors
Secondary uses	nuclear submarines and weapons; depleted uranium is used in ammunitions that can pierce through heavily armored equipment
Mine production	largest producer is Kazakhstan (22 800 t in 2019; 43% of world production); other top producers include Canada (13%), Australia (12%), and Namibia (10%; Statista, 2021b)
Supply/demand outlook	forty-eight new nuclear power reactors are under or nearing construction; 80% of these are in Asia. Nuclear power is expected to be part of the energy mix for the future low-carbon economy (World Nuclear Organization, 2021)
Recovery	processing of uranium ore, particularly high-grade ore, has health risks for humans; airborne exposure to radioactive materials requires mitigation
Recycling	used fuel from reactors and stockpiles of depleted uranium are increasingly being used as a fuel source; 30% of all used uranium fuel has been reprocessed. Commercial reprocessing capacity is estimated at 2000 t per year (World Nuclear Organization, 2021)

Global geological setting: Uranium occurs in sedimentary settings (unconformity-type, paleoplacer and roll-front type), iron oxide gold breccia deposits, vein deposits and felsic intrusive systems.

Yukon geological setting: Exploration targets include mid-Proterozoic Wernecke Breccia and radioactive felsic magmatic systems (intrusion-hosted, skarn, vein, etc.) ranging in age from Neoproterozoic to early Tertiary. The bulk of significant uranium occurrences in Yukon occur in Wernecke Breccia and are located in the Peel River Watershed.

Yukon Occurrences: There are approximately 100 mineral occurrences that contain uranium. Selected Yukon occurrences containing uranium are listed below and illustrated on Figure 10.

Name MINFILE #	Description
Curie 106E 031	trench samples across a shear zone assayed 0.15% to 4.6% U_30_8
Igor 106E 009	drillhole IG-2007-06 intersected 64.7 m of 0.09% U_30_8
Lumina 106C 069	grab samples assayed up to 2.04% U_30_8
Ting 116B 109	trench sample assay of 1.08% U_30_8 across 1.0 m

Vanadium

Description	hard, malleable steel-blue metal; rarely found in native form; thermally insulating, electrically conductive and corrosion-resistant
Sources	titanomagnetite, bauxite, crude oil, coal
Primary use	adds strength and heat-resistance to alloys, e.g., vanadium steel
Secondary uses	in catalysts to create sulfuric acid; in new battery technology (vanadium redox flow batteries) to increase energy density and voltage
Mine production	China is the main world producer (54 000 t; 62% of world production); other producers include Russia (21%), South Africa (9%) and Brazil (7%; USGS, 2021)
Supply/demand outlook	world resources of vanadium are greater than 57 Mt, enough to supply world needs for the foreseeable future; use of vanadium by automakers is expected to result in higher demand for the metal (USGS, 2019)
Recovery	recovery of vanadium during mineral processing is poor. Vanadium is often agglomerated with titanium, which needs to be separated from it (Mills, 2017)
Recycling	vanadium is recycled by processing spent catalysts, petroleum residues and vanadium-bearing pig iron slag. Vanadium-bearing slags from iron and steel-making plants account for 69% of vanadium production (Lee et *al*., 2021)

Global geological setting: The main deposit-types for vanadium are vanadiferous titanomagnetite (commonly found in layered magmatic intrusions), and sandstone-hosted and vanadium black shales. Vanadium substitutes for iron in magnetite, ilmenite and chromite and is also produced as a minor byproduct of coal and tar sands mining.

Yukon geological setting: Some early Paleozoic carbonaceous shales are enriched in vanadium, particularly the upper Devonian Canol formation shales in northern Yukon, which are host to hyper-enriched black shale occurrences.

Yukon occurrences: There are fewer than 10 occurrences containing vanadium. Selected Yukon occurrences containing vanadium are listed below and illustrated on Figure 10.

Name MINFILE #	Description
El Nimo 106E 041	The 'Nick' metal-enriched sedimentary horizon where samples typically average 0.82% vanadium oxide
Nick 106D 092	vanadium + nickel, molybdenum, zinc, platinum and palladium

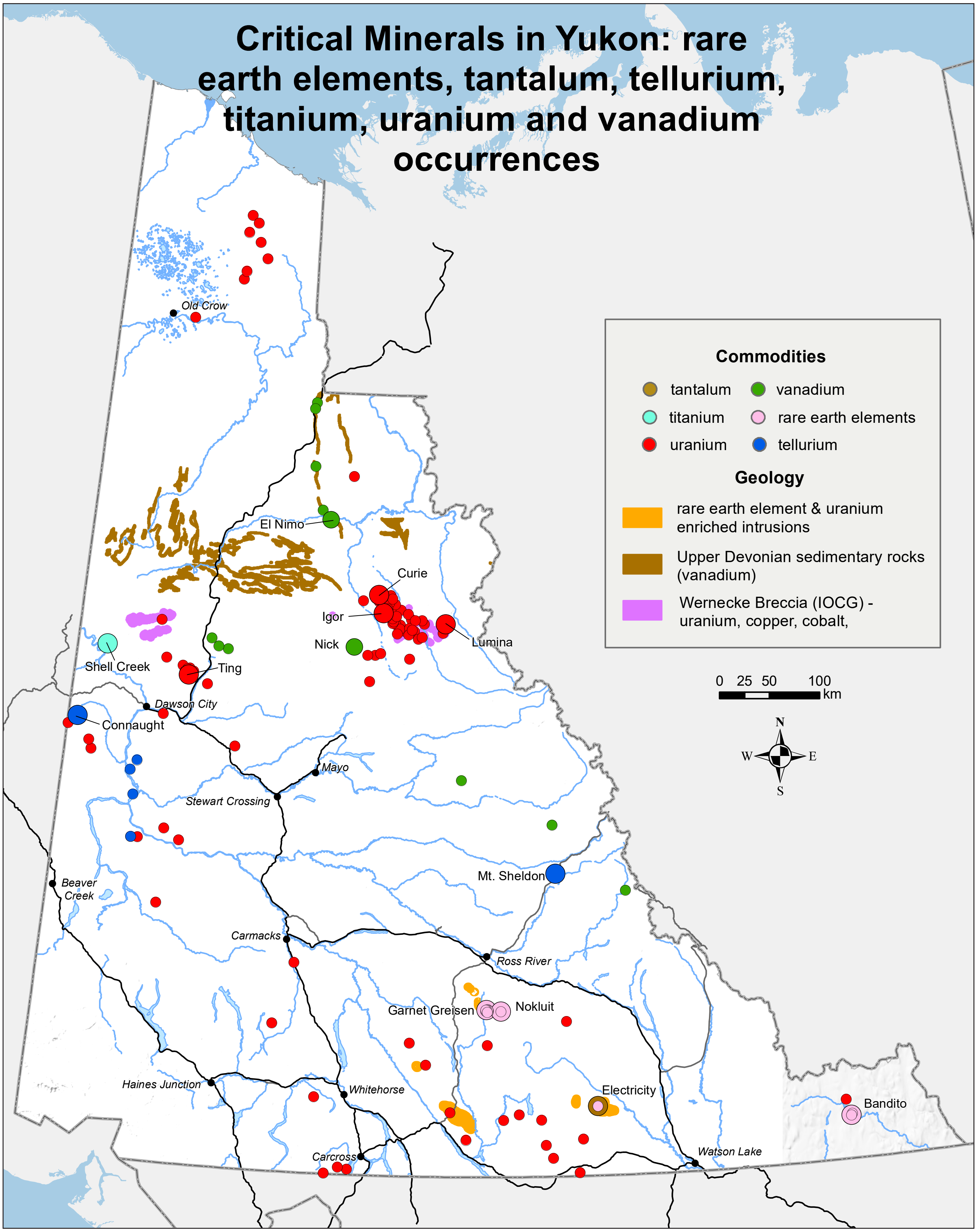


Figure 10. *Map showing the distribution of rare earth elements (REEs), tantalum, tellurium, titanium, uranium and vanadium occurrences in Yukon. Large symbols are listed on the data sheet.*

Data sheets for critical minerals with no documented occurrences in Yukon

Aluminum

Description	soft, low-density silvery metal; readily combines with oxygen to form protective coating; most abundant metallic element in Earth's crust. Does not occur in elemental form, only as compounds with other elements
Source mineral	gibbsite, boehmite, diaspore, kaolinite
Primary use	alloys used for automobiles, bicycles, etc.
Secondary uses	packaging e.g., cans, foils; building and construction; in electrical applications and machinery
Mine production	largest producer is China (35 Mt in 2019; 55% of world production); other producers include India (6%) and Russia (6%; USGS, 2021)
Supply/demand outlook	estimated world resources are 50–68 Bt; no supply shortages projected at this time
Recovery	recovery method well-established but energy intensive; Canada has 10 primary aluminum smelters and 1 refinery
Recycling	32 Mt produced annually through recycling (Statista, 2021c); recycling significantly less energy-intensive than primary production

Global geological setting: Bauxite, the main ore of aluminum, is a sedimentary rock composed of various aluminum and iron minerals and clay. It forms in tropical to subtropical regions.

Yukon geological setting: Bauxites do not occur in Yukon. There are no known aluminum occurrences in Yukon.

Cesium

Description	soft silvery-golden metal; low melting point (28.5°C); very reactive (can ignite spontaneously when exposed to air)
Source minerals	pollucite, lepidolite, petalite, beryl, feldspar
Primary use	in drilling fluid to control well pressures
Secondary uses	optical glass, vacuum tubes and in radiation monitoring equipment; in atomic clocks that are essential to internet and cell phone networks and GPS satellites
Mine production	largest producer is Manitoba, Canada (9000 t pollucite ore in 2019; Tania Martins, pers. comm., 2021). Other producers are Zimbabwe and Australia. Production in all three countries is controlled by China (Cision PRNewsire, 2020)
Supply/demand outlook	cesium market is small; world reserves are large compared to world demand (Butterman *et al.*, 2004)
Recovery	mining occurs on a smaller scale than for most other metals. There are no specific challenges associated with it
Recycling	cesium formate brines used in oil and gas drilling are recovered at a rate of almost 85% and reprocessed for re-use (USGS, 2021).

Global geological setting: Cesium occurs in lithium-cesium-tantalum pegmatites and in brines in Chile and China.

Yukon geological setting: There are no documented occurrences of cesium in Yukon. Figure 11 shows the distribution of alkalic intrusive rocks that have potential for cesium.

Graphite

Description	crystalline form of carbon; very soft; good conductor of heat and electricity
Source mineral	graphite
Primary use	batteries; electrodes; solar panels
Secondary uses	anode material in lithium-ion batteries; pencils and paints; lubricant
Mine production	largest producer is China (700 000 t in 2019; 64% of world production); other producers include Mozambique (10%), Brazil (9%), Madagascar (4%); India (3%); Canada (1%; USGS, 2021)
Supply/demand outlook	demand expected to grow due to increasing production of electric vehicles and portable electronics. World reserves estimated at >800 Mt, so supply is more than enough to meet graphite needs into the future (USGS, 2021)
Recovery	challenging due to size reduction of flakes and contaminants (Reitz, 2016), and use of harmful chemicals
Recycling	can be recycled from spent lithium-ion batteries

Global geological setting: During metamorphism, carbon in sedimentary rocks may be transformed into graphite. Graphite is also associated with high grade coal deposits. Small amounts of graphite also occur in igneous rocks and in fault zones.

Yukon geological setting: Although graphite occurs in minor amounts in faults, shear zones and metamorphic rocks, there are no known economic concentrations of graphite in Yukon. Figure 11 shows the distribution of coal-bearing sedimentary rocks that have potential for graphite.

Helium

Description	second lightest element; colourless unreactive gas; product of radioactive decay of thorium and uranium; lowest boiling point of all elements
Source mineral	associated with natural gas
Primary use	liquid form: coolant for the Large Hadron Collider and superconducting magnets (e.g., in MRIs)
Secondary uses	gas form: used in arc welding; in growing crystals for the manufacturing of silicon wafers; in balloons
Mine production	largest producer is United States (89 Mt in 2019; 56% of world production); other producers include Qatar (28%) and Algeria (9%; USGS, 2021)
Supply/demand outlook	estimated world resources are ~51.9 BCM; U.S. reserves are 20.6 BCM (USGS, 2021). Forecasts of future availability vary widely
Recovery	byproduct of natural gas; separated from other gases if concentration is >0.3% (King, 2021)
Recycling	helium gas can be recovered in laboratories using liquifiers (Kramer, 2020); not a major source of helium

Global geological setting: Helium is captured primarily from gas wells. The largest resources are in Qatar, Algeria, Russia, Canada and China.

Yukon geological setting: Yukon has several gas fields with potential for helium, but the helium potential has never been assessed. Figure 11 shows the distribution of sedimentary basins that have potential for helium.

Potash

Description	potassium-bearing compounds and materials, commonly potassium carbonate or potassium salts
Source mineral	group of minerals consisting of potassium salt mixed with potassium carbonate
Primary use	agricultural fertilizer
Secondary uses	glass, ceramics, dyes, soaps, drugs and explosives
Mine production	largest producer is Canada (12.3 Mt in 2019; 30% of world production); other producers include Belarus (18%), Russia (18%) and China (12%; USGS, 2021)
Supply/demand outlook	estimated world resources are ~250 Bt; Canadian reserves are 4.5 Bt. No known substitutes so demand expected to stay strong
Recovery	fairly simple to mine via conventional solid mining methods or solution mining (hot water pumped into mine to dissolve potash)
Recycling	not recyclable as fertilizer is taken up by plants or lost in run-off

Global geological setting: Potash consists of potassium salt mixed with potassium carbonate. As sea beds evaporated over millions of years, potash deposits formed.

Yukon geological setting: There are no known occurrences of potash in Yukon, and Yukon is not considered prospective to host potash deposits.

Scandium

Description	silver-white metal; easily oxidized; burns readily and reacts with water; often grouped with REEs because it commonly occurs in the same types of deposits
Sources	byproduct of rare earth, uranium, iron and laterite mining.
Primary use	lightweight alloys (e.g., used in aerospace industry and sports gear such as bicycle frames) and solid oxide fuel cells
Secondary uses	electronics, lasers, lighting, radioactive isotopes
Mine production	major producers are China, Russia, Kazakhstan and Ukraine, producing 14–23 t per year (USGS, 2021). Canadian production started in 2021 from titanium dioxide feedstock in Quebec (Rio Tinto, 2021)
Supply/demand outlook	limited supply; high cost; manufacturers reluctant to use it in new materials (Dittrich and Yagmurlu, 2018)
Processing	difficult to process economically; recovered as byproduct of REEs, titanium processing and uranium mill tailings
Recycling	minor; recovery of scandium from bauxite residues (Geomega, 2021)

Global geological setting: There are no primary mine sources for scandium. It is estimated that 90% of scandium resources are hosted in mafic and ultramafic magmatic deposits. Other deposit settings include tungsten-tin hydrothermal deposits and supergene deposits of scandium formed from weathering of mafic and ultramafic rocks and marine sediment-hosted deposits (Wang et *al.*, 2021). Scandium is also found in bauxite residues and in uranium and rare earth deposits.

Yukon geological setting: There are no known scandium occurrences in Yukon. Figure 11 shows the distribution of ultramafic rocks that have potential for scandium.

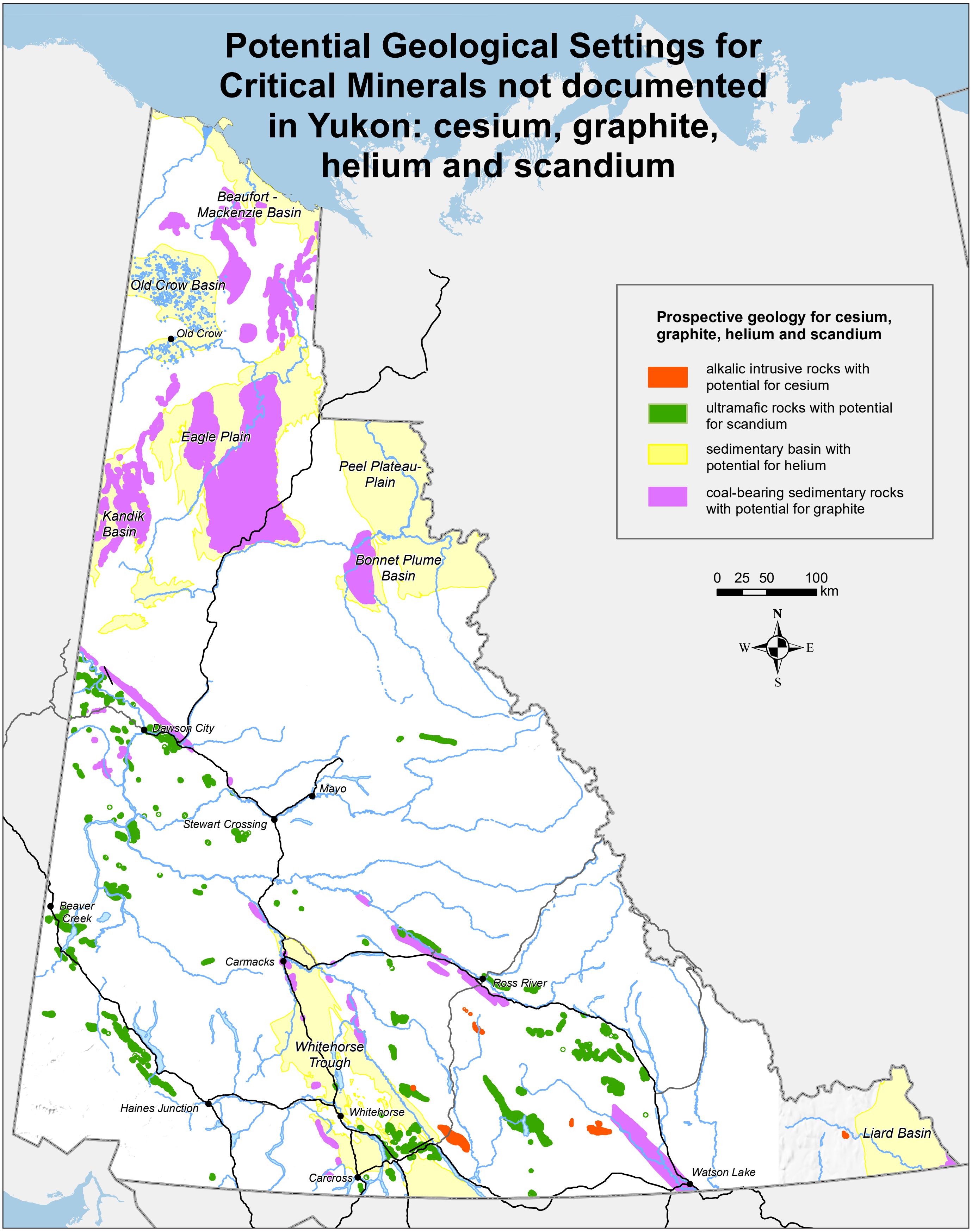


Figure 11. *Map showing potential geological settings for cesium, graphite, scandium and helium. Yukon is not known to be prospective for aluminum or potash.*

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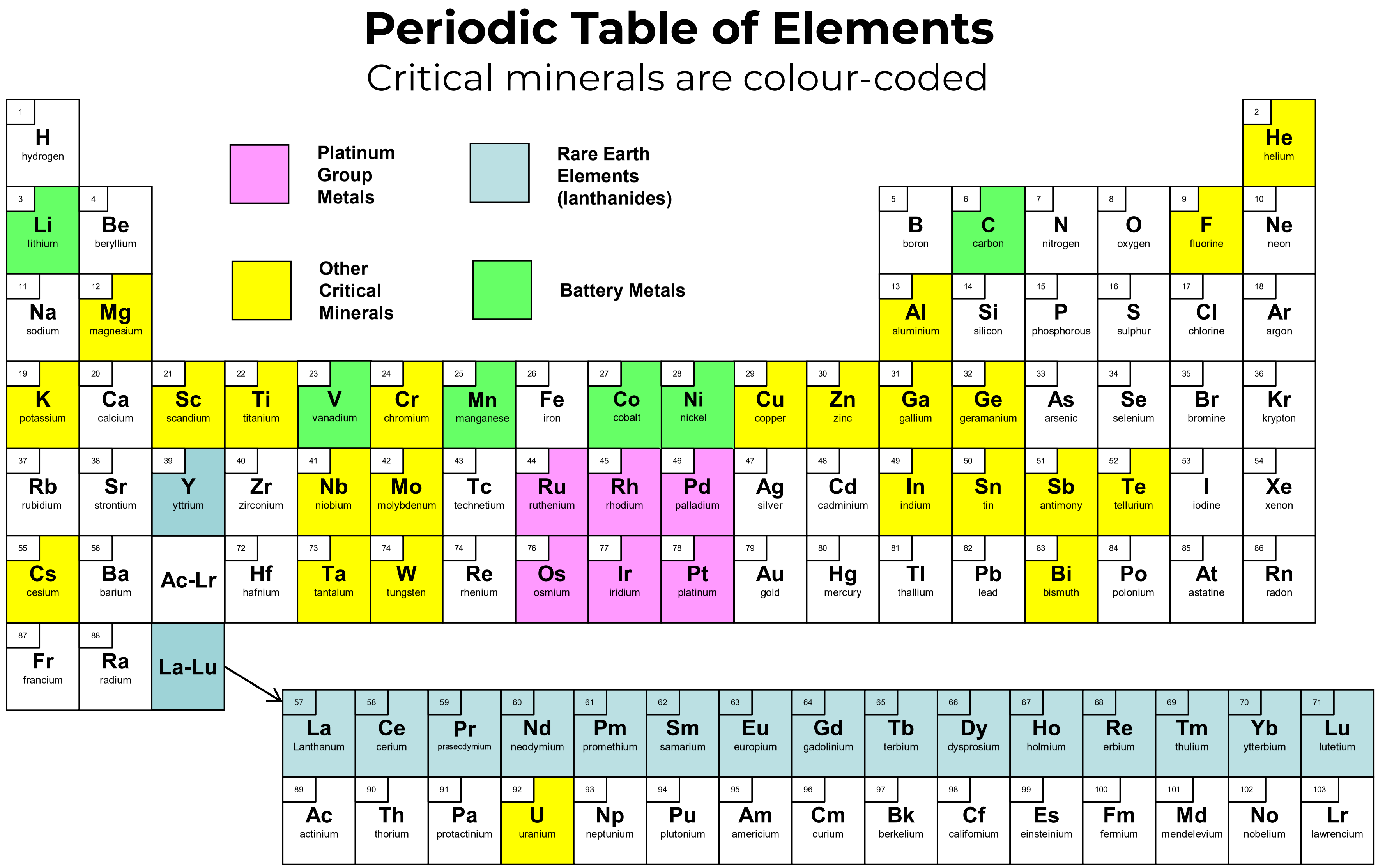
Appendix 1. *Periodic table of elements illustrating critical minerals via colour-coding. Created from:* https://www.presentationmagazine.com/periodic-table-template-7954.htm.



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