INTRODUCTION

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O.R. Eckstrand, W.D. Sinclair, and R.I. Thorpe

OBJECTIVE AND SCOPE

The objective of this volume is to define and summarize in a brief and systematic manner the essential characteristics of all economically significant types of Canadian mineral deposits. These summaries reflect the current general understanding of mineral deposits, and correspond closely to the definitions of mineral deposit types in common use.

Each deposit type summary begins by identifying the main diagnostic geological characteristics, the contained commodities, and examples of deposits of that type, both Canadian and foreign. It subsequently outlines the economic significance, typical size and grade of deposits, and geological features such as geological setting, age, host rocks, associated rocks, form and distribution of mineralization, mineralogy, and alteration. Genetic models, related deposit types, and guides to exploration are also summarized. References and a selected bibliography provide an introduction to the most relevant literature.

Deposits of metallic minerals and some industrial minerals are treated in this volume, but not those of fossil fuels. Each deposit type included in this volume has accounted for at least a moderate or historically significant amount of Canadian production and/or reserves, is represented by mineral occurrences in Canada, or is judged to have potential for significant undiscovered deposits in Canada. Although these guidelines are rather subjective, the resulting collection of deposit types is intended to encompass those that are relevant in the Canadian context.

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Because the emphasis in this volume is on mineral deposit types rather than individual deposits, not all Canadian mineral deposits are described, or even mentioned. The examples described are generally those that have been most studied, commoly because of their economic importance and hence their accessibility, or because they are geologically well preserved.

DEFINITION

Mineral deposits are natural concentrations of one or more mineral commodities. They are the products of various geological processes that have operated in a wide range of geological environments. Within a specified geological setting, or a restricted range of related settings, and under similar conditions (such as temperature, pressure, structural conditions favouring fluid flow, availability of metal sources) a particular genetic process or processes operate to produce mineral concentrations with similar characteristics. Such processes include fractional crystallization of magmas, late stage release of volatiles from crystallizing magmas, magma-country rock interaction, metamorphic dewatering, reduction of oxidizing groundwaters or formation waters, mineral precipitation produced or influenced by organisms, and many others. If more than one ore element is concentrated by a specific process or combination of processes, it is because those elements have similar geochemical properties, and were available in that environment. Most geological processes have recurred repeatedly throughout geological history and around the globe. It is not surprising, therefore, that mineral deposits having similar geological characteristics and suites of commodities occur in comparable settings at numerous locations throughout the world in rocks of different ages.

Mineral deposits that are similar in these ways constitute a mineral deposit type. This leads to the following empirical definition: **a "mineral deposit type" is a**

collective term for mineral deposits that (a) share a set of geological attributes, and (b) contain a particular mineral commodity or combination of commodities such that (a) and (b) together distinguish them from other types of mineral deposits.

Two important corollaries follow from this definition. The first is that **mineral deposits of the same type are likely to have a common or similar mode of genesis**. The concept of a mineral deposit type has great importance for geologists concerned with the genesis of mineral deposits. This is because the definition of a mineral deposit type is a convenient summary of the main attributes that any genetic theory must explain.

Perhaps more importantly, the second corollary is that **rock assemblages which contain the geological attributes that are characteristic of a particular mineral deposit type have the best potential for containing mineral deposits of that type**. Thus, a knowledge of the kinds of rocks and structures, and tectonic, sedimentary, and magmatic environments that typify a certain deposit type, aided by an understanding of its genesis, allows the exploration geologist to focus on the geological areas most likely to contain undiscovered deposits of that type.

Recognition of "types" of mineral deposits is a convenience practiced widely by economic geologists in both mineral exploration and research on ore genesis. Hence the concept of mineral deposit types is a fundamental one in the methodology of all practicing economic geologists.

"Model" is another term that is commonly associated with distinct groups of deposits, in somewhat the same manner as is "type". In this volume, however, the term "type" is preferred in order to emphasize the empirical characteristics that allow groups of deposits to be distinguished from one another, and therefore corresponds closely only to the term "descriptive model". "Genetic models", on the other hand, are considered to be important facets of mineral deposit geology but are not used as criteria for identification of deposit types. This is because an empirically defined type is the main basis on which a genetic model is formulated. It happens commonly that a small addition of new empirical information about a deposit type can lead to a dramatic change in the corresponding genetic model. Thus, genetic models may rise and fall in popularity depending on preferred interpretations, whereas the descriptive models of deposit types represent continually growing databases of information. In this sense, a carefully defined type or descriptive model is more robust, and has a longer useful "life" than its corresponding genetic model.

The usual definition of "ore" is used, namely, material that can be processed to recover useful mineral commodities for purposes of anticipated economic or strategic gain.

MINERAL DEPOSIT TYPES: SOURCES OF MINERAL COMMODITIES

Most mineral deposit types and subtypes that are known or inferred in Canada are listed in the Table of Contents, and additional subtypes are defined in some of the individual mineral deposit type/subtype descriptions. The total number of types and subtypes thus defined is 77. Of these, 21 (shown in bold in the Table of Contents) account for "significant" production in Canada, either currently or in the past.

More than 18 mineral commodities were produced in significant amount in Canada in 1987 (Fig. 1A, Table 1), but two-thirds of the total value was derived from just 4 of these commodities (Au, Zn, Cu, Ni). This mineral production was

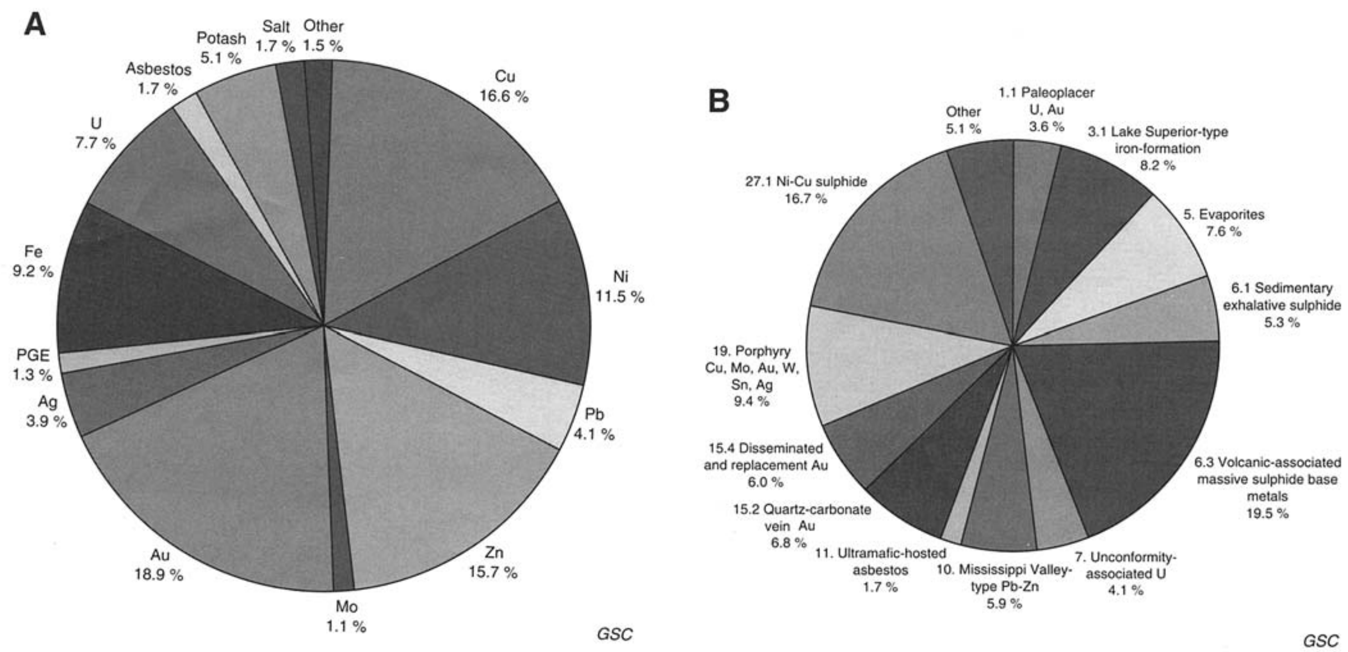

Figure 1. Diagrams illustrating relative proportions of total Canadian mineral production values (1987) by **A)** mineral commodities, and **B)** mineral deposit types.

obtained from more than 25 deposit types (Fig. 1B), but nearly two-thirds of the value of production was obtained from only 5 of these deposit types (6.3 Volcanic-associated massive sulphide base metals; 27.1 Nickel-copper sulphide; 19 Porphyry copper, molybdenum, gold, tungsten, tin, silver; 3.1 Lake Superior-type iron-formation; and 5 Evaporites).

The relationship between mineral commodities and their deposit type sources is illustrated in Table 1. In this table, mineral commodities that were produced in 1987 are listed in the top row, and the deposit types from which they were produced are listed in the left hand column. The numbers listed in the body of the table show, for example, that 300 283 t of zinc valued at CAN$ 382.6 million were produced from sedimentary exhalative sulphide deposits (subtype 6.1), and this represents 17.6% of all zinc produced in Canada in 1987. It may be seen in the bottom row that a total of 1 706 145 t of zinc valued at CAN$ 2147 million were produced in Canada in that year, representing 15.7% of the total value of mineral commodities produced. Similarly, in the right hand column it is seen that sedimentary exhalative sulphide deposits yielded commodities totalling CAN$ 733.6 million in value, representing 5.3% of the total value of all commodities produced in Canada in 1987.

From some mineral deposit types, only a single mineral commodity is produced (e.g., 11 Asbestos); other deposit types produce a number of commodities (e.g., 6.1 Sedimentary exhalative sulphide; 6.3 Volcanic-associated massive sulphide base metals; 19 Porphyry copper, molybdenum, gold, tungsten, tin, silver; and 27.1 Nickel-copper sulphide). Furthermore, some commodities are available from only a single deposit type (e.g., potash), whereas others are recovered from numerous deposit types (e.g., gold, silver, copper, lead, zinc). These associations of commodities in deposit types are the result of (1) the particular processes by which the elements are concentrated, and (2) the similar geochemical behaviors of the associated elements.

DISTINGUISHING MINERAL DEPOSIT TYPES

Many of the mineral deposit types cited here have been recognized and known for a long time; for example, veins of gold (15.2 Quartz-carbonate vein gold) and sedimentary iron deposits (3.3 Ironstone). Others, such as komatiitic nickel deposits (deposit subtype 27.1c), have only been formally recognized as a distinct deposit type for less than 25 years. Still others, such as volcanic redbed copper deposits (deposit Type 9), have received little previous recognition as deposit types. Characterization and understanding of various mineral deposit types evolves continuously as a result of discovery and study of additional mineral deposits, and of advances in research on ore-forming processes and the paleoenvironments in which mineral deposits have formed.

In attempting to classify deposits into types, it is inevitable that some types can usefully be subdivided into two or more subtypes, thus introducing hierarchy into the organizational scheme. This is, for example, clearly the case for the magmatic nickel-copper-platinum group element (PGE) deposit type (27), not only for the purpose of acknowledging the differences between Ni-Cu deposits and PGE deposits, but also for discriminating amongst the various subtypes of Ni-Cu deposits. Subdivision of mineral deposit types into subtypes is a useful way to acknowledge genetic affiliations, while maintaining distinctions that are significant genetically and for exploration purposes. In the opposite sense, the possibility of grouping deposit types can arise; some deposit types that appear rather distinct because of their mining and exploration characteristics can be grouped because they share enough geological similarities that they are better viewed as variants of one type rather than as unrelated types. A good example would be placer gold deposits of the Klondike (1.2 Placer gold, platinum) and paleoplacer uranium deposits of Elliot Lake (1.1 Paleoplacer uranium, gold).

It is inevitable that different choices could have been made in the "lumping and splitting" of types and subtypes. For example, given more emphasis on structure and less on contained metals, the various vein deposit types could have been viewed as subtypes of a single type ("Vein deposits").

Another inherent difficulty in devising a uniform treatment of deposit types is the uneven state of our documentation of mineral deposits. For instance, the many studies on volcanic-associated massive sulphide deposits, porphyry copper deposits, and ultramafic-associated nickel deposits have led to a relatively good appreciation of their characteristics, and have resulted in a relatively clear definition of their types and subtypes. However, other deposits (e.g. some vein deposits) have not received the same attention, and recognition of their specific subtypes seems correspondingly vague.

Names of mineral deposit types

The scheme adopted for the naming of deposit types uses a mixture of traditional and newly proposed terms. Traditional terms such as "placer gold", "Mississippi Valley-type lead-zinc", and "Exhalative base metal sulphide" have been retained. In general, terms are intended to be descriptive, and in most cases consist of two parts. The first part refers to the most noteworthy geological characteristic of that type, which in most cases is the rock association or the related structure. Thus "sandstone-hosted" refers to a type that occurs in sandstone, and "unconformity-associated" refers to one that occurs at or near unconformities. The terms "-hosted" and "-associated" are intended to indicate only a spatial relationship between rock and ore, although in many instances a genetic relationship is also accepted. The second part of the name identifies the main commodities. The commodities linked by hyphens (e.g. Nickel-copper sulphide) consistently occur together, whereas those separated by commas (e.g. Placer uranium, gold) do not occur together in all deposits. The commodities listed first constitute the principal recovered products at one or more deposits of the type in question. However, all the commodities so listed are not necessarily recovered from all deposits of that type. Although this scheme results in some cumbersome names, they are considered useful for the sake of clarity.

Listed order of mineral deposit types

Mineral deposit types in the Table of Contents are listed roughly according to increasing temperature of deposition and/or depth of emplacement. Thus placers as surficial deposits are first and some chromite deposits as mantle-derived

Table 1. Selected mineral commodities produced in Canada (1987) listed by deposit type.

Mineral commodity / Units / Mineral deposit type	Cu tonnes M$	Ni tonnes M$	Pb tonnes M$	Zn tonnes M$	Mo tonnes M$	Au kg M$	Ag 1000 kg M$	PGE kg M$	Fe tonnes M$
1.1 Paleoplacer U, Au									
1.2 Placer Au, Pt						4 009.5 $76.3 2.9%			
3.1 Lake Superior-type iron-formation									33 923 000 $1133.0 88.3%
3.2 Algoma-type iron-formation									3 244 000 $108.4 8.4%
4.1 Enriched iron-formation									1 173 000 $39.2 3.1%
5 Evaporites									
6.1 Sedimentary exhalative sulphide	6 809 $16.5 0.7%		229 905 $243.2 42.6%	300 283 $382.6 17.6%		513.6 $9.8 0.4%	264.2 $81.5 15.1%		
6.3 Volcanic-associated massive sulphide base metals	360 823 $873.7 38.0%		146 803 $155.3 27.2%	893 446 $1138.4 52.4%		10 922.2 $207.9 7.9%	1 069.5 $330.0 61.0%		
7 Unconformity-associated U									
10 Mississippi Valley-type Pb-Zn			157 966 $167.1 29.3%	510 368 $650.3 29.9%					
11 Ultramafic-hosted asbestos									
14.1 Arsenide vein Ag-Co							19.8 $6.1 1.1%		
15.1 Epithermal Au						3 157.8 $60.1 2.3%	6.8 $2.1 0.4%		
15.2 Quartz-carbonate vein Au	560 $1.4 0.1%	99 $0.7 <0.1%	77 $0.1 <0.1%	360 $0.5 <0.1%		49 015.8 $933.0 35.5%	11.9 $3.7 0.7%		
15.3 Iron-formation-hosted stratabound Au						8 872.8 $168.9 6.4%	2.1 $0.6 0.1%		
15.4 Disseminated and replacement Au	9 494 $20.9 0.9%					42 539.8 $809.7 30.8%	28.5 $8.8 1.6%		
16 Clastic metasediment-hosted vein Ag-Pb-Zn			4 396 $4.7 0.8%	1 688 $2.2 0.1%			89.3 $27.6 5.1%		
17 Vein copper	14 978 $36.3 1.6%					5 151.4 $98.0 3.7%	10.9 $3.4 0.6%		
18 Vein-Stockwork Sn, W									
19 Porphyry Cu, Mo, Au, W, Sn, Ag	397 280 $961.7 41.8%				17 583 $149.0 99.1%	7 421.7 $141.3 5.4%	160.1 $49.4 9.1%		
20.2 Skarn Cu	6 827 $16.5 0.7%				161 $1.4 0.9%	23.4 $0.4 <0.1%	2.0 $0.6 0.1%		
20.3 Skarn Au						1 944.5 $37.0 1.4%	1.1 $0.3 0.1%		
20.4 Skarn Fe									63 000 $2.1 0.2%
24 Carbonatite-associated deposits									
27.1 Ni-Cu sulphide	153 790 $372.4 16.2%	227 887 $1591.6 100%				4 458.2 $84.9 3.2%	87.1 $26.9 5.0%	10 930 $181.8 100%	
Total amount of commodity produced: (T,kg) Total value of commodity produced: M$ % of total Canadian mineral production	950 561 $2 299.4 16.6%	227 986 $1 592.3 11.5%	539 147 $570.4 4.1%	1 706 145 $2 174.0 15.7%	17 744 $150.4 1.1%	138 030.7 $2 627.3 18.9%	1 753.3 $541.0 3.9%	10 930 $181.8 1.3%	38 403 000 $1 282.7 9.2%

NOTES:
1) Dollar amounts are in 1987 Canadian dollars
2) Ti production was entirely from Allard Lake (26. Mafic intrusion-hosted Ti-Fe); data are confidential
3) W: no production in 1987
4) The production quantities for base and precious metals are based on metal-in-concentrate data; these are the available figures that permit the most reliable identification of the deposit type source of those commodities.
The values of base and precious metal production were calculated by applying average metal prices for that year to the amounts of metals produced.
5) The total value of deposit types does not include the value of minor byproducts such as Te, Se, S, etc.
6) Small, unknown amounts of Au, Cu, and Ag produced from (6.4) Volcanic-associated massive sulphide gold deposits are included under (6.3) Volcanic-associated massive sulphide base metals, (15.3) Iron-formation-hosted stratabound gold, and (15.4) Disseminated and replacement gold.

Sn	Co	U	Nb_2O_5	Asbestos	Potash	Salt	Na_2SO_4	Gypsum	Value of production from deposit type
tonnes M$	tonnes M$	tonnes M$	tonnes M$	tonnes M$	tonnes M$	tonnes M$	tonnes M$	tonnes M$	M$ % of total Canadian mineral production
		4 214 $499.6 46.8%							$499.6 3.6%
									$76.3 0.5%
									$1 133.0 8.2%
									$108.4 0.8%
									$39.2 0.3%
					7 266 700 $705.8 100%	10 129 053 $238.6 100%	342 076 $26.6 100%	9 093 900 $87.0 100%	$1 058.0 7.6%
									$733.6 5.3%
									$2705.3 19.5%
		8 221 $567.2 53.2%							$567.2 4.1%
									$817.4 5.9%
				664 546 $238.0 100%					$238.0 1.7%
									$6.1 <0.1%
									$62.2 0.4%
									$939.4 6.8%
									$169.5 1.2%
									$839.4 6.0%
									$34.5 0.2%
									$137.7 1.0%
3 439 $31.7 100%									$31.7 0.2%
									$1301.4 9.4%
									$18.9 0.1%
									$37.3 0.3%
									$2.1 <0.1%
			2 630 $17.0 100%						$17.0 0.1%
	2 877 $54.5 100%								$2312.1 16.7%
3 439 $31.7 0.2%	2 877 $54.5 0.4%	12 435 $1 066.8 7.7%	2 630 $17.0 0.1%	664 546 $238.0 1.7%	7 266 700 $705.8 5.1%	10 129 053 $238.6 1.7%	342 076 $26.6 0.2%	9 093 900 $87.0 0.6%	$13885.3 100.0%

Key

		Zn	
6.1	Sedimentary exhalative sulphide	300 283	← tonnes of Zn produced from Sedimentary exhalative sulphide deposits
		$382.6	← value of Zn produced (millions of $ Canadian) from Sedimentary exhalative sulphide deposits
		17.6%	← % of all Zn produced in Canada that was obtained from Sedimentary exhalative sulphide deposits

Sources:
- Economic and Financial Analysis Branch, Natural Resources Canada
- Canadian Minerals Yearbook, 1987
- Canadian Minerals Yearbook, 1988

deposits are last. Obviously, this ordering is not precise; many types overlap widely with others in regard to temperature-pressure conditions of formation, and for others, these conditions are not well known. Nevertheless, this order provides a crude "profile" of the sequence of deposit types through the crust.

Organization of content

The content of each summary is organized in a format intended to provide a ready guide to the type of information sought by the reader. The introduction states the main geological characteristics and the principal commodities of the deposit type, and lists typical examples, usually both Canadian and foreign. This is followed by statements of the importance to Canadian and/or world mineral supply, and size and grade of deposits (single ore bodies, clusters of ore bodies, or whole mining camps, depending on information available). Most summaries include a map of Canada that shows the distribution of selected mineral deposits of that type, on a background consisting of a simplified version of the geological provinces.

Under geological features are the main geological characteristics, including the geological setting, age, relation of ore to host rocks, form of deposits, nature and zoning of the ore, mineralogy, and alteration. In diagrams showing geological features, ore and mineralization are highlighted in tones of red. A brief review of the definitive characteristics of the deposit type precedes a discussion of the current genetic model (or models). Finally a list of exploration guides summarizes both practical and speculative ways in which the search for such deposits may be focused. In a few cases, areas with potential for undiscovered deposits are suggested.

After acknowledgments, the reader's entry into additional literature is aided by references or selected bibliography. As the present volume is a highly condensed review, only the references considered most useful to the reader are cited, and these are supplemented by other, uncited publications that are deemed particularly informative. The most highly recommended of these are indicated by asterisks.

Mineral deposits map

The map of Canadian mineral deposits (Fig. 2, in pocket) shows the distribution of approximately 1200 significant deposits, according to their mineral deposit type, size, and contained metals or minerals. In order to provide a relatively simple and readily distinguishable graphic display, the mineral deposit types that are described subsequently in this volume have been grouped into seven major classes which are represented on the map by different symbols. Five of the classes are based on the principal host rocks affiliated with the deposits: these are 1) sediment-associated deposits, 2) volcanic-associated deposits, 3) felsic and intermediate intrusion-associated deposits, 4) alkaline intrusion-associated deposits, and 5) mafic and ultramfic volcanic- and intrusion-associated deposits. The remaining two classes are vein and/or replacement (and other miscellaneous deposits), and placer deposits.

The size of the map symbol reflects the size of the deposit as determined by the total contained metals or minerals, including both past production and existing reserves. Four size classifications are shown; the criteria for determining the size of different deposits are given on the map. No distinction is made between producers, past producers, and nonproducers.

The colour of the map symbol reflects the prinicipal metals or minerals contained in each deposit. For example, red represents copper or copper-dominant deposits and yellow represents precious metals, including both gold and silver.

Not all deposits in the list that accompanies the map (in Appendix) are represented by individual symbols. In some places, one symbol may represent a number of deposits in mining districts such as Cobalt, Kirkland Lake, Highland Valley, and Noranda. Such deposits are listed under a single number, but have been assigned different letters to distinguish them.

The list of deposits has been compiled from a variety of sources, in particular CANMINDEX (an unpublished, index-level, computer-based file of Canadian mineral deposits and occurrences compiled by the Mineral Deposits Subdivision of the Geological Survey of Canada) and the volume Canadian Mineral Deposits Not Being Mined in 1989" (Mineral Bulletin MR 223 of the former Mineral Policy Sector of Energy, Mines and Resources Canada, now the Mining Sector of Natural Resources Canada). Other sources included Provincial government publications and various trade journals, such as *The Northern Miner.* Complete resource data were not available for all deposits; in such cases, estimates of the deposit size were based on limited data, such as the approximate dimensions of the deposit and representative or typical grades.

Acknowledgments

The structure and organization of mineral deposit types that are presented here grew out of wide-ranging discussions over the years with mineral deposits geologists at the Geological Survey of Canada. Exceptional contributions of this nature, as well as overall guidance in determining the scope and structure of this volume, merit the special recognition of Charlie Jefferson and Rod Kirkham. An earlier publication, "Canadian Mineral Deposit Types: A Geological Synopsis" (Geological Survey of Canada, Economic Geology Report 36, 1984) served as a valuable nucleus around which the present volume grew.

Deep appreciation is expressed to all the contributors to this volume. Their efforts have made this undertaking possible. Editorial contributions by Charlie Jefferson, Ian Jonasson, Vlad Ruzixka, and Don Sangter helped bring the volume to completion and are gratefully acknowledged.

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