

Indium in a Canadian critical minerals context: geology, mineralogy, and potential resources for Canada's future

Stephen J. Piercey ^a and Stefanie M. Brueckner ^b

^aDepartment of Earth Sciences, Memorial University of Newfoundland, 9 Arctic Avenue St. John's, NL A1B 3X5, Canada; ^bMineral Exploration Research Centre Harquail School of Earth Sciences, Laurentian University, 935 Ramsey Lake Road Sudbury, ON P3E 2C6, Canada

Corresponding author: Stephen J. Piercey (email: spiercey@mun.ca)

Abstract

Indium (In) is a critical mineral used in communications technology, optical displays, and alternative energy delivery, and is a byproduct of Zn and/or Sn mining. It is often found in low concentrations (10 s to 100 s of ppm) in Canadian clastic-dominated sediment-hosted Zn–Pb, polymetallic volcanogenic massive sulfide (VMS), magmatic–hydrothermal, and orogenic vein deposits. Indium in Zn-rich mineralization is associated with sphalerite that is spatially associated with chalcopyrite and was influenced by Cu-rich fluids; it is commonly hosted in roquesite (CuInS_2) or as Cu–In nanoparticles within sphalerite. In Sn-rich mineralization, In is associated with roquesite, and to a lesser extent sphalerite, chalcopyrite, wolframite, and Sn-phases (e.g., cassiterite and stannite). Indium occurs in deposits that had evidence for magmatic–hydrothermal fluid input and/or with deposits that have strong associations with black shales/organic-rich mudstones. Future resources will likely come from similar deposits outlined above, but additional resources may be found in carbonate-hosted Zn–Pb deposits and porphyry Cu–Mo deposits, in addition to historic mine tailings. Understanding baseline geochemical and mineralogical distributions of In in rocks and minerals in historic and existing deposits is essential if we are to secure future supplies of In from Canadian mineral deposits.

Key words: indium, critical minerals, hydrothermal, magmatic-hydrothermal, byproduct metals, mineral resources, mineral deposits

Introduction

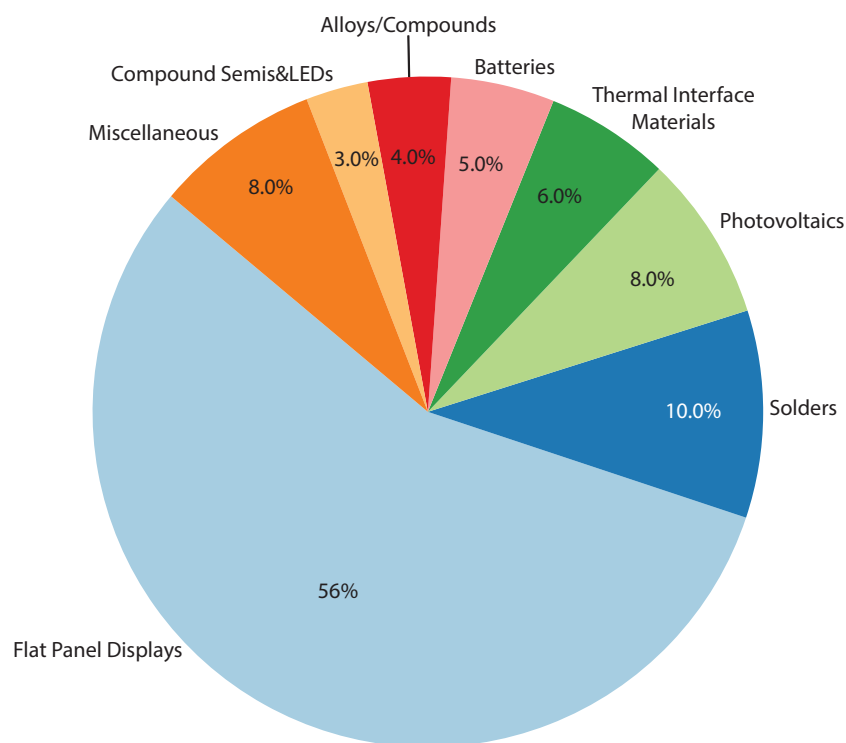
Successful civilizations are dependent upon access to reliable and reasonably priced energy (e.g., Homer-Dixon 2006). Since the industrial revolution, energy delivery and the global economy has centred around cheap, easily available, and high carbon-based fossil fuels. Despite economic benefits, the negative global impacts to the climate due to CO_2 emissions from carbon-based fuel sources (e.g., coal, oil, and gas), have necessitated a shift to a low-carbon economy based on renewable energy (e.g., wind and solar), and less carbon-intensive forms of energy (e.g., nuclear and hydroelectricity). This change in energy sourcing requires a wholesale electrification of the economy to transform our transportation and energy delivery systems, which has resulted in current and predicted future increased demand for metals that is likely to continue for a generation or more (e.g., World Bank 2017). The implementation of electric vehicles, solar panels, wind-mills, and the computer systems and “smart grids” that deliver the electricity will put demand on conventionally mined commodities, including copper (Cu), zinc (Zn), nickel (Ni), lead (Pb), tin (Sn), and iron (Fe). Further, important components of these new technologies increase demand for byproduct elements like cobalt (Co) and lithium (Li), as well as rare

earth elements (REE), many of which have restricted supply and/or from limited sources globally (e.g., REE, Li are sourced in only 3–4 countries globally; Jowitt et al. 2020; Jowitt and McNulty 2021; McNulty and Jowitt 2021; Reich and Simon 2024).

Many of the elements outlined above are on the Canadian Critical Mineral List (NRCan 2024), some of which are the focus of papers in this special issue of FACETS. In this manuscript, we focus on the critical mineral (metal) indium (In). The objectives of the paper are to: (1) provide an overview of In and its chemical attributes, mineral associations, and transport in hydrothermal fluids; (2) outline the geological and mineralogical setting of In in Canadian mineral deposits; (3) discuss what are the main controlling factors of In enrichment in Canadian deposits; and (4) infer where potential future Canadian sources of In may be found.

Indium—general attributes, mineralogy, mineral associations, and transport in hydrothermal fluids

Indium is silvery-white lustrous metal that is found in period 13 (IIIA) of the periodic table with atomic number 49,

Fig. 1. End uses for In. Modified from Lokanc et al. (2015) and Paradis (2015).

an atomic weight of 114.82 g/mol, density of 7.31 g/cm³, and a melting point of 156.60 °C, and occurs in three valence states (+1, +2, or +3; Schwarz-Schampera and Herzig 2002; Schwarz-Schampera 2014; Haynes 2015). Indium is often mixed with Sn to form In–Sn oxides that are used as thin films in liquid crystal displays (LCDs), in semi-conductors as indium-phosphide (InP), and within alloys because of its low melting point (Fig. 1; Jorgenson and George 2005; Lokanc et al. 2015; Mejías et al. 2023). Fifth generation (5G) communication technologies have also resulted in increased demand for In, as InP is used in fiber-optic networks for lasers and receivers, which allow for greater data transfer performance at higher speeds with less signal loss compared to other materials (USGS 2024). Indium is also used in thin films in solar/photovoltaic panels, touch screens, and in control rods for nuclear energy (Moss et al. 2011; Mejías et al. 2023), as well as alloys and solders, microchips, electrical components, semi-conductors, and intermetallic compounds (Fig. 1; Lokanc et al. 2015; Paradis 2015).

Indium is typically a by-product of Zn and/or Sn mining and is enriched in some Zn- and Sn-concentrates; however, over 95% of the In produced globally comes from Zn mining (Schwarz-Schampera 2014; Werner et al. 2015; Mudd et al. 2017; Werner et al. 2017a, 2017b). It is possible that In is a by-product of other types of mining (e.g., Cu mining); however, information on In sources beyond Zn and Sn mining is lacking. The vast majority of refined In is produced by (in decreasing order of amount produced between 2019 and 2023): China, South Korea, Japan, Canada, France, Belgium, and Russia (Fig. 2; USGS 2024). Although most of the In produced is from concentrates derived from mineral deposits

(Schwarz-Schampera and Herzig 2002; Schwarz-Schampera 2014), recent work has shown that it is possible to recycle In–Sn oxides from electronic waste (Anić Vučinić et al. 2023) and there may be abundant In in tailings from past Zn and Sn mining (Werner et al. 2017b; Mejías et al. 2023), such that these sources may also be possible streams of In in the future (Gómez et al. 2023).

There has been a steady increase in In prices from ~\$380 USD/kg in 2018 to ~\$867 USD/kg as of February 2026 (Strategic Metals 2026), largely driven by increased LCD usage and in clean technology such as indium tin oxide-based high-efficiency solar cells and advanced chips (Choubey and Shivaprasad 2026). The elevated price is likely to continue in the immediate term due to increased demand and decreased supply from both South Korea and Chinese refiners (Choubey and Shivaprasad 2026).

Indium is a chalcophile element that has low concentrations in Earth materials, with estimated values of 12.2 ppb (0.0122 ppm) in the depleted mantle (Salters and Stracke 2004), ~75 ppb (0.075 ppm) in mid-ocean ridge basalts (Yi et al. 1995; Arevalo and McDonough 2010), and ~50–66 ppb (0.050–0.066 ppm) in the upper continental crust (Taylor and McLennan 1985; Rudnick and Gao 2003; Hu and Gao 2008). In contrast, most ores have ppm to 100 s of ppm level concentrations and are at least 10–1000+ times enriched compared to the upper crust (Fig. 3; Schwarz-Schampera and Herzig 2002; Werner et al. 2017b).

Indium occurs primarily in sulfide minerals given its chalcophile nature (Schwarz-Schampera and Herzig 2002; Cook et al. 2011; Schwarz-Schampera 2014); however, in rare cases it is present in some ferromagnesian silicates, albeit with

Fig. 2. Production statistics for In from 2019 to 2023. Data from annual USGS production statistics (e.g., [USGS 2024](#)).

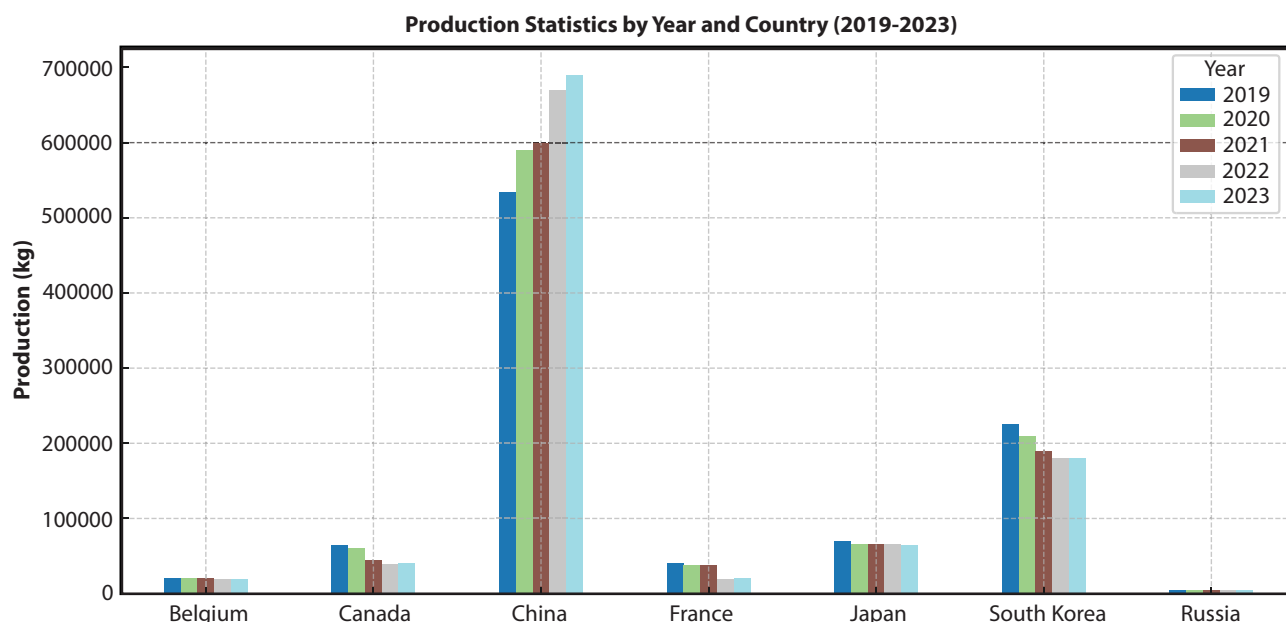
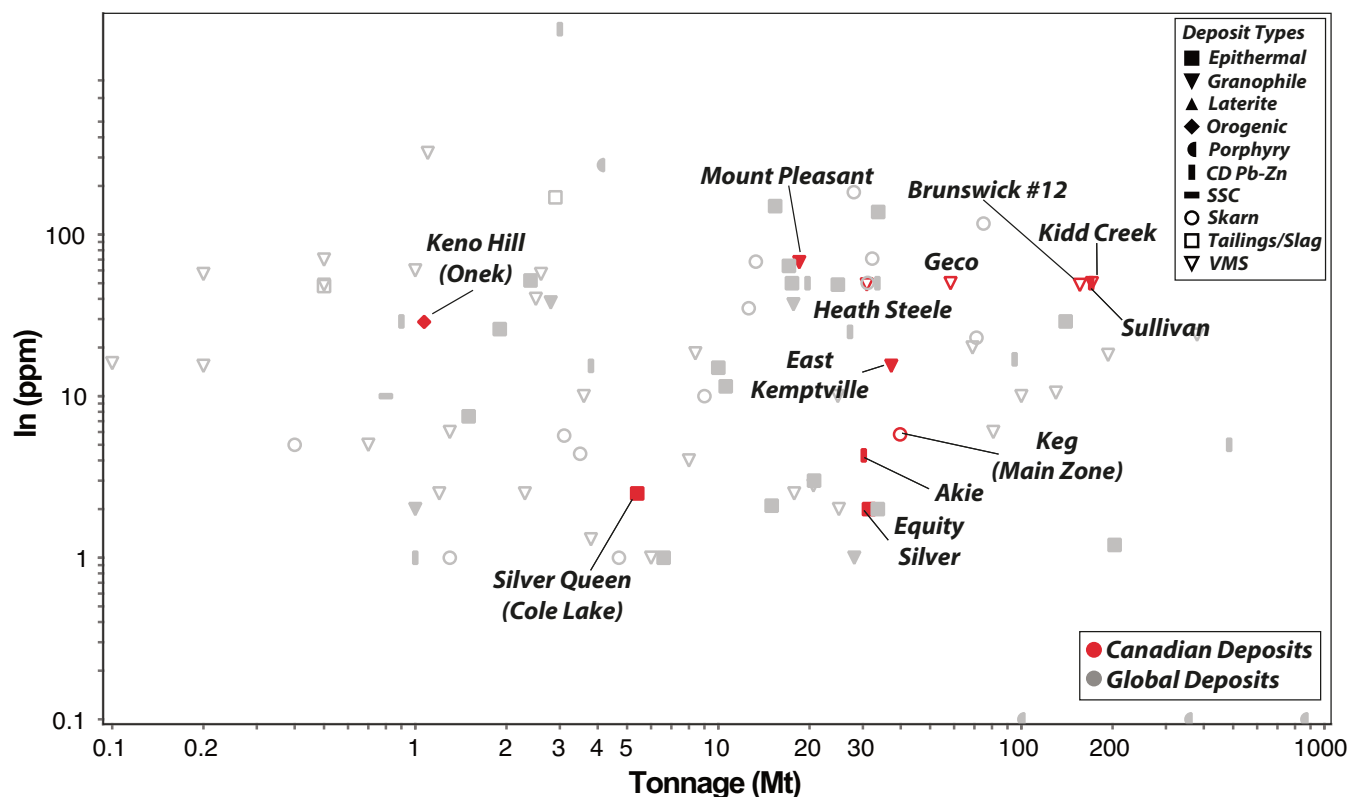


Fig. 3. Grade tonnage plot of In in various mineral deposit types. It is very rare to have In data defined in resources for mineral deposits, thus requiring an assumption of tonnes and grade by proxy. The results presented herein are those that have been inferred by proxy from [Werner et al. \(2017b\)](#) using the method of [Werner et al. \(2017a\)](#). These results are not National Instrument 43-101 (NI-43-101) compliant, are estimates, and to be considered informational only.



much lower abundances given its incompatibility in most silicates ([Gion et al. 2018](#); [Xu et al. 2020](#)). There are ~15 minerals that contain In, most of which are sulfides, with

roquesite (CuInS_2) being the most naturally abundant phase ([Schwarz-Schampera and Herzig 2002](#); [Schwarz-Schampera 2014](#); [Mejías et al. 2023](#)). Indium most readily substitutes into

sphalerite, and to a lesser extent Sn-phases (e.g., stannite, cassiterite, and k sterite), chalcopyrite, and tennantite (Cabri et al. 1985; Schwarz-Schampera and Herzig 2002; Cook et al. 2011; Schwarz-Schampera 2014; Bauer et al. 2017; Cacho et al. 2019; Xu et al. 2020). Within sphalerite, In occurs both in the lattice and potentially as nano-inclusions within sphalerite (Cook et al. 2009); however, the importance of nano-inclusions may not be as important as previously thought (Bauer et al. 2017). Substitution of In in sphalerite occurs via coupled substitution of In^{3+} with other cations (e.g., $\text{In}^{3+} + \text{Cu}^+ = 2 \text{Zn}^{2+}$); as direct substitution of In^{3+} for Fe^{3+} in chalcopyrite (CuFeS_2), stannite ($\text{Cu}_2\text{FeSnS}_4$), and k sterite ($\text{Cu}_2(\text{Zn}, \text{Fe})\text{SnS}_4$); and as a coupled substitution of $\text{In}^{3+} = \text{Cu}^+ + 0.5\text{Sn}^{4+}$ in stannite (Ohta 1989; Cook et al. 2009; Xu et al. 2020; Mej  as et al. 2023; Tor  o et al. 2023).

There is remarkably little thermodynamic and mineral solubility data for In, particularly at higher temperatures (e.g., Seward et al. 2000; Wood and Samson 2006). Despite this, In can be transported in a variety of complexes, but hydroxide and chloride complexes (and OH-chloride complexes) seem to be the most relevant to hydrothermal ore deposits (Seward et al. 2000; Wood and Samson 2006; Huston and Bastrakov 2024; Zhao et al. 2024). In the absence of other ligands (e.g., Cl), In can be transported as hydroxide complexes, with $\text{In}(\text{OH})_3^0$ and $\text{In}(\text{OH})_4^-$ being the most important species from 25 to 300  C (Wood and Samson 2006). In addition, chloride complexes are also important, including InCl_2^{2+} , InCl_2^+ , InCl_3^0 , with the latter being the most important species at low pH in chloride-rich solutions (e.g., Seward et al. 2000; Wood and Samson 2006; Huston and Bastrakov 2024). Huston and Bastrakov (2024) also showed that the high temperature ($T > 150$  C) solubility relationships for In_2S_3 , a proxy for In-bearing sulfide minerals due to the lack of solubility data for other In-bearing phases (e.g., CuInS_2), involves InCl_3^0 as the dominant species at $\text{pH} < 4$ and $\text{In}(\text{OH})_3^0$ as the dominant species at $\text{pH} > 4$; this speciation is likely important for VMS, sediment-hosted Zn–Pb, and some magmatic–hydrothermal systems. Further, Zhao et al. (2024) showed that at magmatic–hydrothermal conditions (800  C, 150 MPa, $f\text{O}_2$ at Ni–NiO buffer) that $\text{In}(\text{OH})_2\text{Cl}$ dominates in low HCl fluids and $\text{In}(\text{OH})\text{Cl}_2$ dominates in high HCl fluids, which may be relevant in high temperature magmatic–hydrothermal systems. Considering the above, there is clearly a need for considerable experimental work on In transport under mineral deposit forming conditions.

Geological setting and In resources in a Canadian context

Indium is known in numerous deposit types in Canada, including clastic-dominated sediment-hosted (CD) Zn–Pb, volcanogenic massive sulfide (VMS), and magmatic–hydrothermal deposits (Figs. 3 and 4). Despite being present in, and in some cases produced from, these deposits there is very little information on the nature of In mineralization, production statistics, grades and tonnes, and mineral residence in Canadian deposits. Despite this uncertainty, grade and tonnage estimates for In in various deposits are outlined in Table 1. The majority of grade and tonnage data

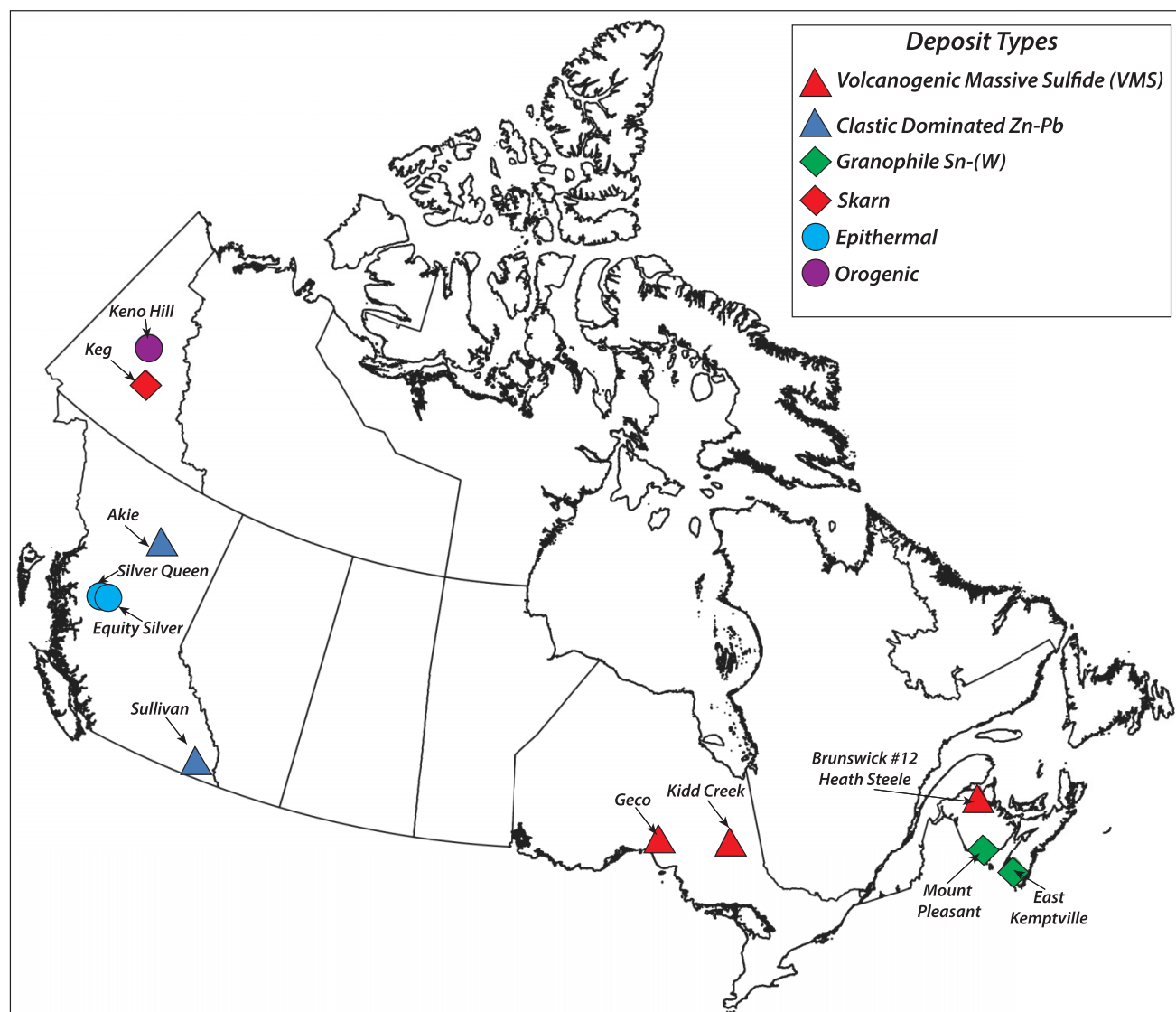
have been obtained from Werner et al. (2017b) and from Schwarz-Schampera and Herzig (2002), most of which involve In grades and tonnes estimated by proxy. We have used some the data from these authors, but where appropriate updated commodity grades and tonnages to more recent sources where appropriate. Details on our methodology and approach is outlined in Appendix A.

Clastic-dominated sediment-hosted deposits

Clastic-dominated sediment-hosted Zn–Pb deposits are stratiform to stratabound deposits hosted in ancient sedimentary basins (Large et al. 2005; Goodfellow and Lydon 2007; Leach et al. 2010; Wilkinson 2014). They form in extensional basins in rifted continental margins, intra-cratonic environments, and/or extended continental back-arcs, with mineralization spatially associated with and hosted within variably carbonaceous and calcareous mudstones, turbiditic sedimentary sequences, and in some cases minor mafic ($\pm$ felsic) volcanic and intrusive rocks (Fig. 4; Large et al. 2005; Goodfellow and Lydon 2007; Leach et al. 2010; Wilkinson 2014). These deposits generally form from low temperature, hydrothermal fluids with temperatures of ~ 200  C or lower, albeit with exceptions, with the fluids being modified basin-derived sedimentary brines (Large et al. 2005; Goodfellow and Lydon 2007; Leach et al. 2010; Wilkinson 2014). These brines are dense and are interpreted to have sunk down extensional faults, leached metals from the underlying rocks in the sedimentary sequence and basement (Fig. 5), which resulted in metal-rich brines where the Zn, Pb, and other commodities are transported as chloride complexes in solution (e.g., ZnCl_2 , PbCl_2) (Large et al. 2005; Goodfellow and Lydon 2007; Leach et al. 2010; Wilkinson 2014). The association of In with Zn in these deposits suggests In was also transported as a chloride complex (InCl_3^0) or a hydroxide complex ($\text{In}(\text{OH})_3^0$) depending on pH of the fluids (Wood and Samson 2006; Huston and Bastrakov 2024). The brines typically become hotter as they transit the crust downward and subsequently move upwards along syn-sedimentary faults due to buoyancy relative to the surrounding lithosphere (Large et al. 2005; Goodfellow and Lydon 2007; Leach et al. 2010; Wilkinson 2014). Sulfides are deposited from these fluids when they interact with reduced sulfur as H_2S either in the ambient water column in the bottom of the ocean (e.g., Goodfellow and Lydon 2007), and/or in the subsurface by interacting with H_2S in sediment or via replacement of SO_4 -bearing rocks in the presence of methane (CH_4) derived from organic material in the sedimentary sequence (e.g., Magnall et al. 2020; Fig. 5).

In Canada and globally, these deposits have been primarily producers of Zn and Pb, with subordinate Cu, Ag, Au, and Sn (e.g., Goodfellow and Lydon 2007). Numerous Canadian CD deposits have produced Zn and Pb, but the Sullivan Deposit, British Columbia, is the only deposit that produced In (Hamilton et al. 1982). Hamilton et al. (1982) noted a sample concentrate with an average concentration of 14.6 ppm In, and Schwarz-Schampera and Herzig (2002) estimated the average concentration of In in ore at Sullivan to be 50 ppm, likely hosted in sphalerite, which had concentra-

Fig. 4. Distribution of Canadian deposits and deposit types with reported In. Base map of Canada obtained from shape files from Natural Resources Canada GeoGratis database (<https://www.geogratis.gc.ca>).



tions of In ranging from 19 to 93 ppm (Yi et al. 1995; Schwarz-Schampera and Herzig 2002).

While not having produced, the Akie (also known as the Cardiac Creek deposit) CD Zn–Pb deposit in northern British Columbia, is suggested to have potential In in some sulfide zones. Johnson (2011) noted that the sulfide mineralogy of the deposit, while dominated by pyrite, barite, sphalerite, and galena, also had occurrences of stannite, and assay data from the deposit had had enrichments in Pb, Zn, Ag, Ba, Fe, Cd, Sn, Tl, Hg, S, Pd(?), In, and Ga. Using these data, Werner et al. (2017b) estimated by proxy that the deposit had potentially 68.2 Mt of mineralization with 4.3 g/t In (Table 1).

Volcanogenic massive sulfide deposits

Volcanogenic massive sulfide (VMS) deposits are important producers and past producers of Zn, Pb, Cu, and in some cases Au and Ag, in Canada and globally (Galley et al. 2007; Piercey et al. 2015). These deposits are hosted in submarine volcanic

and volcano-sedimentary sequences in rifted arc, continental margin rift, and back-arc rift assemblages, and are spatially and genetically associated with magmatic activity, and are the ancient equivalents of modern day seafloor massive sulfides (Franklin et al. 2005; Galley et al. 2007; Hannington 2014). Within these rift environments, magmatic heat drives the circulation of SO_4 - and Cl-bearing seawater through the crust, which heats up and leaches metals and reduced sulfur from the underlying substrate. Additionally, seawater SO_4 is also reduced to H_2S due to reaction of the fluid with rock, resulting in a fluid that is rich in metal chlorides (e.g., ZnCl_2 , PbCl_2 , FeCl_2 , CuCl_2) and H_2S (Large 1992; Ohmoto 1996; Franklin et al. 2005). Given the low pH and Cl-bearing nature of the fluids in VMS/SMS deposits, In was likely also transported as a chloride complex (e.g., InCl_3^0) in VMS settings (Fig. 6). This fluid then rises along syn-volcanic and/or syn-sedimentary faults and when it mixes with seawater, there is precipitation of pyrite, sphalerite, galena, chalcocopyrite,

Table 1. Resource data for Canadian indium-bearing deposits compared to global deposits (from [Werner et al. 2017b](#)).

Deposit	Province/ territory	Latitude	Longitude	Deposit status	Tonnage (Mt)	In (g/t)	Contained In (t)	Zn (%)	Sn (%)	Ag (g/t)	Au (g/t)	Pb (%)	Cu (%)	Deposit type	Notes
Akie	British Columbia	57.377	−124.8586	Developed prospect	30.2	4.3	130	5.2		9		1		Clastic- dominated Zn–Pb	In grade determined by proxy and from Werner et al. (2017b) and other resource data from NI-43-101 resource of Makarenko et al. (2018) .
Sullivan	British Columbia	49.68333	−116	Past producer	170	50	8500	12		128.7		11.2		Clastic- dominated Zn–Pb	In grade determined by proxy and from Werner et al. (2017b) and Schampera and Herzig (2002) . Other resource data include historic production and reserve data (now exhausted) from Goodfellow and Lydon (2007) .
Silver Queen (No. 3-NG3 and Camp vein)	British Columbia	54.0833	−126.7161	Past producer and current resource	5.4	2.5	14	2.92		181.2	1.7	0.62	0.23	Epithermal	In grade determined by proxy and from Werner et al. (2017b) and other resource data from NI-43-101 resource of Stone et al. (2022)
Equity Silver	British Columbia	54.1894	−126.2633	Past producer	31.42	2	63			4.2				Epithermal	In grade determined by proxy and from Werner et al. (2017b) and other resource data are historic data Taylor (2007) .
Keno Hill—Onek	Yukon	63.9097	−135.3003	Past producer and current resource	1.07	28.8	31	10.3		193.8	0.29	1.55		Orogenic	In grade determined by proxy and from Werner et al. (2017b) and other resource data including past production data and NI-43-101 resource data from Tarighi et al. (2021) .
Mount Pleasant (North Zone)	New Brunswick	45.44222	−66.82	Past producer	18.5	67.4	1247	0.8	0.3				0.1	Granophile	In grade determined by proxy and resources were NI-43-101 compliant—both in Werner et al. (2017b)
East Kemptville (Main and Baby Zones)	Nova Scotia			Past producer	37.22	15.4	573		0.15					Granophile	In grade by proxy and from Werner et al. (2017b) and other resource data are NI-43-101 compliant resource from Gowans et al. (2018) .
Keg (Main Zone)	Yukon	44.10306	−65.68083	Developed prospect	39.8	5.8	231	0.8	0	30.3		0.3	0.2	Skarn	In grade determined by proxy and resources were NI-43-101 compliant—both in Werner et al. (2017b)
Brunswick 12	New Brunswick	47.47889	−65.8922	Past producer	156	48.8	7613	8.6		204.4		3.41	0.37	VMS	In grade determined by proxy from Werner et al. (2017b) and resource data are historic production + reserves from Walker et al. (2022) .
Heath Steele	New Brunswick			Past producer	30.9	49.1	1517	5.5		71.2		1.95	0.9	VMS	In grade determined by proxy from Werner et al. (2017b) and resource data are historic production + reserves from all zones of the deposit (ACD, B, C, E, N5 + Stratmat Boundary, West Grid zones) from Walker et al. (2022) .
Kidd Creek	Ontario	48.69	−81.36667	Producing mine	170.98	50	8549	5.88		77		0.22	2.25	VMS	In grade determined by proxy from Werner et al. (2017b) and resource data are historic production + resources and reserves from Hanington et al. (2018) .
Geco/Manitouwadge	Ontario	49.1668	−85.76656	Past producer	58.4	50	2920	3.45		50		0.15	1.86	VMS	In grade determined by proxy from Werner et al. (2017b) and historic resource data from Galley et al. (2007) .

Note: Sources of data and information are noted in the table. Additional information is provided in [Appendix A](#). VMS, volcanogenic massive sulfide.

Fig. 5. Genetic model for clastic dominated (CD) sediment-hosted Zn–Pb deposits. These deposits form from circulating basinal brines that leach metals from the underlying continental crust and sedimentary rocks. Indium is interpreted to have been derived from the underlying continental crust and sedimentary package, potentially from black shales/organic-rich mudstones and/or metamorphosed equivalents in the continental crust. Diagram modified from Goodfellow and Lydon (2007) and influenced by the concepts of Magnall et al. (2020).

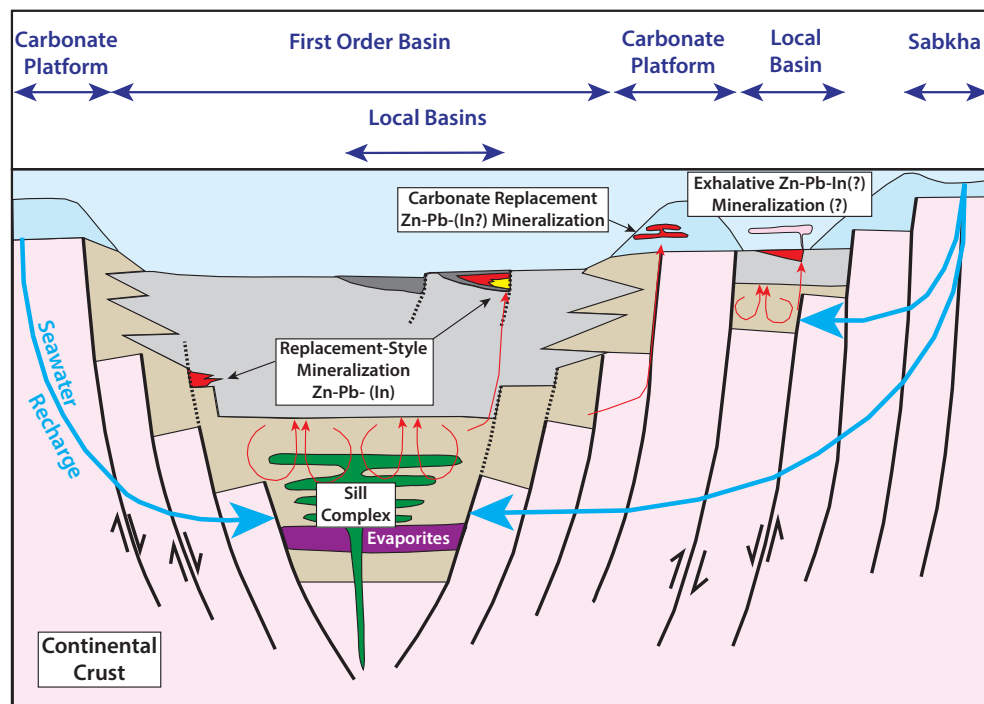
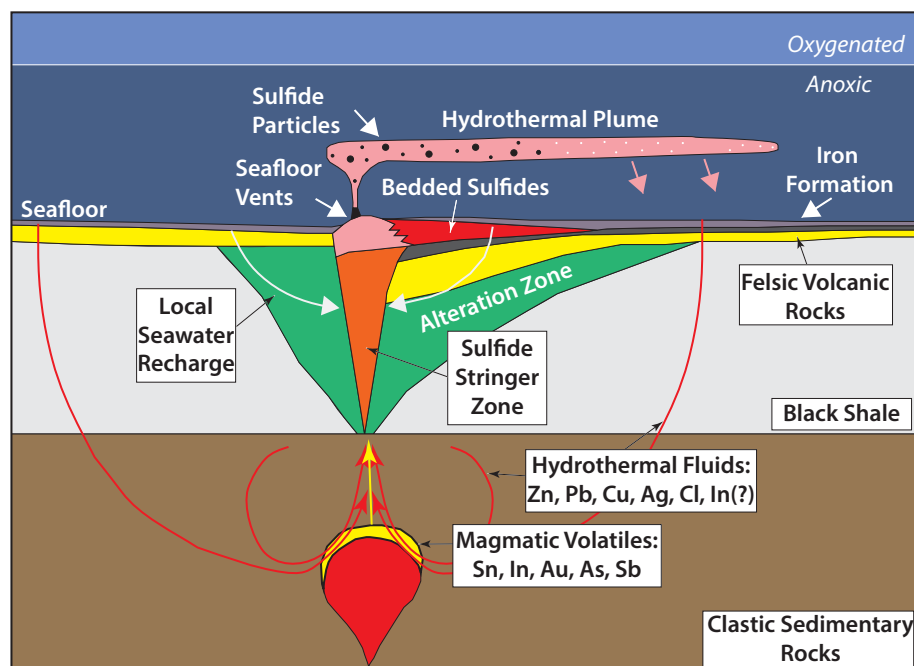


Fig. 6. Genetic model for polymetallic volcanogenic massive sulfide (VMS) deposits in sediment-rich volcanic basins that are commonly host to In-rich VMS deposits based on the genesis of deposits in the Bathurst Mining Camp, New Brunswick. The In in these deposits is interpreted to have been leached from underlying continental crust and sedimentary rocks, potentially from black shales/organic-rich mudstones and/or metamorphosed equivalents in the continental crust, as well as potentially coming from magmatic–hydrothermal fluids emanating from degassing magmas. Diagram modified from Goodfellow (2007).



and other sulfide phases on the seafloor and/or in the shallow subsurface (Fig. 6; Large 1992; Ohmoto 1996; Franklin et al. 2005). In some cases, the magma chambers underlying these deposits emanate magmatic fluids into the seawater dominated hydrothermal system resulting in enrichments in magmatic–hydrothermal elements (e.g., Ag, As, Au, Bi, In, Sb, Se, Sn, and Te), and this appears to be important in some deposits that have enrichments in In (Fig. 6; Sillitoe et al. 1996; Hannington et al. 1999d; Mercier-Langevin et al. 2010; Hannington 2014).

Indium has been reported from several Canadian VMS deposits. The Archean Kidd Creek deposit in Ontario, produced In at the Kidd Creek smelter up to 2010 when the smelter closed (Schwarz-Schampera 2014). The Cu-rich ores at Kidd had concentrations of ~75 ppm In (Hannington et al. 1999c), and the mine produced ~50t In annually with average concentrations of 270 ppm In in the Zn concentrates (Jorgensen and George 2005; Pinto et al. 2014; Schwarz-Schampera 2014; Paradis 2015). There is a strong association of In with Cu in the Kidd Creek deposit with In enriched in chalcopyrite-rich ores immediately above the Bornite zone of the deposit, which has up to 850 ppm In, the South orebody has 300–400 ppm In, and the North and Central ore bodies have ~250 ppm In. In all areas, roquesite is a trace phase and the highest grades of In are associated with massive and to a lesser extent, stringer chalcopyrite mineralization; In is present in bornite-rich mineralization but has lower concentrations compared to chalcopyrite-rich ores (Hannington et al. 1999a, 1999b). Unlike many deposits where sphalerite is the main host for In, at Kidd Creek chalcopyrite-rich mineralization hosts approximately 70% of the In in the deposit; however, some In is associated with stannite and sphalerite, and In is associated with a distinct element suite, including Bi, Cu, Co, Se, Sn, ±Ni, a typical suite of elements that precipitate from high temperature (>300 °C) fluids in VMS deposits (Cabri et al. 1985; Hannington et al. 1999a). Hannington et al. (1999a) noted that the association of In with Cu suggested high temperature emplacement, and they also noted the Cu–In–Sn associations was like some magmatic–hydrothermal deposits, inferring a potential input of In (and Sn and Cu) from magmatic–hydrothermal fluids, rather than from substrate leaching alone.

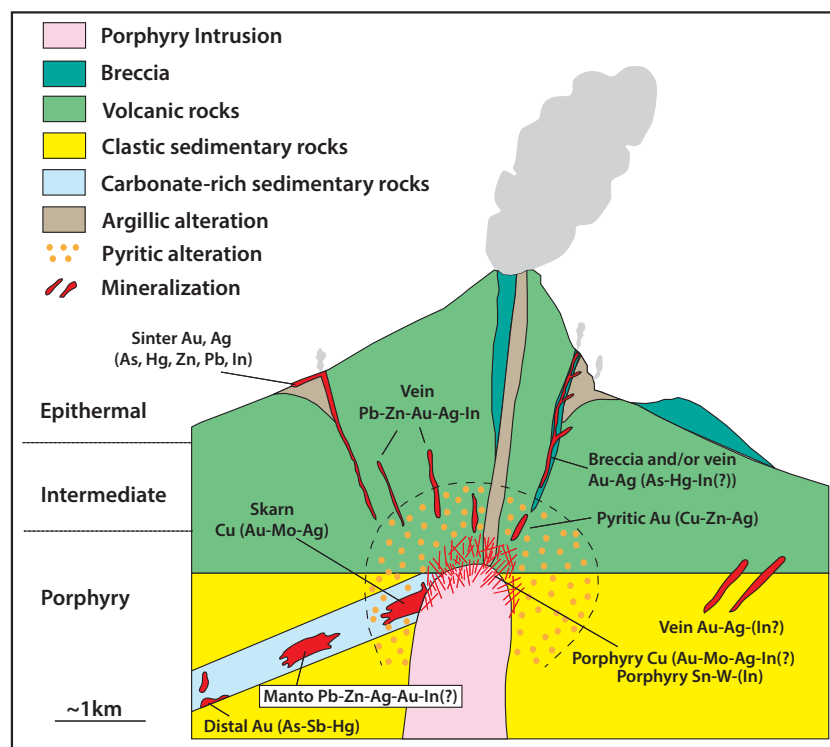
The deposits of the Brunswick and Heath Steele belts in the Bathurst Mining Camp (BMC), New Brunswick, have also produced In until the closure of mines in 1990s–2010s (Chen and Petruk 1980; Goodfellow 2007; Goodfellow and McCutcheon 2003; Petruk and Schnarr 1981). Deposits are associated with four horizons in the camp, from stratigraphically lowest to highest, the Chester, Caribou, Brunswick, and Stratmat horizons (Goodfellow and McCutcheon 2003; Goodfellow et al. 2003). In the Brunswick belt, deposits are zoned with Cu-rich mineralization (associated with Co, Bi) in the cores of deposits and Zn-rich mineralization (associated with Ag, Au, Cd, Sn, In, As, Sb, Tl, and Hg) towards the outer parts of the deposits, with In specifically associated with Zn- and sphalerite-rich mineralization (Goodfellow and McCutcheon 2003; Goodfellow et al. 2003). Indium has its highest concentrations in the bedded sulfide ores in the Brunswick #12 and

#6 deposits (0–590 ppm with average In = 37 ppm), but is also present in the deposits of the Heath Steele belt, and the Key Anacon and Halfmile Lake deposits (Goodfellow and McCutcheon 2003). Metallurgical studies of concentrates sent to the Heath Steele Mill from the Heath Steele deposits noted that In was associated with Zn/sphalerite-rich concentrates, where sphalerite had enrichments in In, Cd, and Hg, and contained inclusions of pyrite, chalcopyrite, magnetite, and stannite (Chen and Petruk 1980). Chen and Petruk (1980) also noted that In was found in the chalcopyrite concentrate and was associated with some unidentified In-bearing phase. Additionally, they noted that the Zn concentrates had the highest concentrations of In with 390 ppm, whereas the Cu concentrate had 180 ppm In, and that 51.4% of In reported to the Zn concentrate, 10.5% reported to the Cu concentrate, ~2.3% reported to the Pb concentrate, and ~35.8% reported to the tailings (Chen and Petruk 1980).

A similar study was performed by Petruk and Schnarr (1981) in the Brunswick smelter materials from the Brunswick #12 and #6 deposits. Similar to the Heath Steele study, the In is associated with sphalerite (~0.03% In in sphalerite) and ~78% was associated with the Zn concentrate, whereas some In was in chalcopyrite with 2% In reporting to the Cu and Pb concentrates, and ~20% reporting to the tailings. In a mineralogical study of the Brunswick #12 deposits, McCleneghan et al. (2009) noted that sphalerite contained ~76 ppm In and was associated with enrichments in Mn, Cd, Hg, Ag, and As, and pyrite had minor enrichments in In that were associated with Cd; they suggested that there were likely inclusions of In-bearing sphalerite in the pyrite. McCleneghan et al. (2009) noted that the high In values in pyrite were also associated with Sn, explaining, in part, the correlations between In–Sn–(Bi) in bulk rock data for the ores, which is similar to the Sn–In correlations noted by Goodfellow and McCutcheon (2003) for ores throughout the BMC. Goodfellow and McCutcheon (2003) also illustrated a strong correlation between Sn, and by proxy In, and size of deposits in the BMC, and argued magmatic fluids were likely responsible for the sizes of the deposits, as well as In–Sn-enrichment. Moreover, they argued that the base metals in the deposits like Cu, Zn, and Pb, were likely derived from leaching footwall rocks, whereas enrichments in In, Sn, Au, As, and Sb, were likely derived from magmatic–hydrothermal fluids, similar to what was proposed for the Kidd Creek deposit.

Indium has also been documented in the Archean Geco deposit, Ontario (Friesen 1982), but whether it was produced from in the deposit is uncertain. Schwartz-Schampera et al. (2002) estimated that the deposit contained ~50 ppm In in the ores, whereas Werner et al. (2017b) estimated that there was 58.3 Mt of ore and 2920 t contained In in the deposit. Cabri et al. (1985) studied a head sample of ores from the Geco mine and showed that sphalerite in the concentrate was the main repository of In and contained ~31–329 ppm In, whereas lesser In was found in chalcopyrite (39–78 ppm In). Although the relationship between In and Sn in the deposit is uncertain, there were Sn-rich phases found in the deposit (cassiterite, stannite, h  gbomite, and nigerite), and that there is an intimate association of Sn minerals with Cu and

Fig. 7. Genetic and descriptive models for magmatic–hydrothermal systems, including porphyry Cu–Mo and Sn–W, epithermal Au–Ag, and skarn/manto/carbonate-replacement Zn–Pb–Ag–Au systems. Indium in these deposits is interpreted to have been derived from magmatic–hydrothermal fluids that have emanated from intrusions/magma chambers underlying these deposits. Diagram modified from Sinclair (2007).



Zn (Petersen 1986). Given In is found in both sphalerite and chalcopyrite, it would be reasonable to assume that Sn–In are associated with one another, like other deposits globally, and were introduced together during VMS formation processes (Petersen 1986).

Magmatic–hydrothermal associated deposits

Magmatic–hydrothermal associated deposits are important global sources of Cu, Mo, Sn, W, as well as Li, Cs, Rb, Nb, Ta ($\pm$ REE) and are typically associated with convergent margin “arc” environments, be they continental or oceanic arcs (Richards 2003; Sillitoe 2010). Magmatic–hydrothermal deposits form from the precipitation of metals from fluids and vapours that originated from a magma, and include porphyry Cu–Mo–Au, granophile Sn–W–(Li–Cs–Ta–Nb–REE), epithermal Au–Ag, and skarn/carbonate-replacement Zn–Pb–(Cu) deposits (Fig. 7) (Cooke et al. 2005; Simmons et al. 2005; Williams-Jones and Heinrich 2005; Sinclair et al. 2006; Sinclair 2007; Sillitoe 2010). In most cases, there is a fractional crystallization of magmas, emanation of an incompatible fluid phase and, depending on the depth, this fluid may separate into a vapour and brine (e.g., Williams-Jones and Heinrich 2005). The single-phase fluid, brines, and vapours can carry various metal ligands as both chloride (e.g., CuCl_2 , SnCl^+) and, in the case of vapours, as hydrated chloride complexes (e.g., $\text{CuCl}_2 \cdot \text{H}_2\text{O}$) (Williams-Jones and Heinrich 2005); it is assumed that In in these systems is transported as a chlo-

ride complex (e.g., InCl_3^0) or a similar hydrated complex (e.g., $\text{In}(\text{OH})_2\text{Cl}$ or $\text{In}(\text{OH})\text{Cl}_2$; Zhao et al. 2024). In contrast, sulfur occurs as aqueous SO_4 , SO_2 gases, and or reduced aqueous/gaseous H_2S depending on $f\text{O}_2$ and P–T conditions; notably, SO_4 and SO_2 in the presence of H_2O will disproportionate into H_2S and H_2SO_4 with cooling ($\pm$ condensation), providing the necessary H_2S to form sulfide minerals found in many magmatic–hydrothermal deposits (Rye 1993; Sillitoe 2010).

Porphyry or granophile Sn–W deposits are important hosts to In in Canada in the Mount Pleasant and East Kempville deposits in New Brunswick and Nova Scotia, respectively. The Late Devonian Mount Pleasant deposit consists of Sn–In–base metal mineralization in sulfide-rich veins, breccias, and replacement zones in both granitic and wall rocks to a late phase of the Mount Pleasant Intrusive Complex (Sinclair et al. 2006). The In is most enriched in eruptive rocks in the North Zone of the Mount Pleasant Intrusive Complex, and one of the most significant deposits is the Upper Deep Tin Zone, which is 1.7 Mt with 280 g/t In, 0.68% Sn, 2.26% Zn, 0.29% Cu (Sinclair et al. 2006). Indium at Mount Pleasant is associated primarily with sphalerite, chalcopyrite, arsenopyrite, and cassiterite, along with other sulfides and sulfosalts, including Sn–Bi–Sb–As-bearing phases (Sinclair et al. 2006). The In is primarily hosted in sphalerite (<0.01–6.90 wt.%) and to a lesser extent chalcopyrite (0.01–0.40%); In also occurs in roquesite (Sinclair et al. 2006). The association with greisen

veins and breccias and spatial association with magmatic rocks has led workers to argue a porphyry Sn/greisen-type origin for In. Specifically, [Sinclair et al. \(2006\)](#) argued that the Sn–In–base metal enrichment and precipitation occurred from mixing between exsolved magmatic–hydrothermal fluids from a late phase of the Mount Pleasant Intrusive suite and meteoric fluids.

The ~380 Ma Devonian East Kemptville deposit is hosted within the East Kemptville muscovite leucogranite and has previously produced 21 000 t of Sn from 1985 to 1992, and since 2006 has been the focus of exploration and development by Avalon Advanced Materials Inc. ([Gowans et al. 2018](#)). The East Kemptville deposit contains the Main and Baby zones that [Werner et al. \(2017b\)](#) has estimated contains 80.5 Mt with 15.4 g/t In, which is ancillary to a primary Sn resource ([Gowans et al. 2018](#)). The mineralization consists of greisen-type mineralization that is dominated by quartz–topaz and quartz–muscovite greisens, as well as quartz–topaz–sulfide veins, which cut the greisens, and locally breccias at granite-metasedimentary rock contacts ([Willson 2019](#)). The greisens have veins and selvages that contain cassiterite, wolframite, arsenopyrite, sphalerite, chalcopyrite, pyrrhotite, and stannite. Cu-rich assemblages also have an unnamed Zn–In mineral that is rimmed by sphalerite, whereas the quartz–sulfide veins are sphalerite dominated with lesser chalcopyrite, pyrrhotite, pyrite, stannite associated with fluorite, siderite, triplite, and albite ([Willson 2019](#)). In East Kemptville, In is associated with cassiterite (1–23.6 ppm), wolframite (3.2–14.8 ppm), sphalerite (700–12 300 ppm, average = 2200 ppm with In correlated with Cu concentrations in the various mineral phases), chalcopyrite (100–1400 ppm, average = 600 ppm), and stannite (up to 3300 ppm; [Willson 2019](#)). There is also an unnamed Zn–In mineral with an average concentration of In ~18%; this mineral has a composition that is intermediate between sphalerite (ZnS) and roquesite (CuInS₂) ([Willson 2019](#)). [Bickerton \(2021\)](#) also noted that fluid inclusions from the East Kemptville deposits contained In (0.5–2 ppm), along with Sn, Cu, Fe, and S. Both [Halter et al. \(1998\)](#) and [Bickerton \(2021\)](#) argued that in the East Kemptville deposit Sn–In were derived from magmatic fluids generated by the East Kemptville muscovite leucogranite with deposition of mineralization caused by fluid reaction with wall rock, as well as mixing with external meteoric fluids.

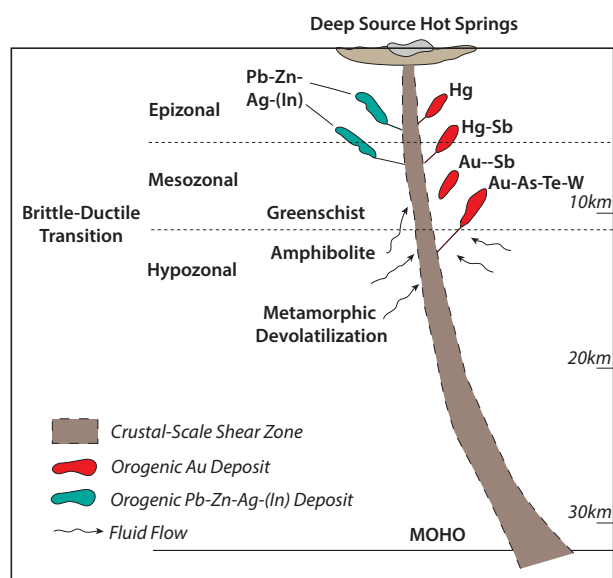
The Equity Silver deposit was the largest producing Ag mine in British Columbia and produced >2 Moz of Ag from 1980 to 1984 ([Jones et al. 1998](#)). The deposit is interpreted to be a high-sulfidation epithermal deposit and is hosted within sedimentary, pyroclastic, and volcanic rocks of the Cretaceous Skeena Group and spatially associated with Eocene (57–48 Ma) volcanic and intrusive rocks ([Cyr et al. 1984](#); [Wojdak and Sinclair 1984](#)). The deposit is hosted specifically in a pyroclastic unit within the Skeena Group and mineralization is interpreted to have formed from magmatic–hydrothermal fluids derived from Eocene magmatic rocks ([Cyr et al. 1984](#)). The mineralization consists of tabular zones of Cu–Ag–Sb–sulfides and sulfosalts that are parallel to stratigraphy and contain disseminated mineralization, open-space fracture fillers, veins, and crackle breccia zones that are spatially associated with an advanced argillic alteration assemblage that

consists of andalusite, corundum, pyrite, quartz, tourmaline, and scorzalite ([Cyr et al. 1984](#)). Mineralization consists of pyrite, arsenopyrite, chalcopyrite, and tetrahedrite that are associated with veins that have low salinity and were deposited at temperatures between 400 and 200 °C, consistent with deposition from magmatic fluids ([Cyr et al. 1984](#)). There are only scant references to In in the deposit, but [Yi et al. \(1995\)](#) noted that tetrahedrite from the deposit contained 428.20 ppm In and [Schwartz-Schampera and Herzig \(2002\)](#) estimated the deposit contained 31.42 Mt grading 2 g/t In.

The Silver Queen deposit is considered a potential correlative to the Equity Silver deposit and had historic production 1981–1994 and produced 2.2 billion grams of Ag as well as 84 086 kg of Cu and 15.80 million g of Au ([Jones et al. 1998](#)). The deposit is spatially associated with an interpreted resurgent caldera consisting of rhyolitic outliers and Eocene volcanic centres that are proximal to the deposits, which are hosted in the Late Cretaceous Top Hill volcanic rocks of the Kasalka Group within the Buck Creek Basin ([Leitch et al. 1990, 1992](#)). The stratigraphy near the Silver Queen deposit, from bottom to top, contains a basal conglomerate, fragmental lapilli tuffs and coarse lapilli tuffs and breccias, and are overlain by feldspar-bearing andesitic flows, and cut by ~78–75 Ma microdiorite and ~84.6 ± 0.2 Ma quartz-feldspar porphyry intrusions, which are all collectively cut by ~51.9–51.3 Ma pre- and post-mineral bladed feldspar porphyritic andesite dykes ([Leitch et al. 1990, 1992](#)). The mineralization occurs as a series of quartz–specularite veins that are up to 1–2 m across and locally contain massive pyrite, sphalerite, chalcopyrite, tennantite, argentian tetrahedrite, and locally in chalcopyrite-rich mineralization where there are Cu–Pb–Bi–Ag–sulfosalts that are spatially associated with propylitic alteration and vein-proximal pyrite–kaolinite alteration ([Hood 1991](#); [Leitch et al. 1990](#)). [Hood \(1991\)](#) noted that there were four paragenetic stages to mineralization including: (1) early fine pyrite, quartz, and hematite with barite, svanbergite, hidsalite, and marcasite; (2) stage 2 massive sphalerite with layered calcite; (3) stage 3 with a complex assemblage of chalcopyrite, galena, tetrahedrite–tennantite, electrum, quartz, and Pb–Bi–Cu–Ag sulfosalts including berryite, matildite, gustavite, and aikinite; and (4) stage 4 with fine quartz, pyrobitumen, and calcite. [Hood \(1991\)](#) noted that sphalerite was well layered and has enrichments in In (0.55–0.70 wt.%) along with Ga and Ge, with In enrichment particularly high where Fe-rich sphalerite is proximal to chalcopyrite. Further, [Hood \(1991\)](#) suggested that the In was introduced to the hydrothermal system in stage 3 Cu-rich fluids resulting in In (±Fe) exchange into the sphalerite from the Cu-rich fluids. He further suggested that the In, Ga, and Ge were derived from non-exposed organic-rich source rocks, but did not elaborate the rationale for why this was an important source for these critical minerals.

The Keg skarn/polymetallic vein deposit, Yukon ([Figs. 3 and 4](#)), is hosted within variable calcareous rocks of the Mississippian to Pennsylvanian Tay Formation and Mount Christie formations within the Selwyn Basin and is distal to Cretaceous (~100–95 Ma) granitic rocks of the Anvil Plutonic suite ([Giroux and Melis 2013](#); [Hart et al. 2004](#)). The deposit is a bulk tonnage Ag–Pb–Zn–Cu±Sn ± In prospect that has a NI-

Fig. 8. Genetic model for orogenic Ag–Pb–Zn vein systems and orogenic Au deposits. Hydrothermal fluids are generated during orogenic activity due to metamorphic dewatering of the crust with fluid movement along regional fault zones to various sites of deposition. It is assumed that In in these environments derived from the metamorphic fluids leaching In from continental crustal substrates and likely black shale/organic-rich mudstones and their metamorphosed equivalents. Diagram modified from Taylor and Hofstra (2025) after original concepts in Groves et al. (2019).



43-101 compliant inferred resource 39.76 Mt of 30.25 g/t Ag, 0.26% Pb, 0.77% Zn, 0.15% Cu, 265.7 ppm Sn, and 5.77 ppm In (Giroux and Melis 2013). The mineralization consists of fracture fill and skarn-replacement zones, as well as cross-cutting polymetallic veins that contain pyrrhotite with lesser sphalerite, chalcopyrite, pyrite, arsenopyrite, galena, and stannite (Giroux and Melis 2013). Metallurgical tests show that In is associated with Zn and reports to the Zn concentrates, with lesser In reporting to the Cu concentrate (Giroux and Melis 2013). The average Zn concentrate grades 43% Zn, 0.63% Pb, 0.90% Cu, 136 g/t Ag, 0.043% Sn, and 320 ppm In, whereas the Cu concentrate grades 27.2% Cu, 4.09% Pb, 4.08% Zn, 1458 g/t Ag, 1.99% Sn, and 150 ppm In (Giroux and Melis 2013). No mineralogical department studies were undertaken on the Keg deposit but based on the elemental associations above there appears to be both a Zn association with In and a Cu–Sn association, common to other In-bearing deposits outlined previous.

Orogenic deposits

There is considerable uncertainty regarding the origin of In in orogenic vein systems, but some deposits contain In associated with structurally controlled Zn–Pb–Ag vein mineralization. While there are different models for the formation of these deposits, the most common model involves the generation of metamorphic fluids associated with accretionary orogenesis (Fig. 8; Beaudoin and Sangster 1992; Beaudoin

et al. 1992; Taylor and Hofstra 2025; Conliffe and Piercey 2026). Fluids in these systems are generally weakly saline, CO₂–(CH₄)–bearing, and are interpreted to have been emplaced at temperatures between 250 and 400 °C, and most likely at 250–350 °C (Beaudoin and Sangster 1992; Beaudoin et al. 1992; Leach et al. 1988; Conliffe and Piercey 2026). The transport mechanisms for Zn, Pb, and Ag in these systems is presumed to be as chloro-complexes (e.g., ZnCl₂, PbCl₂, Ag[Cl[–]]₂; Reed and Palandri 2006) with precipitation being induced by fluid mixing, changes in pressure, and reaction with wall rocks (e.g., Beaudoin and Sangster 1992; Beaudoin et al. 1992). Given the association of In with Zn in these systems, it is assumed that In is also transported as a chloride complex (e.g., InCl₃⁰) or as a hydroxide complex (In(OH)₃⁰), depending on the pH and salinity of the fluids, with precipitation occurring coincident with base metal and Ag precipitation.

The Keno Hill district, Yukon, contained the richest Ag–Pb–Zn vein deposits in Canada and was the second largest producer of Ag in Canada historically, where >200 Moz of Ag was produced from 1913–1990 (Figs. 3–4; Cathro 2006); production has recently recommenced in this district. The district contains variably fault bounded blocks of the western Laurentian margin, including a lower block (Lower Schist) that contains meta-clastic rocks that have been correlated with the Devonian Earn Group of the Selwyn Basin, which is in thrust contact with a Central Quartzite package that is dominated by the Mississippian Keno Hill Quartzite, which itself is in thrust contact with an Upper Schist unit that contains meta-clastic rocks and localized rhyolitic sills that are correlated with the Neoproterozoic Hyland Group (Cathro 2006; Craggs 2022). The deposits in the Keno Hill district are hosted primarily in the Central Quartzite package, which also contains Triassic mafic sills, and Cretaceous felsic intrusive rocks; these intrusive rocks are also found in the other thrust sequences, as well (Cathro 2006; Craggs 2022). Mineralization is found predominantly within the Keno Hill Quartzite, and to a much lesser extent with Triassic mafic rocks, where these competent rocks are found and in contact with less competent rocks and proximal to D2, east–northeast striking sinistral strike-slip faults (Cathro 2006; Craggs 2022). The mineralization occurs in both longitudinal and transverse veins (Cathro 2006). The former are east striking and dip steeply to the north and are up to 5 m thick consisting of massive quartz with arsenopyrite, pyrite, jamesonite, and boulangerite (Cathro 2006). In contrast, the transverse veins are north to north–northeast trending with steep southeast dips and consist of manganiferous siderite with sphalerite, galena, Ag-bearing tetrahedrite, and jamesonite (Lynch 1989; Sack et al. 2003; Cathro 2006). Warren and Thompson (1945) noted trace In in sphalerite from the Keno Hill region, whereas Boyle (1965) noted no significant abundances of In in sphalerite, but local enrichments in Sn, which possibly reflect the limits of analytical methodologies of the time. Watson (1996) also noted native In in the Keno Hill deposits. Alexco Resource Corp., who explored the deposit from 2006 until its acquisition by Hecla Mining in 2022, previously reported numerous high grade Ag–Zn–In intersections with In enriched up between 155 and 701 ppm over intervals of 0.93–5.12 m, and a re-assaying campaign noted enrichments of >50 ppm over widths of 1 m in

25 of 36 drill holes from previous drilling at the Onek deposit (Alexco 2010). More recently, Hecla Mining Ltd. noted that the Inca vein has enrichments of In (1.6 ppm over 6.9 m and 0.9 ppm over 2.3 m) coincident with enrichments in Ag, Zn, and Pb (Lasley 2024). The association with Zn suggests In associations with sphalerite; however, there is insufficient publicly available data to determine the In residence in the Keno Hill deposits at present.

Synthesis—general geological and mineralogical controls on indium in Canadian mineral deposits

Despite In being found in many different geological environments and deposit types within Canada, there are some key features that transcend deposit type, location, and age. In most instances, In is associated with and/or hosted by sphalerite and Zn-rich materials, and to a lesser extent Cu- and Sn-bearing minerals. However, despite the sphalerite association In-enrichment is commonly associated with sphalerite that is spatially associated with Cu-rich minerals and Zn-(Sn)-rich assemblages that have been overprinted by Cu-rich fluids (e.g., Hannington et al. 1999a, 1999c; Sinclair et al. 2006; Willson 2019). In the case of VMS and magmatic-hydrothermal deposits there is also an association of In with magmatic-hydrothermal fluids and there is a common association of In with epithermal suite/magmatic-hydrothermal associated elements, such as Sn, W, Bi, Te, Au, Ag, As, and Sb (e.g., Hood 1991; Goodfellow et al. 2003; Sinclair et al. 2006; Goodfellow 2007). In some cases, In is specifically associated with magmatic-hydrothermal associated deposits and magmatic-hydrothermal fluids, but more work is required to evaluate the importance of In transport in magmatic-hydrothermal fluids and its role in In-enrichment in mineral systems.

There is also a secondary association with many In-bearing deposits being associated with black shales/organic-rich mudstones and evolved continental crust. For example, the deposits of the Bathurst Mining Camp are invariably associated with black shales both in the immediate ore-hosting stratigraphy but also found regionally in the rocks underlying the deposits (e.g., Goodfellow and McCutcheon 2003; Goodfellow 2007). Similarly, the host rocks and footwall rocks to both the Sullivan and Akie sediment-hosted Zn-Pb deposits, the immediate hosts and potential source rocks for mineralization are shales/organic-rich mudstones (Goodfellow and Lydon 2007). The Keno Hill deposits, while vein hosted, have associations with meta-clastic rocks that are variably graphitic (Cathro 2006), whereas Hood (1991) argued that the In in the Silver Queen deposit was likely derived from organic-rich sedimentary rocks. Despite this black shale/organic-rich mudstone association, there are many deposits that have such rocks, but not In enrichment, and it remains to be seen if this lack of In is due to a lack of data or if there are process-related reasons for the lack of In enrichment. Evaluating specific role of black shales/organic-rich mudstones and In-enrichment in various mineral deposit types is a fruitful area for research and a significant knowledge gap in our understanding of In enrichment in mineral deposits.

Potential targets for future indium resources in Canada

Most In in Canadian (and global) mineral deposits have been produced as a byproduct of conventional mining and is found in trace phases associated with variably Zn-Cu-Sn-enriched mineralization. To secure stable supplies of In for Canada in the future, it will require explorers and developers to find similar deposits to those outlined above, including similar deposit styles that have insufficient mineralogical or geochemical data for In but are geologically similar. Considering this, potential sources of future In in Canada may include:

- CD deposits: The Sullivan and Cirque deposits are clastic-dominated, sediment-hosted Zn-Pb deposits that contain In. It is possible, that other clastic dominated deposits in the Selwyn Basin or other basins in Canada may have In as a by-product; however, such deposits will likely show evidence for deposition from higher temperature fluids and unique metal associations. For example, in the Sullivan deposit, there are features that are atypical of many CD Zn-Pb deposits including abundant pyrrhotite, tourmaline breccia pipes, higher ore fluid temperatures (>250 °C), abundant Sn with Zn, and spatial association with mafic magmatism (Goodfellow and Lydon 2007). Future searches should look at deposits that have features like the above, including those that have been previously deemed Broken Hill-type deposits (Spry and Teale 2021).
- Carbonate-hosted Zn-Pb deposits: We have not noted any carbonate-hosted Zn-Pb deposits in Canada that contain In in this paper; however, it is possible that sub-types of these deposits may contain In. Most Mississippi Valley-type (MVT) and carbonate-hosted Pb-Zn deposits were deposited from low temperature fluids (e.g., $T < 200$ °C), but subsets of this deposit type, including Irish-type Zn-Pb, are interpreted to have been deposited from higher temperature (>300 °C) fluids given their association with elements that require higher temperatures to be transported (e.g., Ni, Co; Wilkinson 2014). Paradis (2015) also noted In enrichment in sphalerite from carbonate-hosted Zn-Pb mineralization in Robb Lake in British Columbia and Pine Point in the Northwest Territories, indicating the presence of In in some carbonate-hosted Zn-Pb in Canada. Future searches should focus on carbonate-hosted deposits that display evidence of deposition from higher fluid temperatures ($T > 250$ °C) and carbonate platformal rocks of the Appalachians, Cordillera, and in the Canadian Arctic should be considered as potential In target regions.
- VMS deposits: There are subsets of VMS deposits that have In and these appear to be those that have evidence for contributions from magmatic-hydrothermal fluids, Sn, and/or black shales in their footwall, mineralization hosting sequence, and regionally. We envision that future In resources in Canada may exist in districts that have already hosted In-bearing mineralization (e.g., Bathurst Mining Camp, New Brunswick), but also similar VMS districts in Canada where there are polymetallic, Zn-rich deposits with Cu($\pm$ Sn) associations (e.g., Finlayson Lake district,

Yukon; Victoria Lake Supergroup, Newfoundland and New Brunswick).

- **Magmatic–hydrothermal deposits:** There are clear associations with In and magmatic–hydrothermal deposits, including greisen, skarn, and epithermal Ag–Zn–Pb–Sn–In deposits. Indium is likely also present in other Canadian Sn skarns (e.g., JC deposit, Yukon; Ash Mountain occurrence, British Columbia), greisen Sn (e.g., Ackley batholith, Newfoundland), and epithermal Ag–Zn–Pb vein systems (e.g., Sulphurets district (?), British Columbia). Little information is available on In in porphyry Cu–(Mo) deposits in Canada, but given their high tonnages, any trace In could be potentially valuable and evaluation of porphyry Cu–(Mo)–skarn–epithermal systems in the Canadian Cordillera should also be considered.
- **Orogenic Ag–Zn–Pb vein deposits:** Some orogenic Ag–Zn–Pb vein systems like Keno Hill host In, as do similar deposits globally (e.g., Coeur d’Alene, Idaho; [Taylor and Hofstra 2025](#)). Similar vein hosted systems in British Columbia (e.g., Kokanee ranges and Belt–Purcell basin), Northwest Territories (e.g., Nonacho basin), Ontario (e.g., Port Coldwell veins), and Newfoundland (e.g., Sail Pond veins) have similar geological features to the Keno Hill deposits and may be potential future sources of In.
- **Other deposit types:** It is also possible that other mineral systems that have associations with black shale/organic-rich mudstones and/or magmatism/magmatic fluids, including five element vein deposits (e.g., Cobalt), unconformity-type uranium, and/or magmatic sulfide systems that have been contaminated by black shales, could potentially contain In, and should be evaluated.
- **Historic mine tailings:** Many past producing deposits described in the paper (e.g., Sullivan, Brunswick #12), and of Zn–Cu–Sn-bearing deposits of various types are mined out but have historic tailings. Past production from many deposits did not focus on critical minerals and it is possible that these processed wastes may provide potential future sources of In (e.g., [Mejías et al. 2023](#)).

A major challenge and knowledge gap for understanding In in Canada (and globally) is the lack of baseline information on In abundance, mineral residence in all deposit types, and In behavior during ore formation. Specifically, there is a lack of baseline geochemical data on various ores, host rocks, and metal source rocks, as well as a very poor understanding of In mineral residence and concentration variability in ore and accessory minerals. It will require significant investments in focused geochemical and mineralogical research on In in Earth materials to remedy this deficiency but is essential for finding the next generation of In resources needed for Canada.

Summary

Indium (In) is an important critical mineral used in liquid crystal displays, alloys, communications technology, optic lasers, solar/photovoltaic cells, and in control rods for nuclear energy. It is rarely a primary mined commodity and is a byproduct of Zn and Sn mining and is typically associated with Zn and Sn concentrates, often in 10 s of ppm concen-

tration. In Canada, In has been produced from or found in resources from clastic-dominated sediment-hosted Zn–Pb deposits (e.g., Sullivan mine), polymetallic volcanogenic massive sulfide deposits (e.g., Brunswick #12, Heath Steele, and Geco mines), magmatic–hydrothermal deposits (e.g., Mount Pleasant and East Kemptville greisen Sn deposits; Equity Silver and Silver Queen Ag–Pb–Zn deposits; Keg Ag–Zn–Pb–Sn–In skarn deposit), and orogenic vein deposits (e.g., Keno Hill deposits). In deposits where In occurs with Zn-rich mineralization, it is generally spatially associated with Cu within the mineralization, occurring as roquesite (CuInS_2) or as Cu–In nanoparticles within sphalerite. In the case of Sn-rich mineralization, it is also associated with roquesite, but also sphalerite, chalcopyrite, wolframite, and other Sn-phases (e.g., cassiterite and stannite). In general, In is associated with deposits that had evidence for magmatic–hydrothermal fluid/vapour input, including deposits with magmas that likely had continental crustal input, and/or with deposits that have strong associations with black shales/mudstones. Future resources will likely come from similar deposits as outlined above, but additional resources may be found in carbonate-hosted Zn–Pb deposits and porphyry Cu–Mo, epithermal, and granophile deposits, in addition to historic mine tailings. It will be essential to obtain better understanding of baseline geochemical and mineralogical distributions of In in rocks and minerals in historic and existing deposits if we are to secure future supplies of In from Canadian mineral deposits.

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Data availability

The data presented in [Figs. 1](#) and [2](#) can be obtained from the original sources quoted in these figure captions or from the author upon request. Data for [Fig. 3](#) are included in [Table 1](#).

Author information

Author ORCIDs

Stephen J. Piercey <https://orcid.org/0000-0002-1931-5745>

Stefanie M. Brueckner <https://orcid.org/0000-0002-0702-1037>

Author contributions

Conceptualization: SJP, SMB

Resources: SJP

Visualization: SJP

Writing – original draft: SJP

Writing – review & editing: SJP, SMB

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The authors have no competing interests.

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Appendix A

Given that In is a byproduct, it is rarely listed as an element that defines a resource and is estimated by proxy. [Werner et al. \(2017a\)](#) outline a methodology whereby they estimate In grades and tonnage in deposits by proxy using statistical comparisons to commodity elements in global geochemical databases, through comparisons between resource data and

inter-element ratios with In from said resource data, and the utilization of published In estimates for grades in given deposits using both bulk rock data and In residence in the minerals present in deposits. Within [Table 1](#) we utilize the estimates of In grades and where relevant the tonnage and other commodity element grades from [Werner et al. \(2017b\)](#). Where appropriate, for deposits that have had more recent NI-43-101 resource or reserve estimates, or for which there are updated production or historic resource data, we re-calculated the contained In using the tonnages from these updates using the In grades previously estimated by [Werner et al. \(2017b\)](#). Proxy estimates of In grade have considerable uncertainty and rely on significant assumptions; however, these provide the best estimates we have given the lack of grade-tonnage data for In in mineral systems. Even with these updates, until resources/reserves/production data are defined using In as a primary production commodity, grades and contained In results presented herein (and in the general literature) should be considered as best guess estimates and are highly subject to change with more robust resource updates.