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Geological Survey of Canada
Commission Géologique du Canada

A PRELIMINARY OVERVIEW OF CANADA'S MINERAL RESOURCES
UN APERÇU DES RESSOURCES MINÉRALES DU CANADA

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Consolidating Canada's Geoscience Knowledge Program
Consolidation du savoir géoscientifique du Canada

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", 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 poster 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 deecision maker.

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.

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:

Deposit type	Commodity	Description	Panel No. for Distribution	Panel No. for Description
Ni-Cu-PGE	Ni_2Cu_2 (PGE)	Magmatic sulphides in ultrabasic-basic igneous rocks	14	15
Lode Gold	Au	Quartz/carbonate veins and sulphide disseminations,and Au-rich massive sulphides (especially VMS)	8	9
Porphyry deposits	Cu (Mo, Au, Ag)	Veins, replacements, disseminations, skarns around felsic plutons	16	17
Sedex	Zn,Pb,Ag	Massive sulphides in sedimentary	12	13
U	U	Veins, replacements at redox front (esp unconformities); paleoplacers	18	19
MVT	Zn,Pb, (Ag)	Replacements, open soace fillings, veins in carbonate rocks,	10	11
Ni-Cu-PGE	Ni_2Cu_2 (Au,Ag)	Magmatic sulphides in ultrabasic-basic igneous rocks	14	15
PGE	PGE (Cu,Ni,U)	PGE in hydrous magmatic segregations; chromite; veins	included with Ni-Cu-PGE	
IOCG	Cu,Au (U)	Cu, Au, etc in magnetite/hematite veins, breccias associated with felsic plutons	22	23
Diamonds	Diamonds	Kimberlite pipes	20	21

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 poster. 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 deposit is determined by weighing the costs of mining, beneficiation, transportation, energy supplies, together with mining dilutions and milling recoveries, etc., against the revenue expected from concentrate sales. The dollar equivalent has been calculated by multiplying the metal content by the prices listed in panel 5.

In order to facilitate display of mineral resources at the scale of the map of Canada, the distributions of mineral resources shown in panels 6, 8, 10, 12, 14, 16, and 18 are for metallogenetic districts. These districts are defined by contiguous areas containing deposits of sensibly the same type and age. Panels 20, 22, and 24 show individual deposits.

GEOTECTONIC ENVIRONMENTS OF MINERAL DEPOSITS

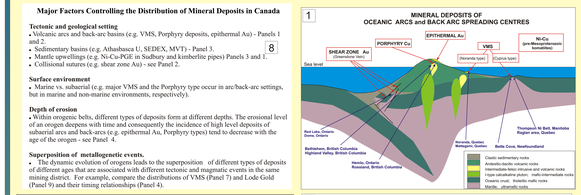
Major Factors Controlling the Distribution of Mineral Deposits in Canada

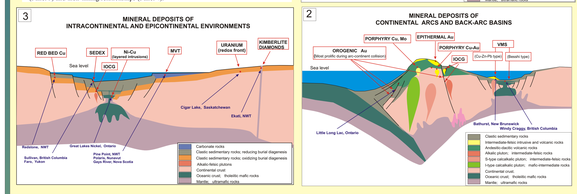
Tectonic and geological setting
- Volcanic arcs and back-arc basins (e.g. VMS, Porphyry deposits, epithermal Au) - Panels 1 and 2.
- Sedimentary basins (e.g. Athabasca U, SEDEX, MVT) - Panel 3.
- Mantle upwellings (e.g. Ni-Cu-PGE in Sudbury and kimberlite pipes) Panels 3 and 1.
- Collisional sutures (e.g. shear zone Au) - see Panel 2.

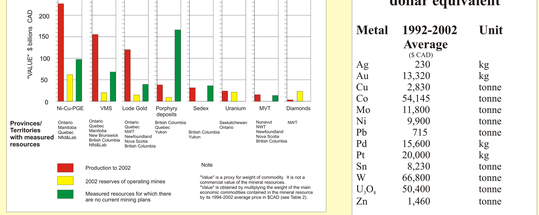
Surface environment
- Marine vs. subaerial (e.g. major VMS and the Porphyry type occur in arc/back-arc settings, but in marine and non-marine environments, respectively).

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 (e.g. epithermal Au, Porphyry types) tend to decrease with the age of the orogen - see Panel 4.

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 in the same mining district. For example, compare the distributions of VMS (Panel 7) and Lode Gold (Panel 9) and their timing relationships (Panel 4).



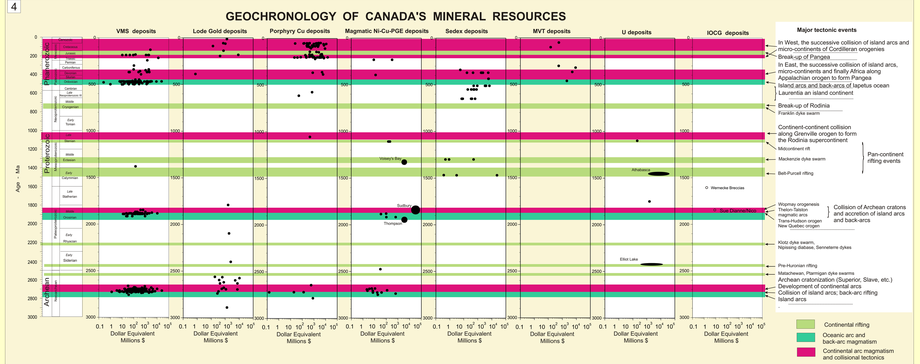




Values used in calculating dollar equivalent

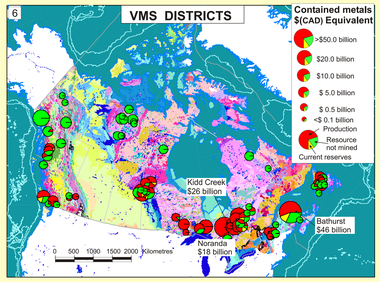
Metal	1992-2002 Average ($ CAD)	Unit
Ag	230	kg
Au	13,320	kg
Cu	2,830	tonne
Co	54,145	tonne
Mo	11,800	tonne
Ni	9,900	tonne
Pb	715	tonne
Pd	15,600	kg
Pt	20,000	kg
Sn	8,230	tonne
W	66,800	tonne
U_3O_8	50,400	tonne
Zn	1,460	tonne

GEOCHRONOLOGY OF CANADA'S MINERAL RESOURCES



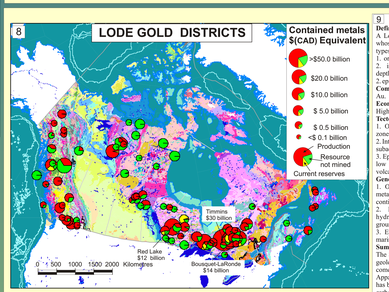
Age of mineralization versus dollar equivalent metal content for Canadian mineral deposits.

The ages of mineralization for deposits that are syngenetic with magmatic host rocks (VMS, Magmatic Ni-Cu, Porphyry Cu) are relatively well known, because of the rapidly increasing data base of U-Pb dating especially of magmatic zircon. The ages of deposits syngenetic with sedimentary host rocks (Sedex) can be estimated from paleontological controls or bracketing by radiometric dating of volcanic rocks. 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, and most **Lode Gold** deposits are associated with tectonism and volcanic arcs associated with arc-continent collision, the latter also producing **Porphyry Cu**. 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 beakup of super-continents, also produce **Sedex** deposits where they are infilled by marine sedimentary basins. **MVT** deposits, which, like Sedex deposits, are genetically related to formational brines of marine sedimentary basins, appear to be a Paleozoic phenomenon.



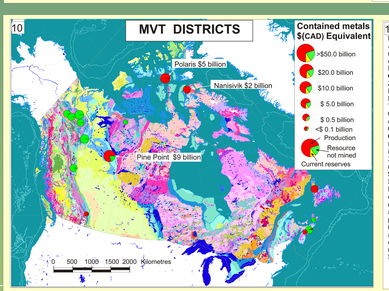
7 **VMS**

Definition
A VMS deposit is a concordant body of massive iron, copper, zinc and sometimes lead sulphides, which formed by the sea-floor venting of hydrothermal fluids in a submarine volcanic environment.
Commodities
Cu, Zn, (Pb), Ag, Au.
Economic attraction
High value (polymetallic); low mining dilution.
Tectonic setting
Submarine environments of oceanic and continental arcs and back-arc basins, especially at felsic volcanic centres. (see Geotectonic Environments 1 and 2)
Genetic model
Seafloor quenching of hydrothermal fluids of magmatic and/or sea water convection systems.
Summary statement
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.



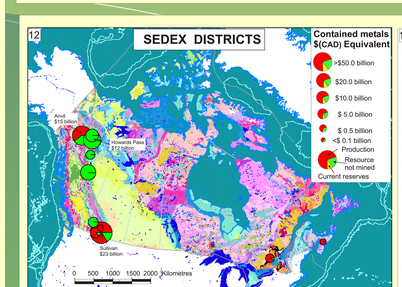
9 **Lode Gold**

Definition
A Lode Gold deposit is a hydrothermal deposit whose principal commodity is gold. Sixteen subtypes 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.
Tectonic 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 and low sulphidation deposits) and shallow marine volcanic environments (Au-rich VMS deposits).
Genetic models
1. Orogenic hydrothermal fluids derived from metamorphic dewatering of sedimentary prisms at continental margins.
2. Intrusion related: interaction of low salinity hydrothermal fluids of felsic plutons with groundwater/rock at mesothermal depths (1-5 km).
3. Epithermal: precipitated by subaerial or shallow marine volcanic fumaroles and acid hot springs.
Summary statement
The Superior has been by far the most productive geological province in Canada. Production has also come from the Slave, Trans-Hudson, Cordillera and Appalachians. 80% of Canada's gold production has been from greenstone-hosted Archean quartz-carbonate vein deposits (orogenic sub-type).



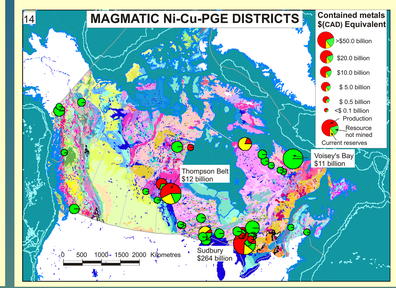
11 **MVT**

Definition
A MVT deposit is an epigenetic replacement and/or open space filling of a carbonate sedimentary rock by zinc and lead sulphides.
Commodities
Zn, Pb, Ag.
Economic attraction
High zinc, low lead deposits.
Tectonic setting
Carbonate platforms adjacent to epicontinental sedimentary basins (see Geotectonic Environments Panel 3).
Genetic model1) Lateral expulsion of formational brines of sedimentary basin into adjacent carbonate rocks of platform; 2) Sour gas migration through a metalliferous 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



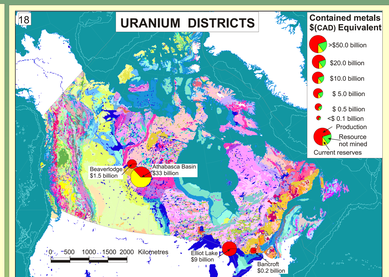
13 **SEDEX**

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.
Tectonic setting
Intracontinental and epicontinental submarine rifts (see Geotectonic Environments Panel 3).
Genetic model
Tectonically-induced expulsion of formational brines on to sea floor; association with growth faults and anoxic bottom conditions.
Summary statement
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 Shuswap 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 extension of the highly productive Irish ore district.



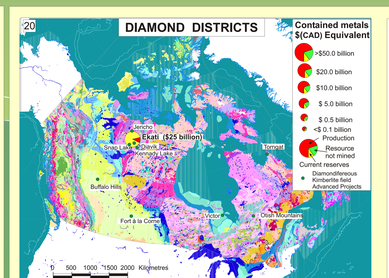
15 **Magmatic Ni-Cu-PGE**

Definition
Ni-Cu-PGE sulphide concentrations in mafic-ultramafic igneous intrusions and volcanic flows.
Commodities
Ni, Cu, PGE.
Economic attraction
High value.
Tectonic 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 boleiitic 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.



19 **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.
Tectonic setting
1. Intracontinental sedimentary basins.
2. Intracontinental or epicontinental sedimentary basins.
3. High grade metamorphic granitic terranes.
Genetic models
1.At redox front involving 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.

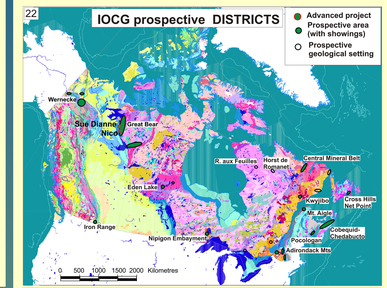


17 **Porphyry Deposits**

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.
Tectonic 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 the younger segments of the Cordillera, where the depth of erosion is relatively shallow and these high level continental deposits have been preserved. With the exception of Gaspe 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 on tonnage vs cut-off grade for the deposit types, and the socio-economic factors associated with open pit mining.

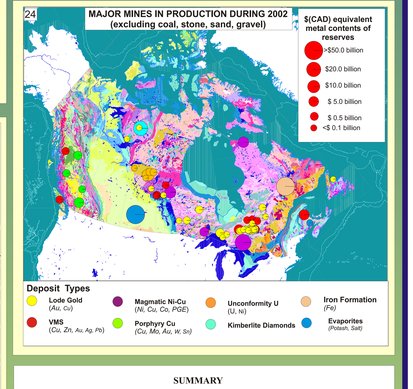
21 **Kimberlite Diamonds**

Definition
Kimberlite craters and diatremes containing diamond xenocrysts of sufficient grade and stone quality to be economic.
Commodities
Diamonds.
Economic attraction
High value.
Tectonic setting
Areas of thick lithosphere, usually underlain by Archean crust
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.



23 **IOCG Deposits**

Definition
Stratiform, stratabound or discordant breccia bodies, veins, disseminations and massive bodies of low-Ti magnetite and/or hematite with polymetallic enrichments, especially Cu and Au, that are genetically associated with granitic to diorritic plutons with A-type geochemical affinities or with carbonatite.
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. Some world-class deposits (e.g. Olympic Dam, Kimavaara, Bayan Obo, Candelaria) have been classified as the IOCG type, and therefore similar deposits are an attractive exploration target. 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.



SUMMARY

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 of exterior coasts and along the border with the U.S.A. (Panels 6, 8, 10, 12, 14, 16, 18, 22, 24). This corridor is distinguished from the frontier area of interior Canada by it having a surface transportation infrastructure connecting established communities.

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 frontier areas are:
- High value, small bulk commodities (e.g. diamonds and gold) amenable to a FIFO mining strategy.
- Other deposit types (e.g. Ni-Cu-PGE, VMS, 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.
- Airborne geophysical and regional geochemical ipeorrneiral surveys.
- Development and testing of ore deposit genetic/exploration models to recognize the geological environments with high mineral potential.

The reserve:production ratios for Lode Gold, VMS, Sedex and MVT deposits (Panel 5) 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.

Recommended citation
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