GEOLOGICAL SURVEY OF CANADA

OPEN FILE 4668

A preliminary overview of Canada's mineral resources

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Geological Survey of Canada
Open File 4668

A preliminary overview of Canada's mineral resources

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INTRODUCTION

As part of the Geological Survey of Canada's effort to consolidate Canada's geoscience knowledge base and to make this information easily accessible via the internet (in accordance with the Federal Government's "Government-On-Line" policy), the CCGK Project X15 - *Consolidation and Synthesis of Mineral Deposit Knowledge* - is working towards a GIS-based information system of Canada's mineral resources. The purpose of the information system is to provide the key information on Canada's mineral resources at various levels of detail to satisfy the needs of technical decision makers (e.g. mineral explorationists, scientific researchers), non-technical decision makers (e.g. politicians, government planners) and the general public.

This Open File presents a sampling of some of the outputs that are possible at the current stage of development of the system, concentrating on a level of detail of interest to the non-technical decision maker. The contents of this Open File was first released as a poster display at the Mineral Exploration Roundup of the British Columbia and Yukon Chamber of Mines, 26th-29th January 2004 in Vancouver, and subsequently, after some modifications and additions, as a poster at the annual convention of the Prospector and Developers Association of Canada, March 7th-10th 2004 in Toronto. Although only intended as an interim product, the number of requests for copies of the poster has prompted its release as an Open File, both as a wall poster and a booklet.

COMPILATION OF MINERAL DEPOSIT DATA

Index level data of measured Canadian mineral resources have been compiled as spreadsheets, a format that can be readily used in GIS systems or by data analysis software. The data consist of information on name, location, grade and tonnage, mining history and geological contexts of the deposits, including age, names and lithologies of host rocks, age of mineralization, and geotectonic setting.

Data on grade and tonnage are compiled as three categories:
Production: The grade and cumulative tonnage of ore that has been mined.
Economic reserves: The aggregate grade and tonnage of current Proven, and Probable Reserves, as per definitions of the CIMM ad hoc Committee on Ore Reserves, 1996.
Resource not mined: The aggregate grade and tonnage of a measured resource, which is not part of a currently operating mine.

A measured resource is the estimated quantity and grade of that part of a deposit for which the size, configuration, and grade have been very well-established by observation and sampling of outcrops, drill holes, trenches, and mine workings. Consequently, the spreadsheets do not contain information on deposits or occurrences that have not been at least systematically drilled. These spreadsheets will be made publicly available by the Geological Survey of Canada during 2004.

Deposit type	Commodity	Description	Distribution map & deposit notes pages
Ni-Cu-PGE (Nickel-Copper-Platinum Group Elements)	Ni,Cu, (PGE)	Magmatic sulphides in ultrabasic-basic igneous rocks	5
VMS (**V**olcanogenic **M**assive **S**ulphides)	Cu,Zn, (Pb, Au, Ag)	Massive sulphides in submarine volcanics	6
Lode Gold	Au	Quartz/carbonate veins, sulphide dissemin-ations, and Au-rich massive sulphides	7
Porphyry deposits	Cu (Mo, Au, Ag)	Veins, replacements, disseminations, and skarns around felsic plutons.	8
Sedex (**Se**dimentary **Ex**halative)	Zn,Pb,Ag	Massive sulphides in sedimentary basins	9
U	U	Veins, replacements at redox front (especially unconformities); Paleoplacers	10
MVT (**M**ississippi **V**alley **T**ype)	Zn,Pb, (Ag)	Replacements, open space fillings, veins incarbonate rocks	11
PGE (**P**latinum **G**roup **E**lements)	PGE (Cu,Ni,U)	PGE in hydrous magmatic segregations; chromite layers; veins	incl with Ni-Cu-PGE
IOCG (**I**ron **O**xide **C**opper **G**old)	Cu,Au, (U)	Cu, Au, etc in magnetite/hematite veins, breccias associated with felsic plutons	12
Diamonds	Diamonds	Kimberlite pipes	13

Table 1. List of deposit types considered by this overview. See indicated pages for details of their distribution in Canada, and notes of their geological and economic characteristics. These deposit types, along with iron formations, account for > 90 % of the wealth derived from the development of metalliferous mineral resources in Canada.

Commodity	1994-2001 Average ($CAD)	Unit
Ag	230	kg
Au	13,320	kg
Cu	2,830	tonne
Co	54,145	tonne
Mo	11,800	tonne
Ni	9,900	tonne
Pb	715	tonne
Pd	15,600	kg
Pt	20,000	kg
Sn	8,230	tonne
W	66,800	tonne
U_3O_8	50,400	tonne
Zn	1,460	tonne

Table 2. Values used in calculating "dollar equivalent" of mineral resources. Source: Statistics section, Canada Minerals Yearbook and USGS Commodity Statistics. Both data sets based on values reported by *Metals Week*.

Sources of data for the spreadsheets include the World Minerals Geoscience Database *(Geological Survey of Canada)*; Canada Minerals Yearbook and "Canadian Mineral Deposits not being Mined in 1989" Publication MR 223 *(Mining and Metals Sector, Natural Resources Canada)*; web-based assessment files of Canadian Provinces and Territories; and web-based annual reports of mining companies.

SCOPE OF OVERVIEW

Canada has proven favourable geological environments for a wide range of mineral deposit types. However, this overview is restricted to those major mineral deposit types most likely to attract mineral exploration investment during the near future. These are listed in Table 1.

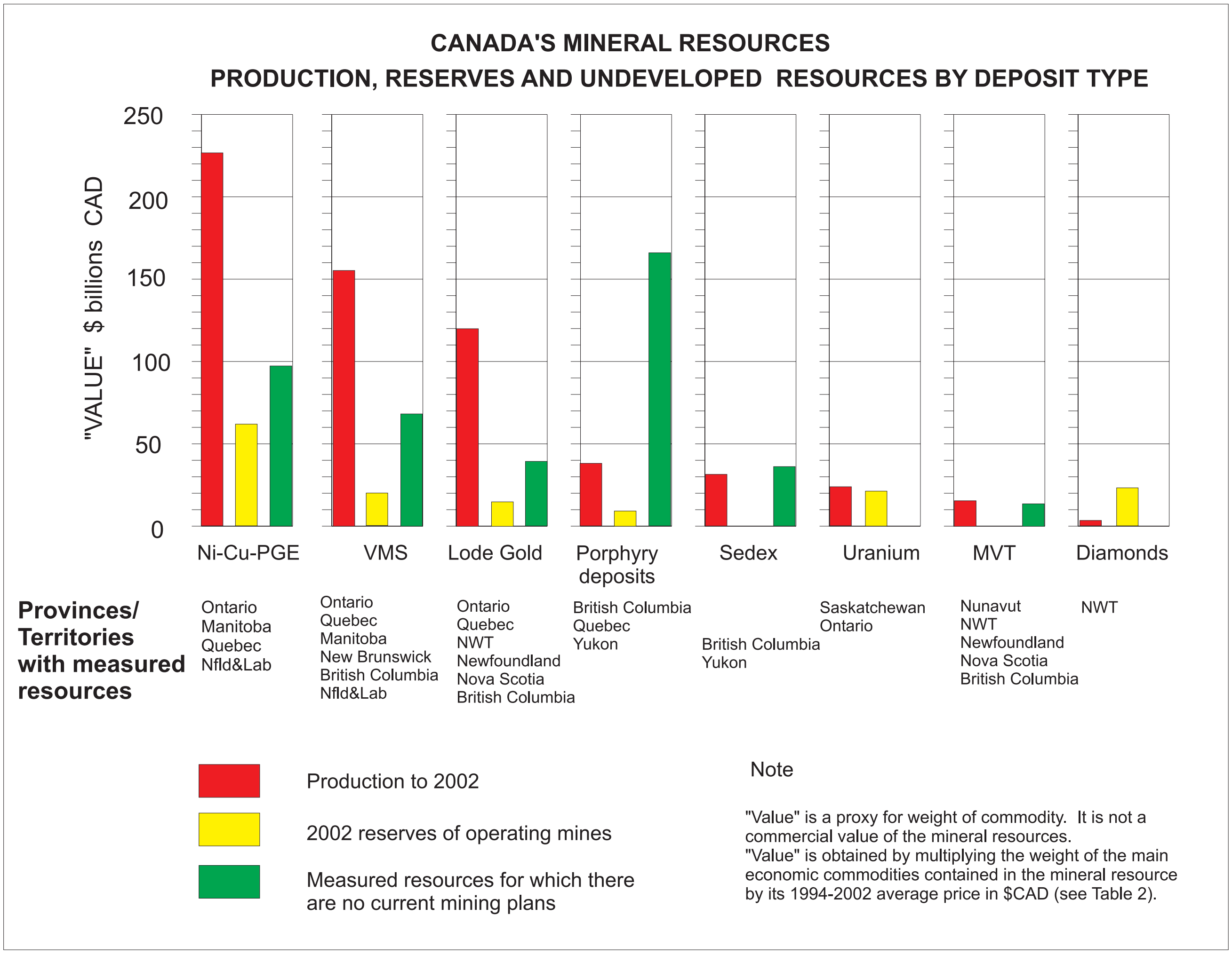

Figure 1. Summary of total production, current reserves and mineral resources not being mined for Canada by deposit type. The "value" of the mineral resource is obtained by multiplying the weight units by the values given in Table 2. Because the data bases are compiled from a variety of sources, some of which contain estimated rather than reported quantities, the calculations must be considered as approximations. Note that in some cases the resource not being mined contains the discrepancy between the amount of a metal measured for a deposit and the amount of metal delivered in the concentrate from mining operations, and would thus include metal contained in tailings ponds or left in the ground as unminable pillars, etc.
Major facts shown by this diagram include:
i) The importance of the Sudbury district (from which most Ni-Cu has been obtained) to the value of Canada's mineral resources.
ii) The historical importance of the VMS and Lode Gold mineral deposit types to mineral resource production in Canada.
iii) The depletion of reserves in Canada for the Sedex and MVT deposit types.
iv) The large known resources (usually high tonnage, low grade), almost entirely in British Columbia, contained in the Porphyry deposit type.

DISTRIBUTION AND DOLLAR-EQUIVALENT OF CANADA'S MINERAL RESOURCES CONTAINED IN MAJOR MINERAL DEPOSIT TYPES

In order to facilitate comparison between different deposit types and to reduce polymetallic deposits to a single quantitative term, metal contents of the deposits have been converted to a "dollar equivalent" in illustrations in this Open File. Although this conversion helps the non-technical person to better grasp the economic significance of mineral deposits, the "dollar equivalent" does not represent the economic value of the deposit. The economic value of a

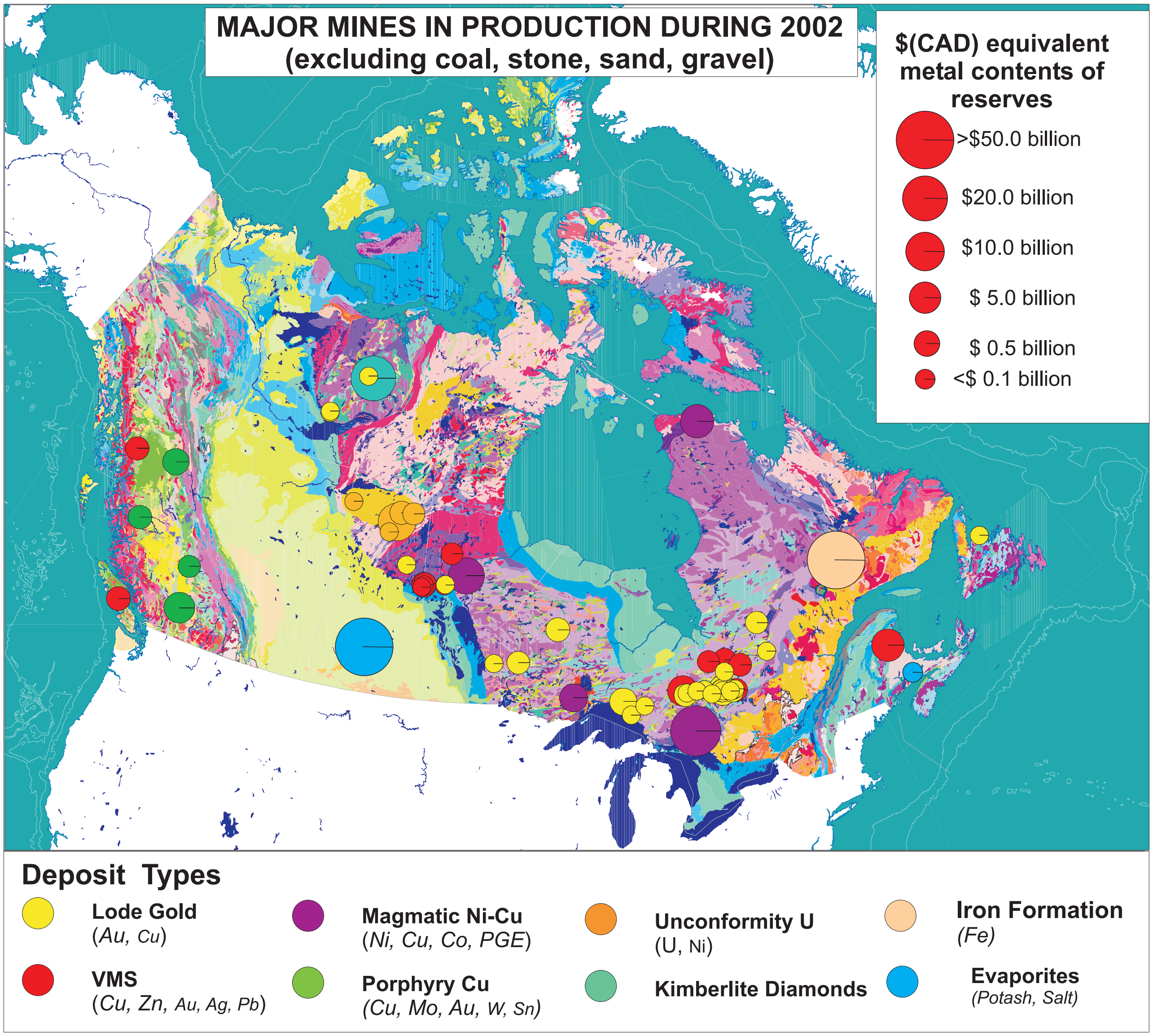

Figure 2. Distribution and value of reserves of the major non-fuel mineral mining operations in Canada during 2002. Note that the mines are distinguished by mineral deposit type and not by commodity. Most of the locations are for single mines, but some, particularly the Ni-Cu mines of Sudbury and Thompson, the iron mines of the Labrador Trough, and the potash mines of Sasckatchewan, represent mining districts containing several mines.

deposit is determined by weighing the costs of mining, beneficiation, transportation, energy supplies, together with consideration of mining dilutions and milling recoveries, etc., against the revenues expected from concentrate sales. The dollar equivalent has been calculated by multiplying the metal content by the prices listed in Table 2.

In order to facilitate display of mineral resources at the scale of the map of Canada, the distributions of mineral resources shown in Fig. 3 through Fig. 11 are for metallogenetic districts, which decreases the number of data points. These districts are defined as a sensibly contiguous area containing deposits of the same type and similar age. Fig. 10 and Fig. 11 show individual deposits. Fig. 3 through Fig. 11 shows the distribution and dollar equivalent value of these districts and deposits for the deposit types listed in Table 1. . The total mineral resource on these diagrams is subdivided into the three categories: i) total past production, ii) current reserves and iii) the unmined measured resource for which there are no current mining intentions.

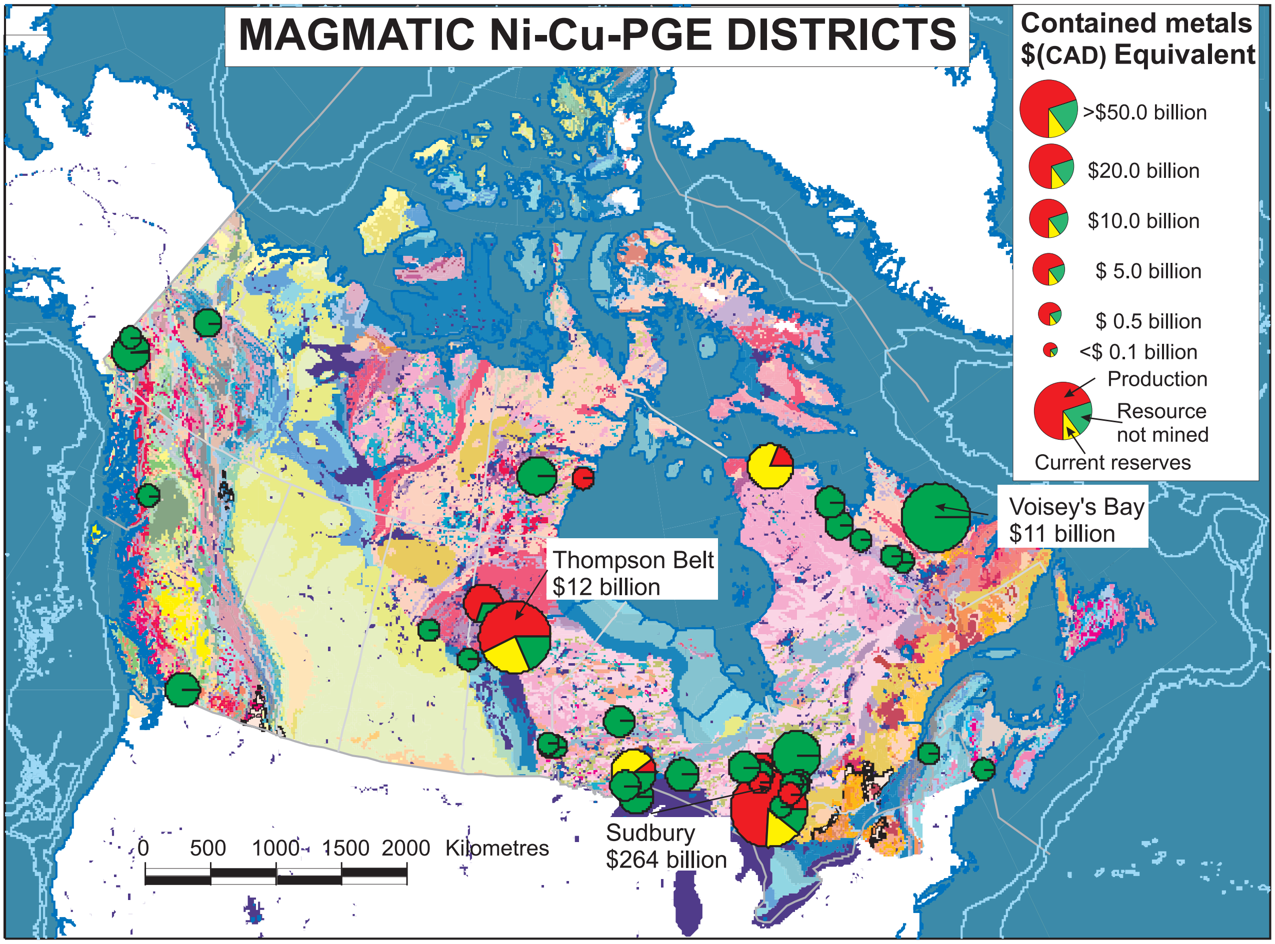

Figure 3. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for metallogenetic districts of the Magmatic Ni-Cu type of mineral deposit.

Magmatic Ni-Cu-PGE

Definition

Ni-Cu sulphide concentrations in mafic-ultramafic igneous intrusions and volcanic flows.

Commodities

Ni, Cu, PGE.

Economic attraction

High value.

Geological setting

1. Rift-related layered intrusions and komatiite flows of back-arcs and continental rifts.
2. Intracontinental mantle upwelling by mantle plumes (flood basalt-related) or triggered by asteroid impact.

Genetic models

Segregation of sulphide melt from mantle-derived magmas that have been contaminated with crustal sulphur.

Summary statement

The great majority of Canada's Ni production has been from the Sudbury astrobleme, which is a unique metallogenetic district. Early Proterozoic komatiite flows of the Thompson and Cape Smith belts have been the second most important producers. Minor production has occurred in B.C., Manitoba, and Ontario from tholeiitic intrusions ranging in age from Archean to Mesozoic. The subeconomic Great Lakes Nickel deposit of western Ontario is part of the flood basalt-related Duluth Complex.

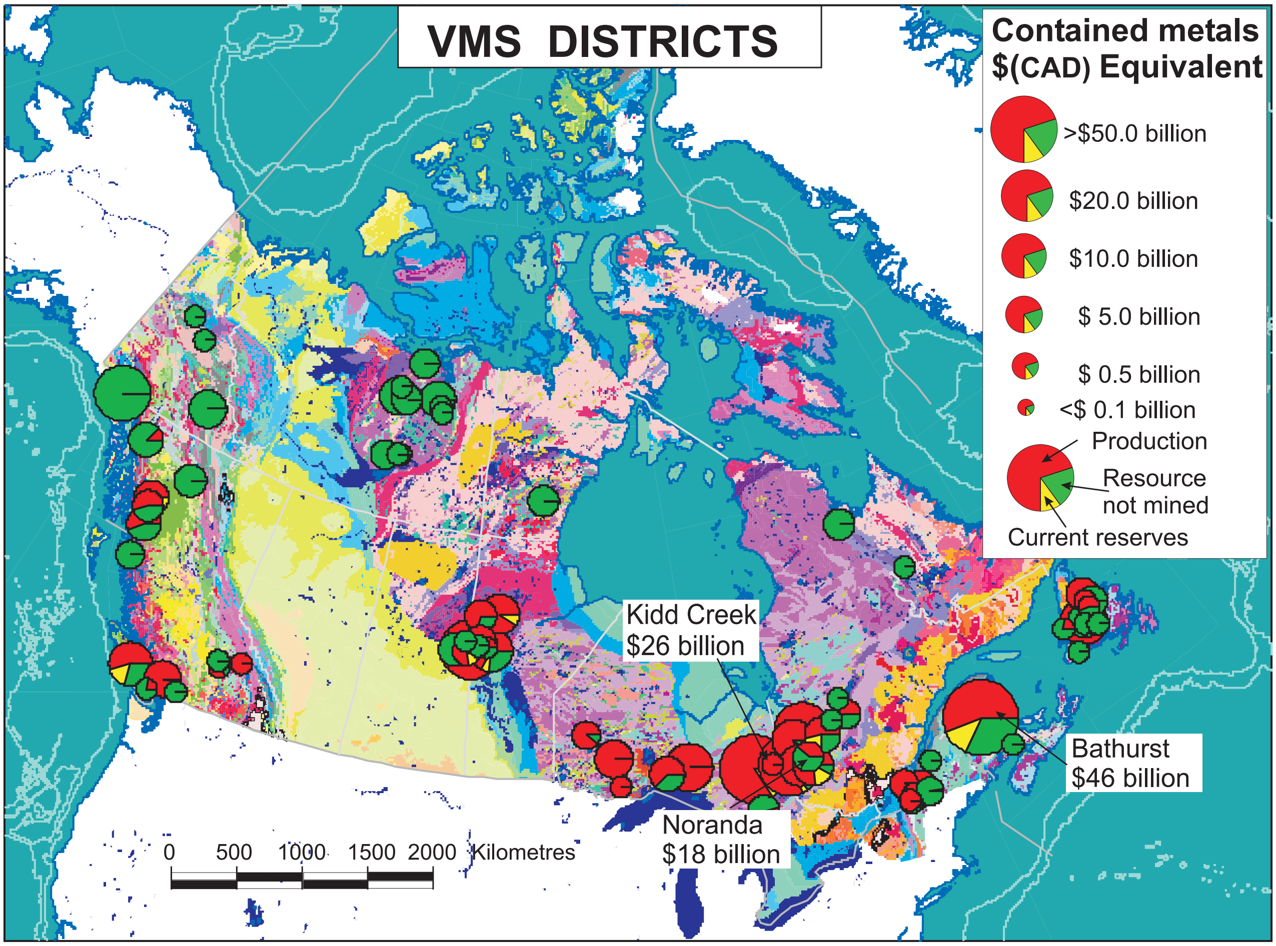

Figure 4. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for metallogenetic districts of the VMS type of mineral deposit.

VMS Deposits

<u>Definition</u>
A VMS deposit is a concordant body of massive iron, copper, zinc and sometimes lead sulphides, which formed by the venting of hydrothermal fluids at the sea floor in a submarine volcanic environment.

<u>Commodities</u>
Cu, Zn, (Pb), Ag, Au.

<u>Economic attraction</u>
High value (polymetallic); low mining dilution.

<u>Geological setting</u>
Submarine environments of oceanic and continental arcs and back-arc basins, especially at felsic volcanic centres. (see Fig. 12 and Fig. 13). a

<u>Genetic model</u>
Precipitation of sulphides at hydrothermal vents of active submarine volcanoes. Sulphide precipitation caused by the quenching of hot (>300^{o}C) hydrothermal fluids of magmatic and/or sea water convection systems by mixing with seawater at or just below the sea floor.

<u>Summary statement</u>
VMS deposits occur in most submarine volcanic belts of Canada. The most productive have been the Archean Abitibi belt, the Proterozoic Flin Flon-Snow Lake Belt, and the Paleozoic Bathurst district.

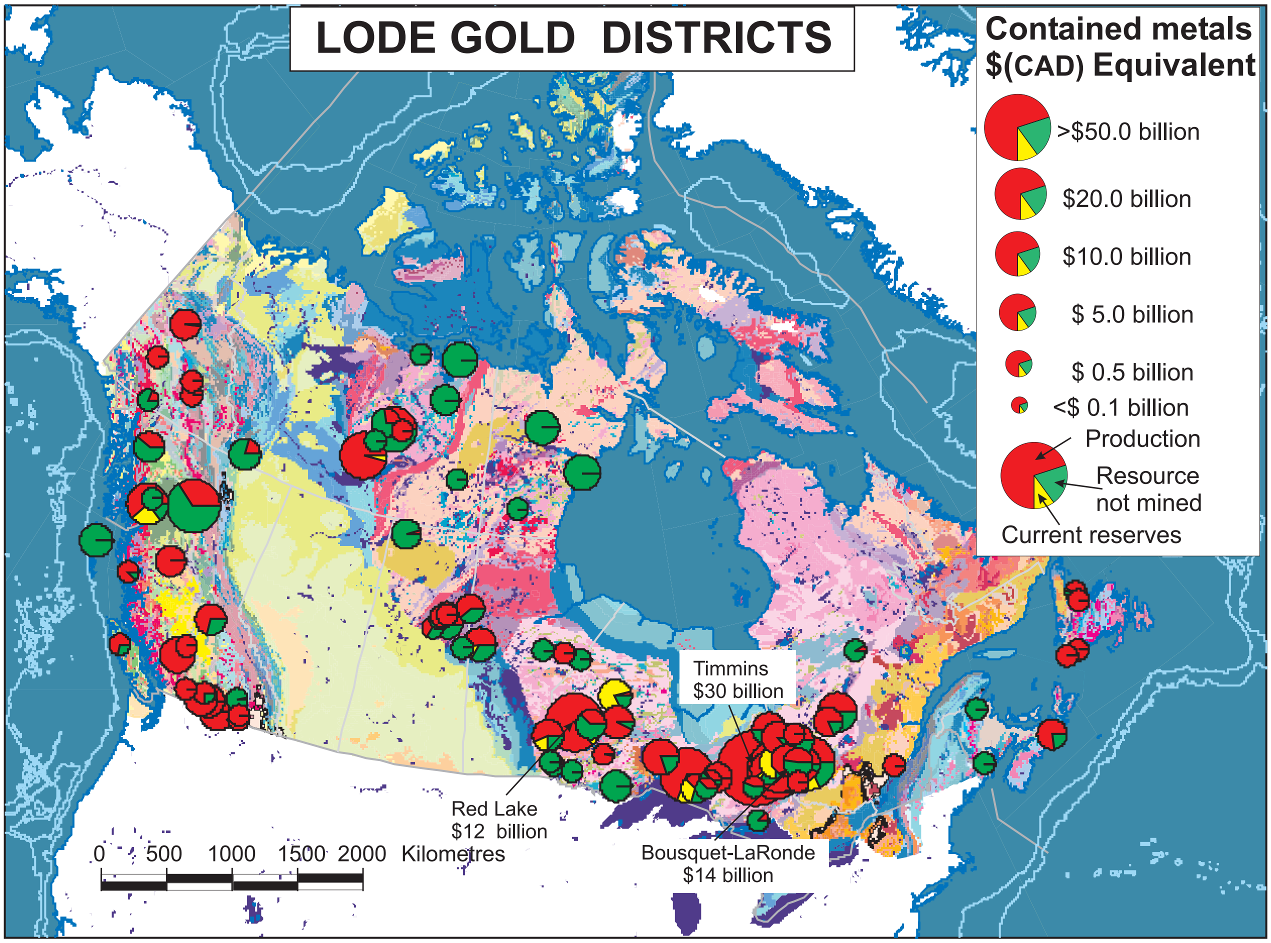

Figure 5. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for metallogenetic districts of the Lode Gold type of mineral deposit.

Lode Gold

Definition
A Lode Gold deposit is a hydrothermal deposit whose principal commodity is gold. Sixteen sub-types can be considered to form three main groups:
1. orogenic (shear zone and fault-related deposits).
2. intrusion-related deposits (formed at 1-5 km depth)
3. epithermal deposits (formed at < 1 km depth).

Commodities
Au.

Economic attraction
High value.

Geological setting
1. Orogenic: associated with major faults/shear zones of collision tectonics.
2. Intrusion-related: associated with felsic plutons of subaerial oceanic and continental arcs.
3. Epithermal: associated with sub-aerial (high sulphidation and low sulphidation deposits) and shallow marine volcanism (Au-rich VMS deposits).

Genetic models
1. Orogenic: hydrothermal fluids derived from metamorphic dewatering of sedimentary prisms at continental margins and transported along major collisional structures.
2. Intrusion-related: interaction of low salinity hydrothermal fluids from felsic plutons with groundwater/rock at mesothermal depths (1-5 km).
3. Epithermal: volcanic hydrothermal systems consisting of fumaroles and acidic hot springs generated by degassing of felsic magma in subaerial or shallow water environments.

Summary statement
The Superior has been by far the most productive geological province in Canada. Production has also taken place in the Slave Province, Trans-Hudson Orogen, Cordillera and Appalachians. 80% of Canada's gold production has been from greenstone-hosted Archean quartz-carbonate vein deposits (orogenic).

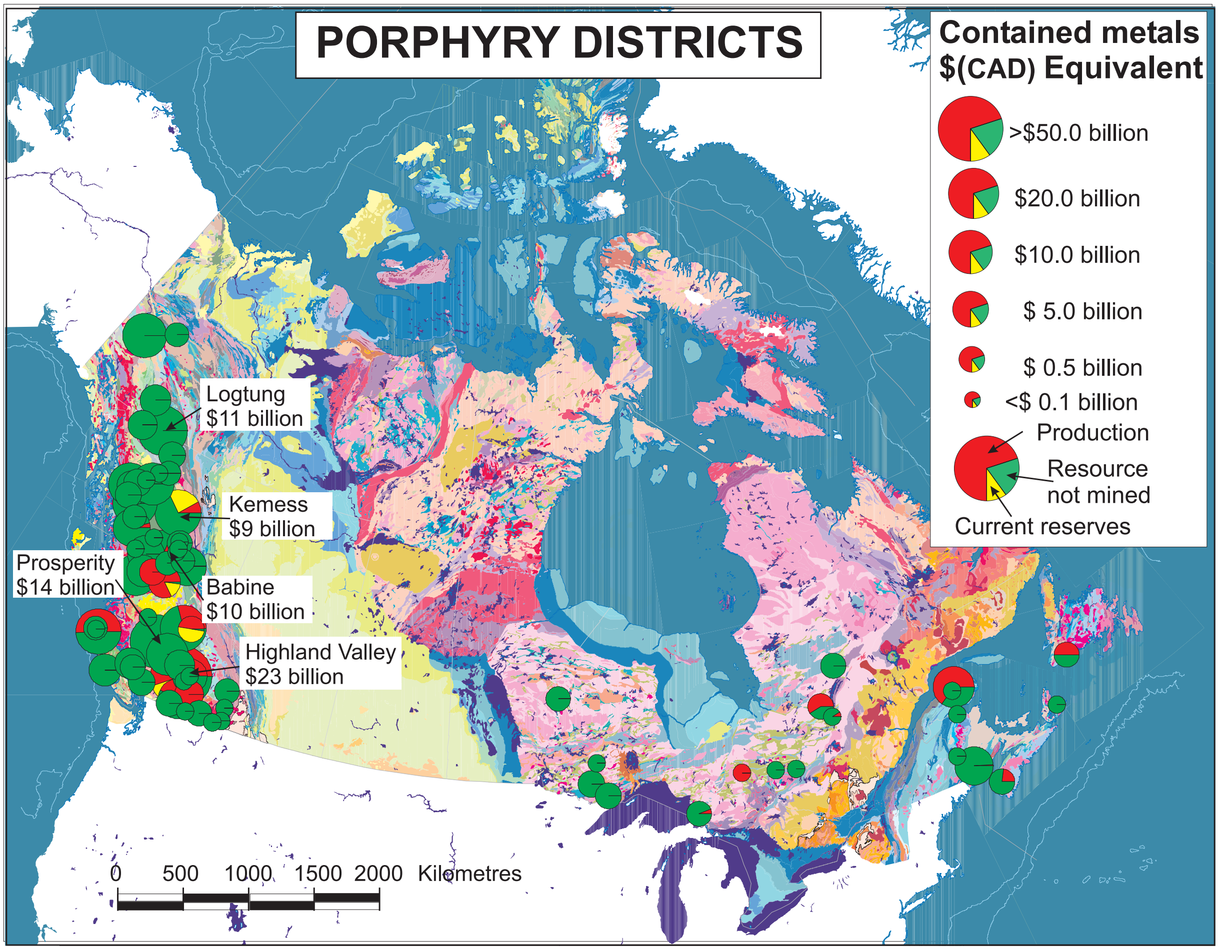

Figure 6. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for metallogenetic districts of the Porphyry Cu type of mineral deposit.

Porphyry Deposits

Definition

As used here, a Porphyry deposit is a concentration of base metal minerals genetically associated with a felsic pluton. The form of the mineralization may be veins, disseminations, or replacements (including skarns).

Commodities

Cu, (Mo, Au, Ag, Sn, W).

Economic attraction

Large tonnage; bulk mining.

Geological setting

Continental and oceanic arcs.

Genetic models

Polyphase interactions between magmatic hydrothermal systems and convective hydrothermal systems involving meteoric water.

Summary statement

The great majority of Canada's Porphyry production has been from Porphyry Cu and Porphyry Cu-Mo deposits of the younger orogenes of the Cordillera, where the depth of erosion is relatively shallow and these high level continental deposits have been preserved. With the exception of Gaspé Copper, Porphyry-type mineralization of Paleozoic and older orogens have not been economic for their base metal content. There is a spatial and genetic association between Porphyry deposits and epigenetic Au deposits. Only 20% of measured Porphyry resources have been mined, a reflection of the strong dependence of tonnage to cut-off grade for the deposit types and the socio-economic, especially environmental, factors associated with open pit mining.

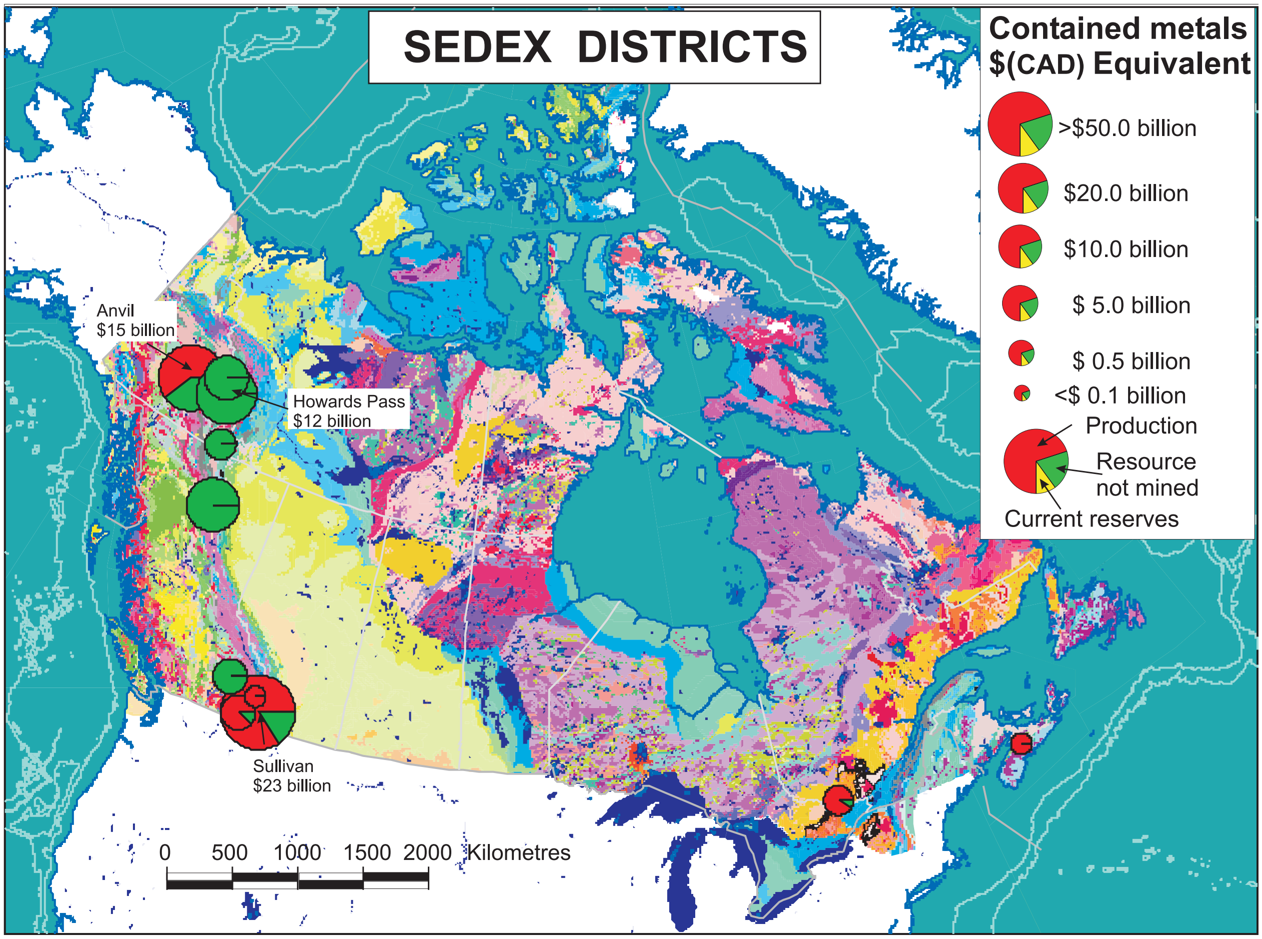

Figure 7. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for metallogenetic districts of the Sedex type of mineral deposit.

Sedex Deposits

Definition

A Sedex deposit is a stratiform to stratabound body of dominantly iron, zinc and lead sulphides formed in a sedimentary basin by the submarine venting of hydrothermal fluids.

Commodities

Zn, Pb, Ag.

Economic attraction

Large tonnage, medium grade.

Geological setting

Intracontinental and epicontinental submarine rifts (see Fig. 14))

Genetic model

Tectonically-induced expulsion of formational brines on to sea floor; association with growth faults and anoxic bottom conditions.

Summary statement.

There has been no active mining of Sedex deposits in Canada, since Sullivan closed at the end of 2001. The great bulk of Canada's SEDEX resources are in B.C. and Yukon and occur in the Mesoproterozoic Belt-Purcell Basin and the Lower Paleozoic Selwyn Basin. A number of small Zn-Pb deposits in Cambrian carbonate rocks of the Nelson, B.C. area and eastern Shushwap metamorphic complex may be of the SEDEX type. In eastern Canada, the Walton deposit (and MVT deposits) of the Mississippian Windsor Basin may represent the transatlantic equivalent of the highly productive Irish ore-forming environment.

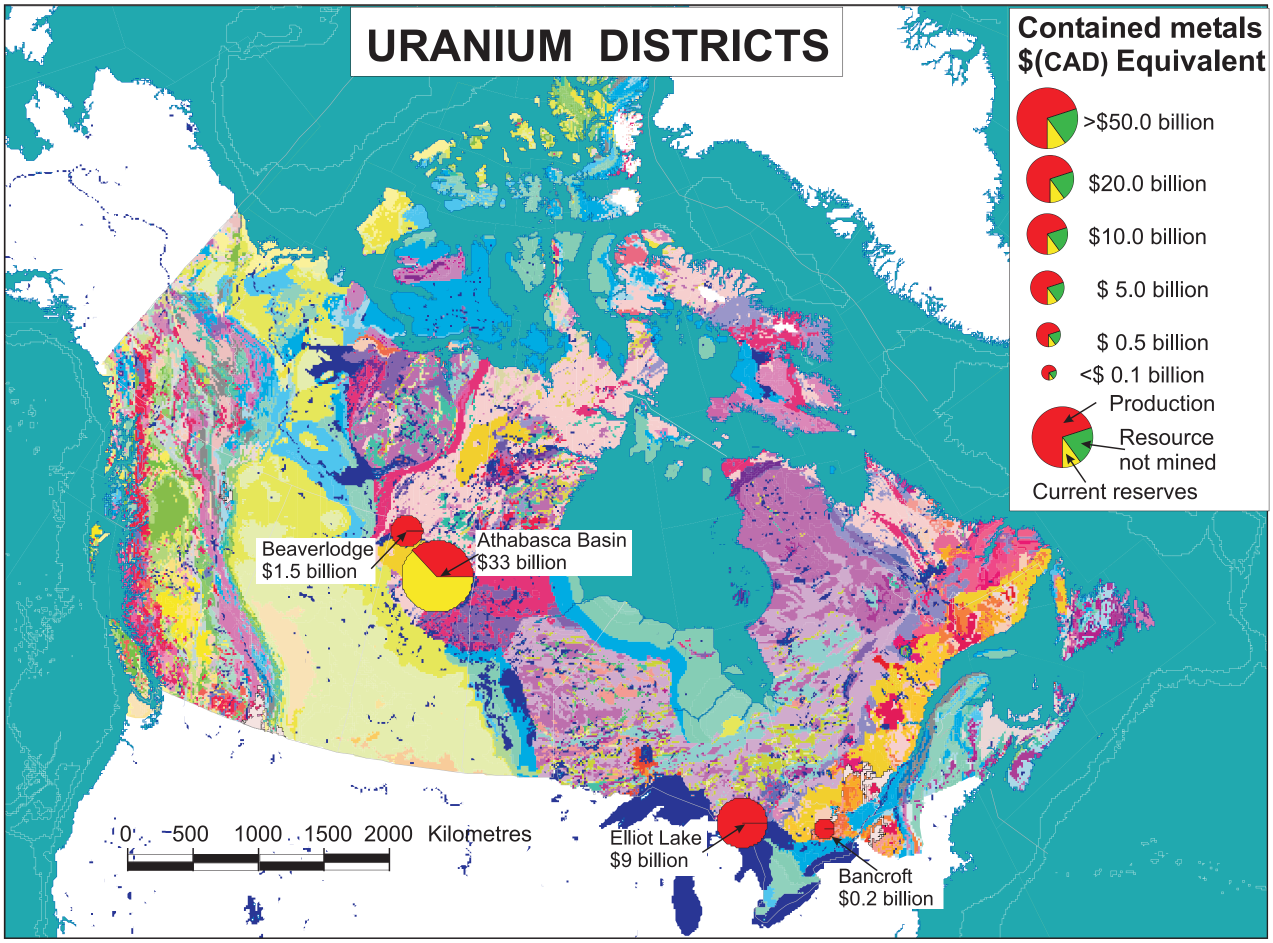

Figure 8. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for metallogenetic districts of the Uranium types of mineral deposits.

Uranium Deposits

Definition

There are three genetic types that have produced in Canada:
1. Unconformity-related uranium deposits.
2. Paleoplacer uranium deposits.
3. Pegmatite uranium deposits.

Commodities

U.

Economic attraction

High value.

Geological setting

1. Intracontinental sedimentary basin.
2. Intracontinental or epicontinental sedimentary basin.
3. High grade metamorphic granitic terranes.

Genetic models

1. Formed at redox front by the mixing of reduced fluids with oxic fluids containing dissolved uranium.
2. Placer concentrations of uraninite prior to an oxic atmosphere (Paleoproterozoic and older).
3. Partial melting of uranium-enriched protolith.

Summary statement

All of Canada's world-leading uranium production is currently from unconformity-related uranium deposits at the base of the Athabasca Basin in Saskatchewan. There are > 25 years of reserves. Prior to 1984 most uranium production was from Huronian paleoplacers of the Elliot Lake district, Ontario.

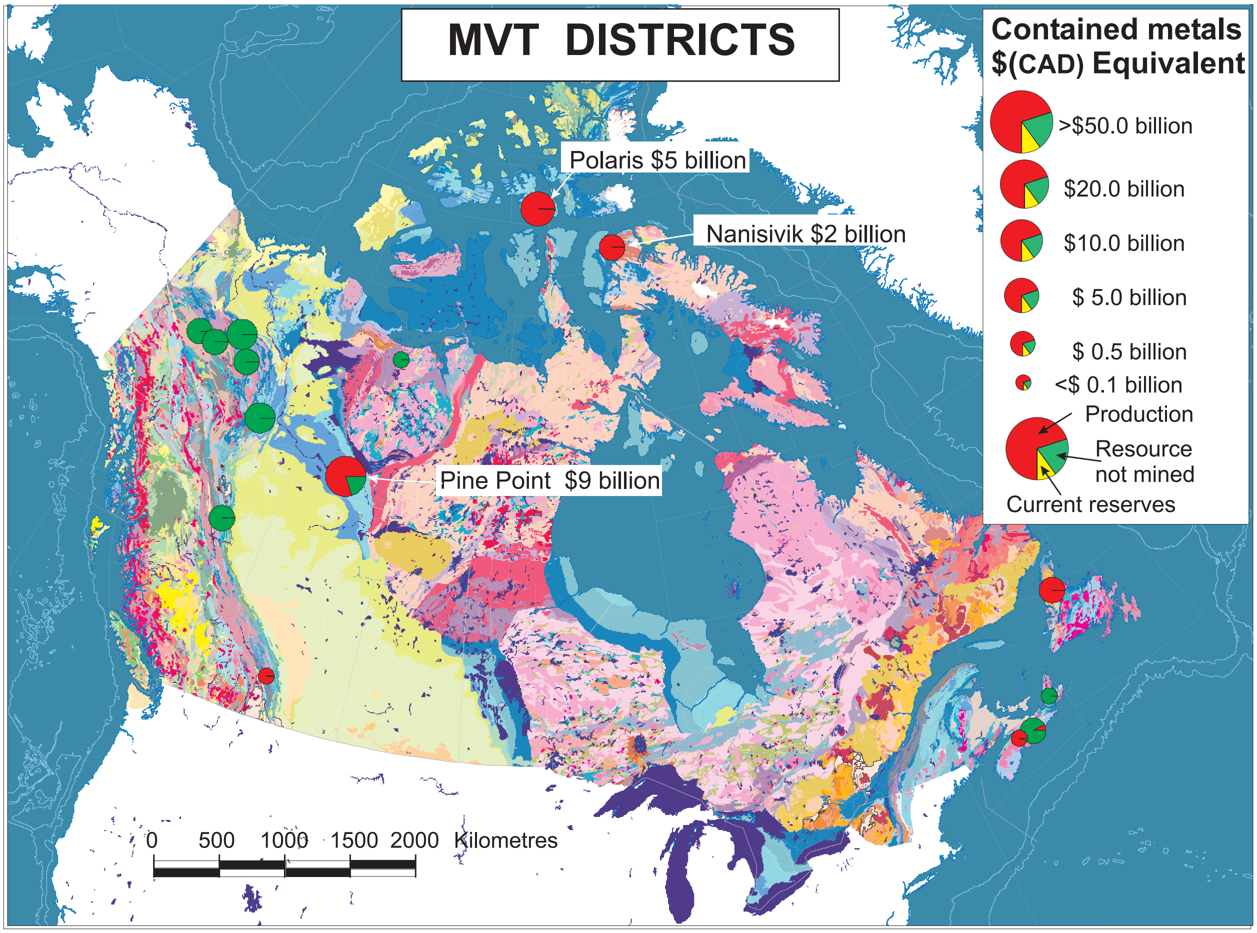

Figure 9. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for metallogenetic districts of the MVT type of mineral deposit.

MVT Deposits

Definition

A MVT deposit is an epigenetic replacement and/or open space filling by zinc and lead sulphides of a carbonate sedimentary rock.

Commodities

Zn, Pb, Ag

Economic attraction

High zinc, low lead deposits.

Geological setting

Carbonate platforms adjacent to epicontinental sedimentary basins, (see Tectonic Setting Fig. 14)

Genetic model

1) Lateral expulsion of formational brines of sedimentary basin into adjacent carbonate rocks of platform;

2) Sour gas migration through a metaliferous aquifer.

Summary statement

Most of Canada's MVT resources are in Paleozoic (except Nanisivik) platformal carbonates that border the Paleozoic miogeoclines of the Cordilleran, the Arctic, and the Appalachian orogens. Major past production has been from Pine Point (NWT), Polaris and Nanisivik (Nunanvut), and Daniel's Harbour (Newfoundland) deposits. Most known resources are in the northern Rocky Mountains of B.C. and the McKenzie Mountains of Yukon and NWT.

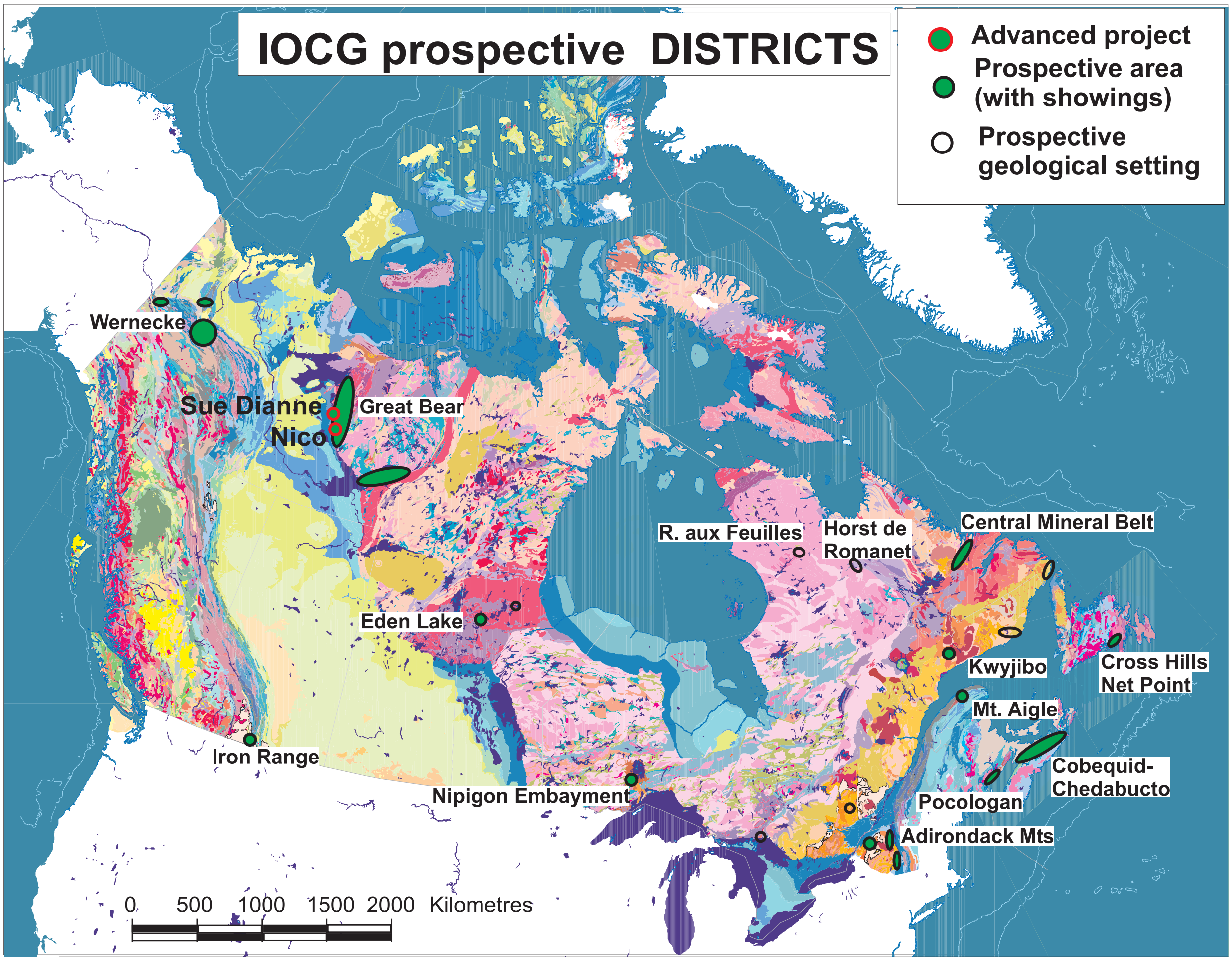

Figure 10. Distribution of prospective deposits and districts of the IOCG type in Canada.

IOCG Deposits

Definition
Stratiform to discordant breccia bodies, veins, disseminations and massive bodies of low-Ti magnetite and/or hematite with polymetallic enrichments, especially Cu and Au. Ores appear to be genetically associated with A-type granitic to dioritic plutons or with carbonatites.

Commodities
Cu, Au, Nb, P, REE, especially LREE, Ag, U (± As, B, Ba, Bi, Co, F, Mo, Mn, Ni, W, Te).

Economic attraction
Large tonnage of economic commodities especially Cu, Au, U and REE.

Tectonic setting
Extensional settings in intracratonic and intra-arc rifts, continental magmatic arcs and back-arc basins, commonly in the vicinity of an Archean craton.

Genetic models
Polyphase interactions between high temperature magmatic hydrothermal fluids derived from long-lived granitic to intermediate plutons and low temperature oxic intraformational brines or meteoric water and/or oxidized host rocks along crustal-scale fault/shear zones in active extensional to transpressional settings.

Summary statement
Because of the diversity of IOCG deposits there is debate as to whether they are a single deposit type or whether they are iron oxide-rich variants of different deposit types. There are no producing mines of this type in Canada, but exploration for them is still at an early stage and occurrences with IOCG characteristics have been recognized.

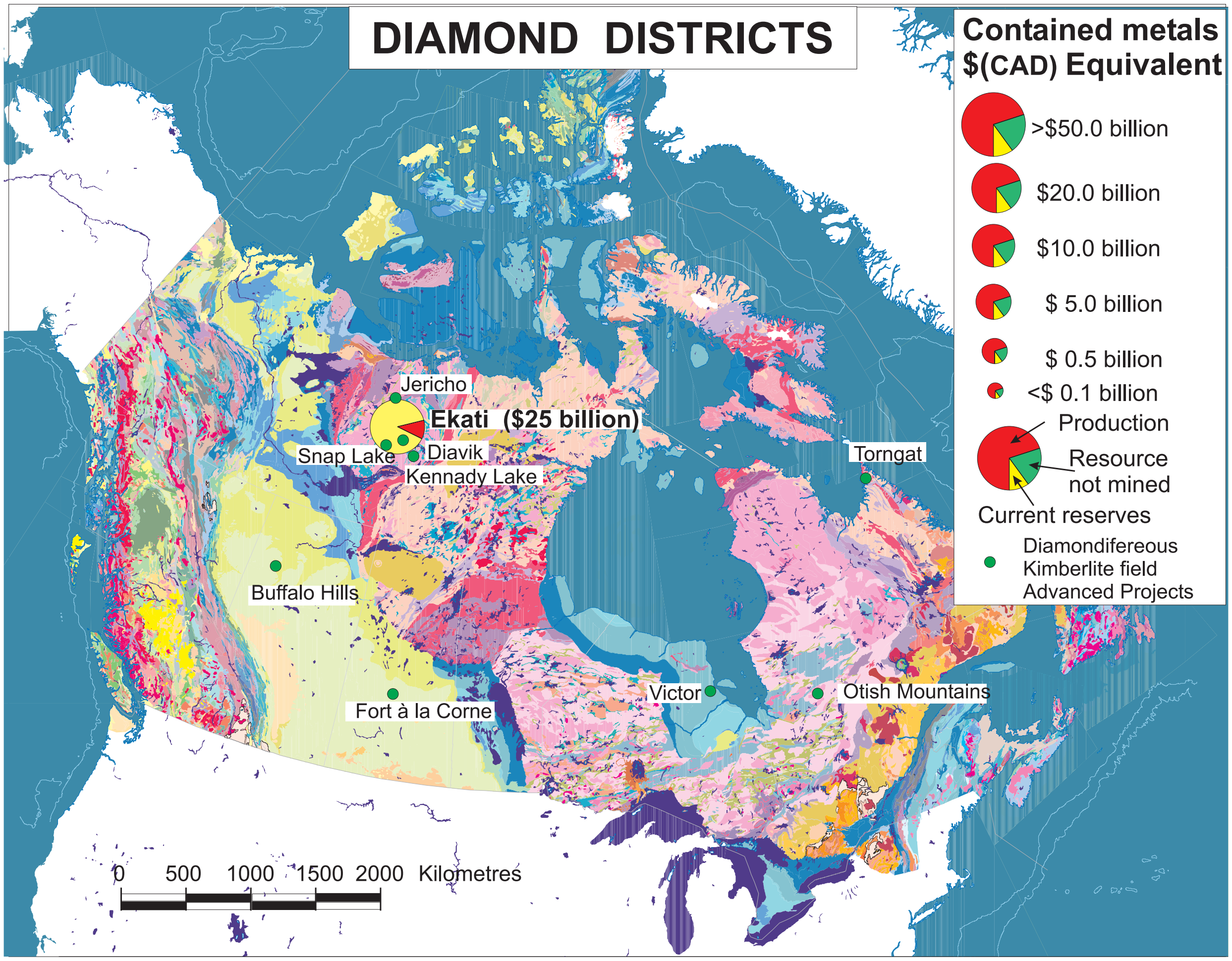

Figure 11. Distribution and value of all past production, 2002 reserves, and mineral resources for which there are no current mining plans for the kimberlite diamond type of mineral deposit.

Kimberlite Diamonds

Definition

Kimberlite craters and diatremes containing diamond xenocrysts in sufficient grade and stone quality to be economic.

Commodities

Diamonds.

Economic attraction

High value.

Tectonic setting

Areas of thick Archean lithosphere.

Genetic models

Partial melting of carbonated peridotite mantle at depths >150 km, and rapid rise of the melt to the surface.

Summary statement

Mining for diamonds in Canada commenced in 1998 at the Ekati mine in NWT. The nearby Diavik mine is likely to commence production soon. The discovery of other diamondiferous kimberlite fields across the country augers well for a very important diamond mining industry in Canada. Diamonds have very high value but small bulk and are amenable for developing FIFO (fly in, fly out) mines in remote areas.

GEOLOGICAL SETTINGS OF CANADA'S MINERAL RESOURCES.

Plate tectonics.

The processes which form mineral deposits are related to plate tectonics. The margins of tectonic plates are in a continuous state of either growth by accretion of volcanic arcs and/or continental micro-plates or consumption by subduction. Plate tectonics has been in effect for at least 2.8 billion years, and has produced cycles of supercontinent construction (a state when most if not all continental crust is assembled into a single plate), supercontinent break-up by rifting, continental drift, and final continental reassembly into a new supercontinent.

The most productive geological environments for metalliferous mineral deposits are volcanic arcs which mark the consumption of a plate by subduction at a plate margin (Fig. 12 and Fig. 13). Most of the mineral deposits formed in this environment can be directly related to magmatic, especially volcanic, events.

Certain environments within the interior of continental plates (Fig. 14) may also be highly productive for metalliferous mineral deposits. Most of these deposit types can be ultimately related to rifting. Some deposit types are directly related to magmatism induced by the extensional forces acting within the plate. Other deposit types are indirectly related by being products of processes induced by thick sedimentary basins that infill tectonically controlled depressions of the continental crust.

Continental arcs

Continental arcs (Fig. 12), together with their associated back-arc basins, are formed by the subduction of a plate under a continental plate. This environment has produced the majority of economic mineral deposits. Mineral deposit types include VMS (in submarine volcanics), Porphyry deposits (in and under subaerial volcanic belts), IOCG and a spectrum of Gold deposits. The latter may not only be related to

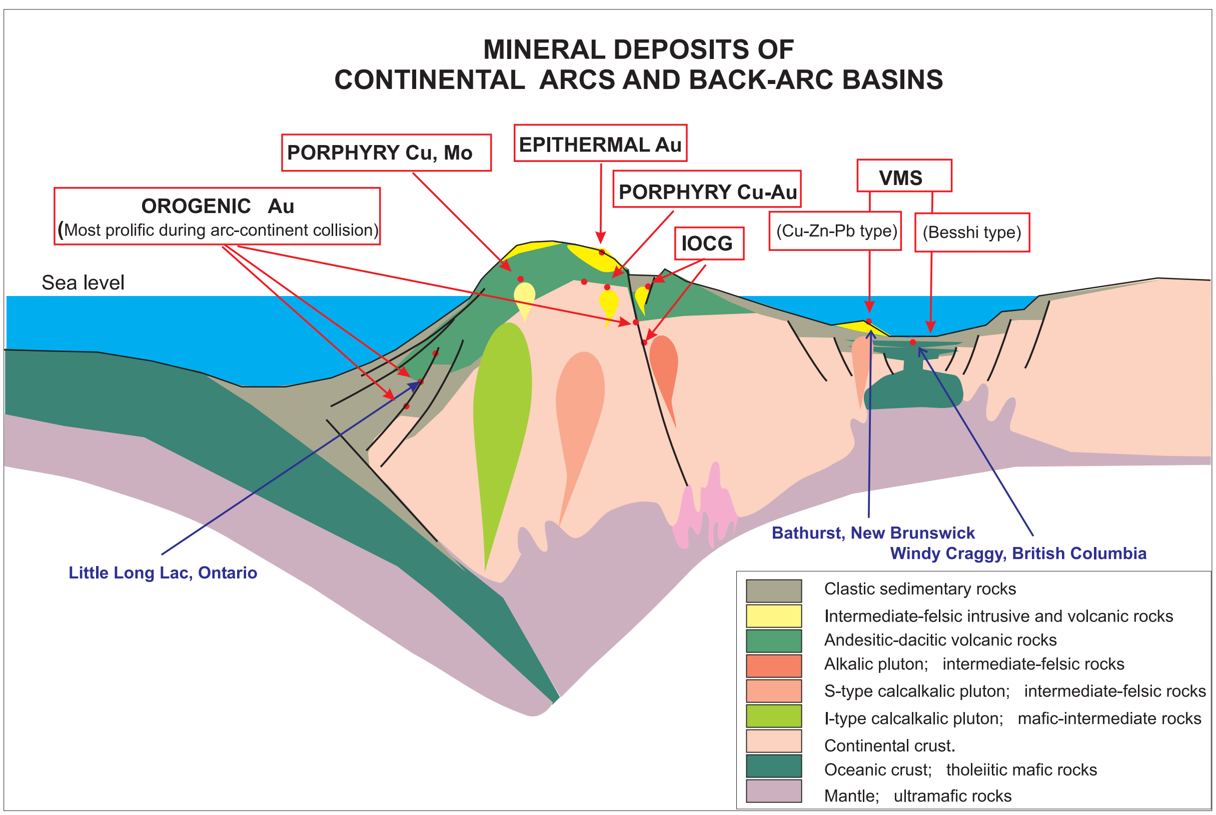

Figure 12. Schematic cross section of a continental arc and associated back-arc basin showing major geological features and the setting of major mineral deposit types. Note that the final development of the continental arc is closing of the back-arc basin and collision of the arc with the continent.

arc magmatism (intrusion-related and epigenetic deposits), but also to tectono-metamorphic processes spawned by the collision of the arc with the continent (orogenic deposits).

Oceanic arcs

Although oceanic arcs (Fig. 13), which are formed by the subduction of oceanic crust under oceanic crust, produce deposits types that are similar to those of continental arcs (e.g. Porphyry Cu and Au deposits of Indonesia), they are less common than continental arcs. This is a consequence not only of arcs preferentially developing at continental margins, but also that preservation of an oceanic arc requires that it collides and is accreted to a continental plate.
Mid-oceanic spreading centres, at which the majority of modern submarine volcanism and associated metalliferous hot spring activity takes place, are only rarely preserved on continental plates. Ophiolites, which have similar geological characteristics to mid-oceanic crust, represent oceanic crust generated at back-arc spreading centres and thrust on to continents (obducted). Spreading centres in oceanic crusts have not proved to be highly productive for mineral deposits, the most common being Cyprus-type VMS deposits and podiform chromite deposits. However, old oceanic crust formed during the Paleoproterozoic or earlier (>2 billion years) when the Earth's crust was thinner and heat flow higher, may contain Ni-Cu deposits such as those of the Thompson Belt. (Fig. 13).

Rifts and other Intracontinental environments

Mineral deposit types that form in or on continental crust (Fig. 14) can be divided into two categories:
1) Mineral deposits that are associated with continental magmatic events, which in turn are related to mantle upwelling, either as plumes or along rift systems. The injection of diamondiferous kimberlite as dykes or diatremes from the mantle through thick parts of continental crust is of

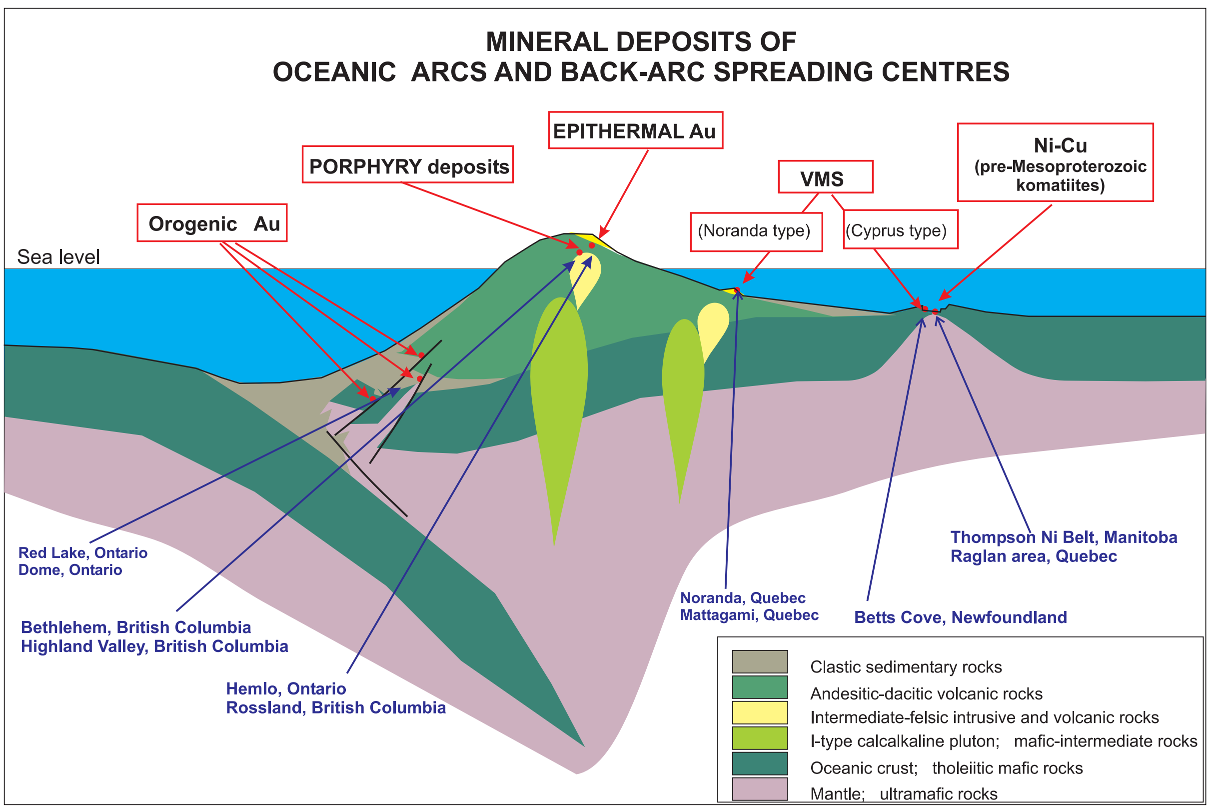

Figure 13. Schematic cross section of an oceanic arc and associated back-arc basin (which has a geological architecture similar to a mid-oceanic ridge spreading centre) showing major geological features and the setting of major mineral deposit types. Note that for preservation in the geological record, the oceanic arc must collide with and be obducted on to a continent.

particular importance to Canada today. Magmatic Ni-Cu deposits associated with layered intrusions of rift systems is another major deposit type associated with mantle upwelling. The prolific Cu-Ni district of the Sudbury area may be considered to be very fortuitous for Canada, because the mantle upwelling from which the Ni-Cu separated was triggered by a large meteorite impact.

2) Mineral deposits of sedimentary basins. Intracontinental sedimentary basins accumulate in depressions of continental crust caused either by rifting or by tectonic loading in the forelands of thrust belts. Epicontinental sedimentary basins at the margins of continents are either supra-subduction zone sedimentary prisms or successors of sedimentary rifts along which oceans initially opened. The two main mineral deposit groups in this category are Zn-Pb-Ag deposits formed from basinal brines at the sea floor (Sedex) or within carbonate rocks (MVT), and deposits formed at redox fronts from basinal fluids, most importantly unconformity-related U deposits and Red Bed Coppers (not detailed in this report). Paleoplacers, the most important source for South Africa's world-leading gold production, and for Canada's Elliot Lake uranium production, accumulte at the edges of sedimentary basons in fluviatile or estuarine sediments.

GEOCHRONOLOGY OF CANADA'S MINERAL DEPOSITS.

The ages of the mineral deposits and the ages of the rocks in which they occur are of paramount importance to understanding the distribution of mineral deposits and to prognosticate where new resources may occur. The ages of mineralization for deposits that are syngenetic with magmatic host rocks (VMS, Magmatic Ni-Cu-PGE, Porphyry deposits) are relatively well known, because of the rapidly growing data base of U-Pb ages of magmatic zircon. The ages of deposits syngenetic with sedimentary host rocks (Sedex) can be estimated from paleontological controls or by bracketing the stratigraphic hori-

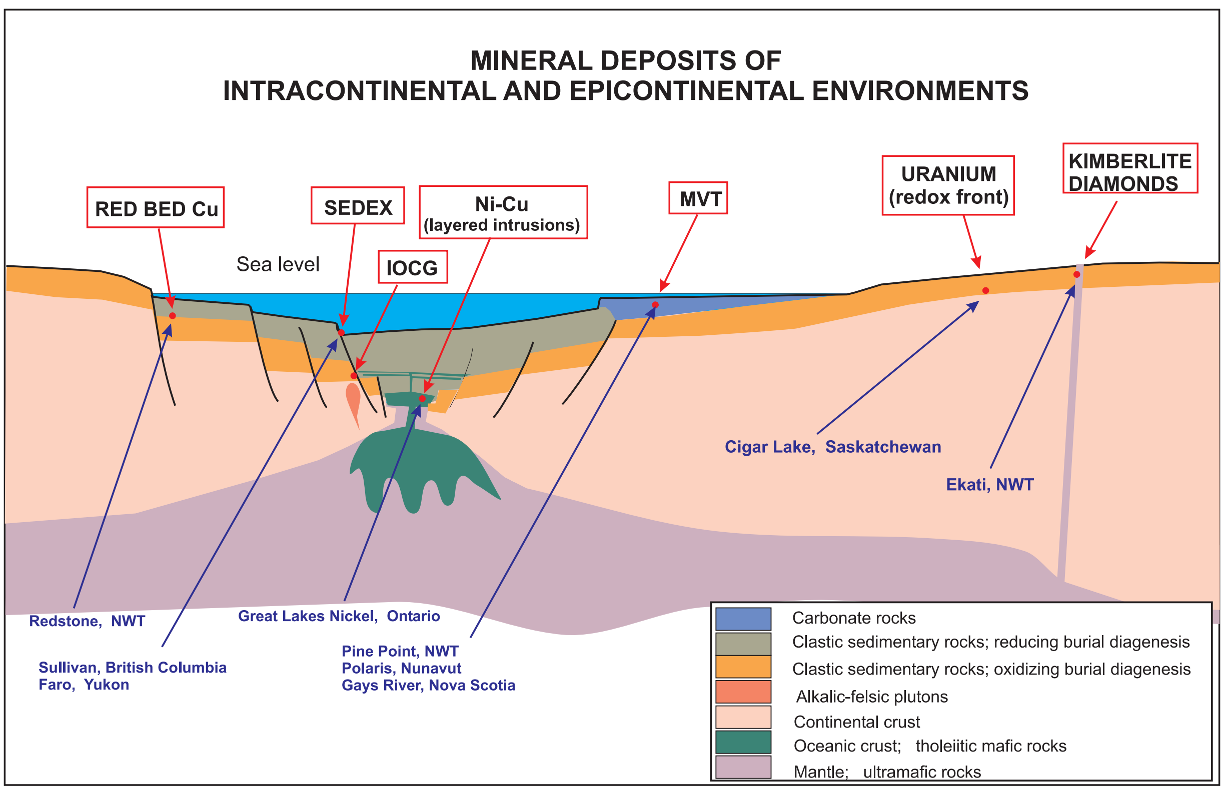

Figure 14. Schematic cross section of a marine sedimented intracontinental rift and surrounding continental crust showing major geological features and the setting of major mineral deposit types.

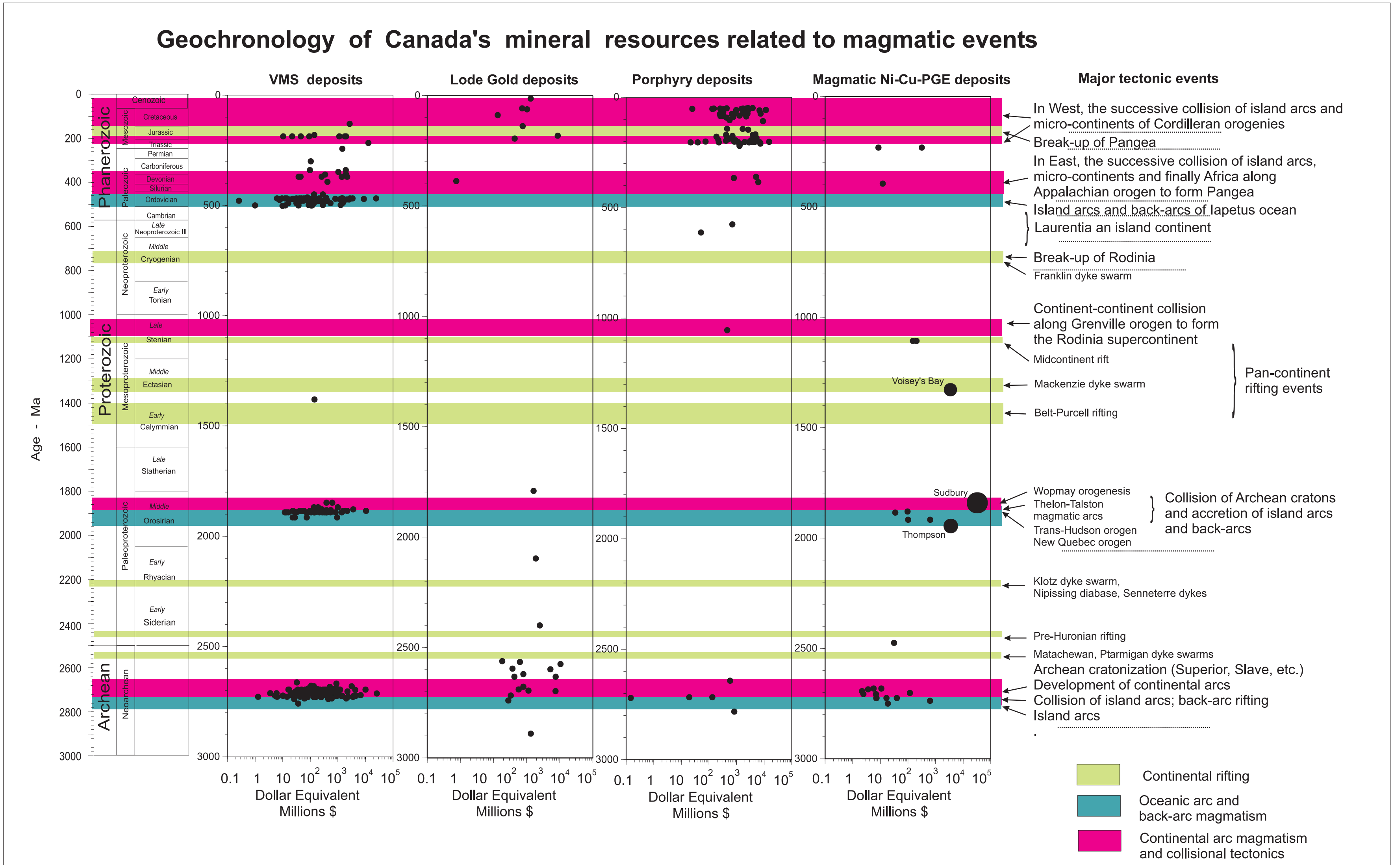

Figure 15. Geochronology of Canadian mineral deposits genetically associated with magmatic and/or volcanic events. For VMS, Porphyry Cu and Ni-Cu deposits the great majority of ages are U-Pb zircon ages of cogenetic igneous rocks. Ages of Lode Gold deposits are by a variety of methods on gangue or alteration minerals. The text column on the right indicates the ages of the major tectonic events that have affected the Canadian land mass..

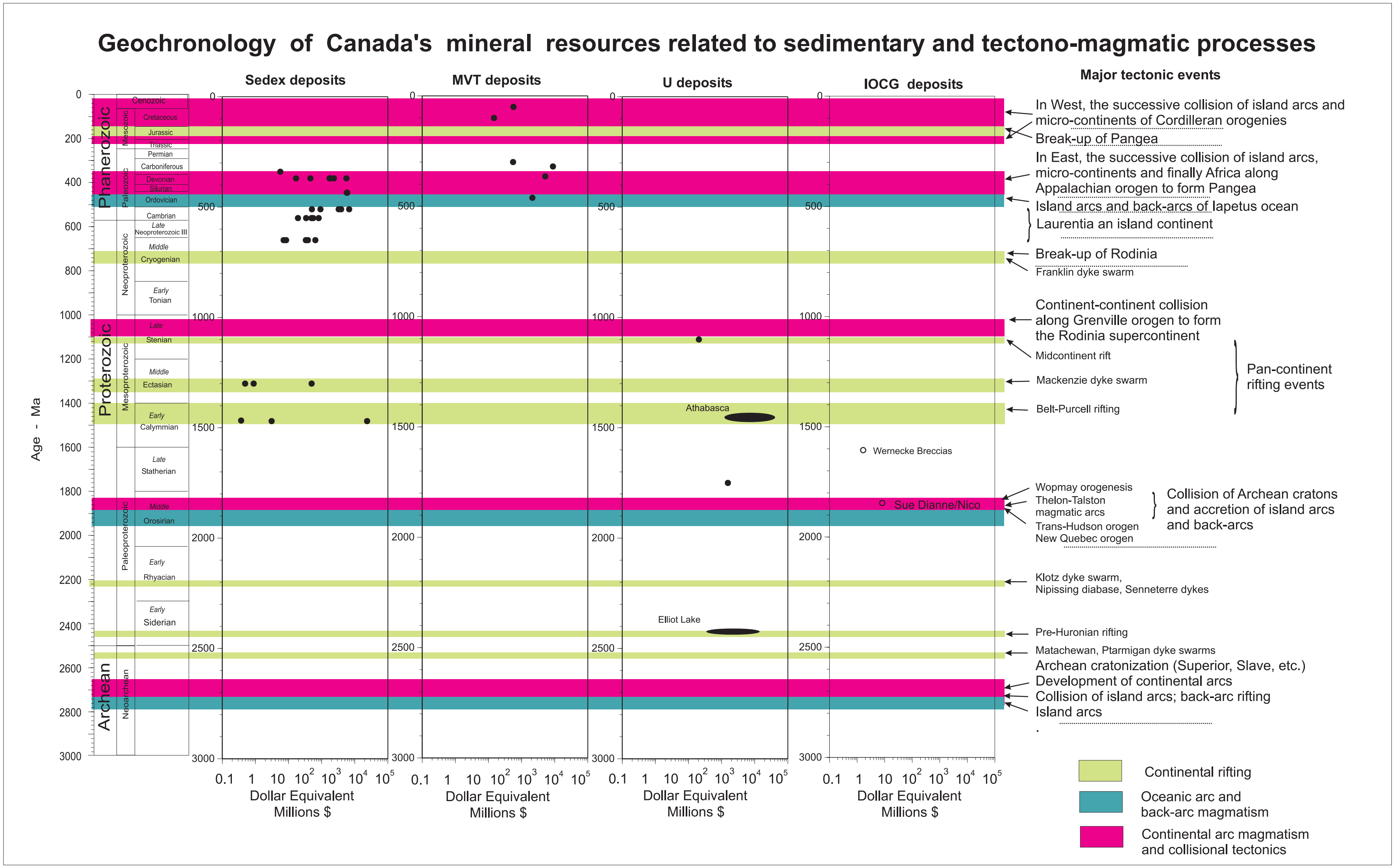

Figure 16. Geochronology of Canadian mineral deposits genetically associated with sedimentary and/or tectonomagmatic events. For Sedex deposits, ages are by geochronological bracketing and stratigraphic correlation with host rocks. Ages for MVT and U deposits are by a variety of methods on ore, gangue and alteration minerals. Ages for IOCG deposits are U-Pb zircon ages of cogenetic igneous rocks or ages of titanite associated with mineralisation. The text column on the right indicates the ages of the major tectonic events that have affected the Canadian land mass.

zon hosting the deposit by radiometric dating of intercalated volcanic rocks if present. The ages of epigenetic deposits (Lode Gold, MVT) are difficult to determine, as shown by the few data points for these deposit types.

On a continental scale, there is a good correlation between metallogenetic epochs and major geotectonic events. VMS deposits are associated with accreted oceanic arcs and back-arc basins of convergent plate boundaries. Lode Gold deposits are associated with volcanic arc and tectonism/magmatism associated with arc-continent collision. Subaerial volcanic arcs, both oceanic and continental, also produce Porphyry deposits. Apart from the fortuitous asteroid impact that produced deposits of the Sudbury camp, Magmatic Cu-Ni deposits are associated with Archean-Proterozoic back-arc or mantle plume volcanism, and with mantle upwelling along intracontinental rifts. These intracontinental rift systems, which can be considered to be harbingers of the eventual breakup of super-continents, also produce Sedex deposits where they are infilled by marine sedimentary rocks. MVT deposits, which, like Sedex deposits, are genetically related to formational brines of marine sedimentary basins, appear to be a Paleozoic phenomenon.

MAJOR FACTORS CONTROLLING THE DISTRIBUTION OF MINERAL DEPOSITS IN CANADA

Tectonic and geological settings

1) Volcanic arcs and back-arc basins
   VMS, Porphyry deposits, intrusion-related and epithermal Au (Figs. 12 & 13).
2) Sedimentary basins
   Unconformity-related U, Sedex, MVT (Fig. 14).
3) Mantle upwellings
   Ni-Cu-PGE and diamondiferous kimberlite pipes (Figs. 12 & 14).
4) Collisional sutures
   Orogenic Au (Fig. 13).

Surface environment

Marine vs. subaerial (e.g. both major VMS and the Porphyry type occur in arc/back-arc settings, but are characteristic of marine and subaerial environments, respectively).

Depth of erosion

Within orogenic belts, different types of deposits form at different depths. The erosional level of an orogen deepens with time and consequently the incidence of high level deposits of subaerial arcs and back-arcs, such as epithermal Au and Porphyry deposits, tend to decrease with increasing age of the orogen (Fig. 15). However, because of the vagaries of tectonic shuffling during orogenesis, high level deposits may be preserved in high grade metamorphic rocks that have been tectonically buried to great depths.

Superposition of metallogenetic events

The dynamic evolution of orogens leads to the superposition of different types of deposits of different ages that are associated with different tectonic and magmatic events (i.e. different metallogenic events) within the same mining district. For example, compare the distributions of VMS (Fig. 4) and Lode Gold (Fig. 5), which are broadly similar, and their timing relationships, which are different or overlap (Fig. 15).

SUMMARY

Developed versus frontier areas

Most development of mineral resources in Canada has taken place in a corridor of mature mining areas that forms an arc about 500 km wide along the Pacific and Atlantic coasts and the border with the U.S.A. (Fig. 4 through Fig. 11). This corridor is distinguished from the frontier area of interior Canada by it having a surface transportation infrastructure connecting established communities.

Frontier areas

Most of the frontier area is underlain by the Archean-Proterozoic Canadian Shield. The Shield has been the most productive geological terrane within the area of mature development, and thus must be considered to have comparable potential in the frontier area. Most likely resource development targets in the frontier area are:

- High value, small bulk commodities (e.g. diamonds and gold) amenable to a FIFO

mining strategy.
- Other deposit types (Ni-Cu-PGE, VMS, IOCG, Sedex, MVT) that are within approximately 100 km of a bulk transportation route such as the coast.
- World-class deposits remote from existing infrastructure are also exploration targets, because they can support the establishment of their own transportation corridors.

The main geoscience infrastructure required to support mineral resource development in frontier areas are:
- 4D regional to local geological mapping of collisional terranes and sedimentary basins, including geochronological mapping.
- Airborne geophysical and regional geochemical/geomineral surveys.
- Development and testing of ore deposit genetic/exploration models to recognize the geological environments with high mineral potential.

Mature areas

The reserve:production ratios for Lode Gold, VMS, Sedex and MVT deposits (Fig. 1) are below those required for sustained development in mature mining areas.

The geoscience infrastructure required for the discovery of new resources in brownfields areas are:
- District scale 4D geological, geophysical and geochemical mapping, combined with U/Pb geochronology.
- Mineral deposit modelling to improve prognostication.
- Development and application of deeply penetrating methods of detecting mineralization.

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