Giant Metallic Deposits

Future Sources of Industrial Metals

Second Edition

Springer
Preface

This book has been written for those interested in, and concerned about, the future sources of metals for the industry, and through it for the rapidly growing population of the world. At present over 95% of the industrial metals come from mines situated on land and the exceptionally large (giant or world-class) deposits contribute the bulk, regardless of where they are located: one of the most practically relevant lessons of globalization. This role of the oversize deposits is projected to persist until at least the end of this century, but finding them is going to be increasingly more costly and will require all the sophistication and effort the exploration community could muster. This requires a solid broad knowledge to identify prospective areas for more detailed exploration, or to evaluate mineral occurrences available for acquisition, based on the time-tested technique of geological analogy. The chance of finding an orebody by accidentally stumbling upon it, or by unsophisticated prospecting, has by now been severely reduced. As mineral exploration is, and will continue to be, mainly precedent-oriented activity, there has been a need for a comprehensive text to provide essential facts about the global distribution of metals now and in the future, above the textbook level.

The exponential increase of information that includes printed as well as electronic literature has combined with sharply reduced opportunity to access and to follow it, resulting in “knowledge gaps caused by lack of access to deposits or literature” (Cuney and Kyser, 2009). This book has been designed to help, by gathering essential scattered information about the world’s metalliferous giants under a single cover.

The book consists of three parts followed by a database, although the parts are not explicitly marked as such. Part I (Chapters 1–3) is a short review of the changing sources and utilization of metals for the industry, and it explains the various approaches to magnitude classification of ore deposits as related to geochemical backgrounds. Part II (Chapters 4–14) is a factual review of the “ore giants” in a rather loose empirical framework of depositional environments and rock associations. The spectrum of the geological settings follows the plate tectonic arrangement, but the plate tectonic concepts, as related to the actual ore formation, are used sparingly because many are still in the hypothetical realm, they change rapidly, and there is the ubiquitous multiplicity of interpretations. The emphasis here is on the demonstrable, lasting “facts” one can actually see in the field. The closing Part III (Chapters 15–17) deals with the common geological attributes of “ore giants” and how they relate to industrial needs and how ore search or acquisition are influenced by politics and economic factors. It ends up with some revelations as to how and where the future “giants” might be found.

In writing this book I have made a good use of the over 40 years long experience in the ore deposits field, and personal familiarity with at least 4,000 ore sites in some 140 countries and large territories, along with a multilingual reading capability. I have compressed many “facts” into a series of “inventory diagrams” of rocks and ore occurrences in close to 80 lithotectonic settings, interspersed throughout this book. The diagrams came from my electronic book “Total Metallogeny” that also includes the ore types considered of limited significance in addition to the “giants”. This alleviates somewhat my feeling of guilt of catering to the “big and rich” only. The small deposits are, moreover, often indicative of the larger ore presence and have to be recognized and interpreted as such.
The years 2003 through mid-2008 brought us a mineral exploration boom unprecedented since the late 1960s. This followed decades of stagnation of commodity prices, mining industry downturn and decline of exploration. The short boom came to an abrupt end in late 2008 as a consequence of the Great Financial Crisis, but there are already signs of early rebound.

During the recent boom a number of new giant/world class deposits have been discovered and/or announced. As the previously antagonistic politico-economic world systems came closer and globalization advanced, much of the previously unavailable quantitative information on ore deposits in China, the former Soviet Union, Mongolia, Vietnam and Eastern Europe have been gradually published. This has made it possible to quantitatively define additional ore giants the number of which has increased well above the mid-500s quoted in Laznicka (1999). These additions and some interpretational changes created a need for updated text. It has been a pleasure to accept the Publisher’s invitation to prepare a second edition of this book which, in addition to new data, also benefits from the rapid progress of electronic publishing and information transfer. The first book edition has been warmly accepted, especially by the exploration industry that has also provided valuable new unpublished information, site access, feedback and critique.

Acknowledgments: More than 2,000 references in this book and additional ones in the database make it clear that this is a collective undertaking, an extract of knowledge generated by tens of thousands of colleagues in the industry, governments and academia. The shared purpose and enthusiasm of international professionals and students supported a wonderful, politically neutral fellowship, very helpful in alleviating the antagonism that divides this world along political, religious, racial, wealth and other lines. My thanks thus go to the thousands of persons and organizations who provided direct or indirect help to keep my project moving, and all I can do is to print a short list of names, the tip of an iceberg. The main supporters were: Amira International, Christian Amstutz, Anglo-American Corporation, Australian Mineral Foundation, Australian Selection Ltd., Chris Bates, Rob Bills, BP Minerals, Alfred Bogaers, Bill Brisbin, Leif Carlson, Chen Guoda, Roy Corrans, CVRD Ltd., Directorate of Mineral Resources Jeddah, Peter Freeman, Geoscience Australia, Magnus Garson, Alan Goode, David Groves, G. von Gruenewaldt, Greg Hall, Douglas Haynes, Paul Heithersay and PIRSA Adelaide, INCO Ltd., Douglas Kirwin, Mel Kneeshaw, KSA Geological Survey, Jan Kutina, Jim Lalor, Manitoba Geological Survey, Don Mustard, Národní Museum Praha, Jingwen Mao, Normandy Ltd., Kerry O’Sullivan, Zdeněk’s Pertold and Poubal, Rio Tinto Ltd., Dimitri Rundkvist, Phil Seccombe, Nikos Skarpelis, Art Soregaroli, Teck Ltd., Jim Teller, Universities of Manitoba, Charles (Prague), Colombia-Medellín, Heidelberg, Moscow State, New England, Oriente (Cuba), Western Australia and Zimabwe; Cesar Vidal, Richard Viljoen, Western Mining Ltd, HDB Wilson, Karl Wolf, Roy Woodall, Zhai Yusheng, and many others.

The actual book writing has been a lonely affair, as one of the organizations that brought me to Australia (AMF) went out of business so I have had to do without access to my own materials locked in containers for the fifth consecutive year, as well as a lack of technical assistance from anywhere: a source of immense frustration in struggling with the computer while physically manufacturing the ready to print document. I am grateful to Springer-Verlag in Heidelberg, especially to Dr. Christian Witschel for invitation to prepare second edition of this book and thank Ms. Almas Schimmel for bringing it into production. My geological wife Šárka, a most reliable co-worker, deserves the greatest thanks.

Peter Laznicka, Adelaide, January 2010
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16th Century mine dewatering technology from Georgius Agricola’s De Re Metallica Libri XII
Book Context and Background

This book is a self-contained member of a much broader realistic knowledge system about the world’s mineral deposits and their settings that supplied most figures found in this book (Fig. A1). Two types of figures are predominant and have to be explained:

- Rock/ore ‘inventory diagrams’ rendered in color in the electronic version of this book (Fig. A2) are a variety of empirical models of rock-forming environments and associations that include plots of ore deposits (not only giant). These graphs have been selected and reprinted from the book and posters ‘Total Metallogeny-Geosites’ (Laznicka 2001, 2004) that include 240 of such sets (with descriptions and databases) that cover the entire spectrum of geological settings (‘geosites’);

- Cross-sections of ore deposits labeled ‘from LITHOTHEQUE’ (Fig. A3). These come from explanation sheets for sets of miniaturized rock/ore samples permanently attached to aluminum plates and stored like books in a ‘rock library’ (=Lithotheque, LT). This ‘library’ is the core component of a knowledge (expert) system about ore deposits of the world and their settings Data Metallogenica (DM) presently managed by Amira International (www.amira.com.au), and my own DMO (DMO). Each LT figure here has a reference number under which it is listed in DM(O) and can be accessed electronically at www.datametallogenica.com for those with subscription. There, each LT entry comprises high resolution photos of geological samples, descriptions, references, some field photos and graphics. The physical collection (~4000 entries from ~85 countries) on which the images are based presently awaits re-installation in Adelaide. 90% of the geological materials in DM have been collected by Peter Laznicka on location between 1970 and 2010 and this author also prepared and drafted the figures modified from quoted references. I accept responsibility for the inevitable errors I may have introduced while trying to produce uniform and mutually comparable graphics. The Lithotheque system and its application in exploration and metallogeny is briefly described in Epilogue (the last Chapter) and in Laznicka (2010).

Figure A2. Total Metallogeny rock units (numbered) and ore occurrences (marked by letters) in the Precambrian komatiite association. About 70 similar graphs (out of a total of 240) appear throughout this book.

Figure A3. A typical cross-section of a deposit taken from LITHOTHEQUE explanation sheet, several hundred of which appear throughout this book. Note the reference number of the plate {From LITHOTHEQUE No. 2420 modified after Atkinson et al. (1996)}. This is the Figure 7.8. of Los Pelambres porphyry Cu-Mo, Chile (in Chapter 7) and the numbered objects (rock units) and lettered objects (various types of mineralization, hydrothermal alteration, breccias, etc.) are explained in figure captions. The rock units are numbered from youngest to oldest. Abbreviations of objects used throughout this book are explained below.
REFERENCE BOOK
desk reading, introductory information

DATA METALLOGENICA (ORIGINAL)
on-line data on world’s mineral deposits
based on miniaturized sample sets

DATA METALLOGENICA
PHYSICAL COLLECTION
~70,000 miniaturized rock/ore samples from
~4000 localities in ~80 countries that can be browsed,
examined and nondestructively tested

FIELD LOCALITIES
(DEPOSITS) the ultimate object
of geoscientific learning

CONVENTIONAL CONCEPTUAL & EMPIRICAL ORE MODELS

TOTAL METALLOGENY-GEOSITES
collection of graphs and text showing place of ore
deposit types in 240 geological settings and associations
Figure 2 (on left). This book can be used as a starting point to a more extensive knowledge search about world’s metallic deposits. Giant deposits briefly described here with cross-sections marked ‘from LITHOTHEQUE’ (LT) and provided with a LT number (e.g. LT 2184) are represented in the Data Metallogenica (Original) knowledge system (DM(O)); and can be accessed on-line at www.datametallogenica.com (by readers with DM subscription). Total Metallogeny-Geosites (TM) is a book, database and a 3m long poster (Laznicka, 2004) that integrates, compares and extends information contained in the rock/ore ‘inventory diagrams’ (graphs) interspersed throughout this book. Geosites can be browsed to establish similarity (or a lack of) among various local geological settings and to suggest potentially present ore types. Geosites, in turn, merge into empirical, hybrid and conceptual models as published in the literature (e.g. the 2005 Economic Geology 100th Anniversary Volume). Field site visits are the ultimate object of geological learning and experience. More information about these systems and how they can assist mineral exploration and prediction appear in the closing chapter (Epilogue).

Explanations of uniform styles, numbering and lettering used in figures marked ‘from LITHOTHEQUE’

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Rock units, arranged from the youngest to the oldest</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>Mineralization; sites of metal accumulation, in most cases economic orebodies. Massive to densely distributed ores are shown in solid black; disseminated, stringer, etc. ores are shown by outline</td>
</tr>
<tr>
<td>M1, M2...</td>
<td>Various styles of mineralization</td>
</tr>
<tr>
<td>MW</td>
<td>Weathering-modified ‘primary’ orebodies, e.g. gossans, oxidation zones</td>
</tr>
<tr>
<td>A</td>
<td>Hydrothermally altered rocks</td>
</tr>
<tr>
<td>A1, A2...</td>
<td>Various types of alteration</td>
</tr>
<tr>
<td>MA</td>
<td>Mineralization and alteration considered jointly</td>
</tr>
<tr>
<td>F</td>
<td>Fault filling rocks (e.g. gouge, breccia, mylonite, phyl lonite, etc.); fault traces are shown as wavy lines, usually not labeled</td>
</tr>
<tr>
<td>FA</td>
<td>Hydrothermally altered fault rocks</td>
</tr>
<tr>
<td>Bx</td>
<td>Breccias</td>
</tr>
<tr>
<td>W</td>
<td>Weathered rocks (and ores)</td>
</tr>
<tr>
<td>W3, 5W...</td>
<td>Weathered numbered rock units</td>
</tr>
</tbody>
</table>

Geological ages

They are widely abbreviated in figures, tables and lists as letter codes, or they have the form of Ma (millions of years ago) or Ga (billions of years ago). In explanations to the ‘from LITHOTHEQUE’ graphs letter abbreviations (e.g. Pe=Permian; Cm=Cambrian) or Ma/Ga values appear at the start of the explanatory sentence, e.g. Cm3 Bonnerete Formation limestone. 1, 2, 3 stand for Lower, Middle and Upper, e.g. Cm3=Upper Cambrian. For list of abbreviations please see Table A.1.

Table A.1 (upper right). Abbreviations of geological ages used in figures, tables and lists. Most abbreviations correspond to Series but if this is not available (or the age spans several Series) a System, Erathem or Eonothem are used. The geochronology is after the International Union of Geological Sciences 1989 Global Stratigraphic Chart.

<table>
<thead>
<tr>
<th>Stratigraphic division</th>
<th>Age Ma</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Phanerozoic</td>
<td></td>
<td>PhZ</td>
</tr>
<tr>
<td>Cenozoic</td>
<td></td>
<td>CZ</td>
</tr>
<tr>
<td>Quaternary</td>
<td>1.6</td>
<td>Q</td>
</tr>
<tr>
<td>Tertiary</td>
<td></td>
<td>T</td>
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<tr>
<td>Pliocene</td>
<td>5.3 (4.8)</td>
<td>Pl</td>
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<tr>
<td>Miocene</td>
<td>23 (23.7)</td>
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<tr>
<td>Oligocene</td>
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<tr>
<td>Eocene</td>
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<td>Eo</td>
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<tr>
<td>Paleocene</td>
<td>65 (64.4)</td>
<td>Pc</td>
</tr>
<tr>
<td>Mesozoic</td>
<td></td>
<td>MZ</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>135 (140)</td>
<td>Cr</td>
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<tr>
<td>Jurassic</td>
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<td>Paleozoic</td>
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<td>Permian</td>
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<tr>
<td>Devonian</td>
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<tr>
<td>Silurian</td>
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<tr>
<td>Ordovician</td>
<td>510</td>
<td>Or</td>
</tr>
<tr>
<td>Cambrian</td>
<td>570 (540)</td>
<td>Cm</td>
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<td>Mp</td>
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<tr>
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<td>2500</td>
<td>Pp</td>
</tr>
<tr>
<td>Archean</td>
<td>4200</td>
<td>Ar</td>
</tr>
</tbody>
</table>

Ma figures are the lower age boundaries of each division

Miscellaneous abbreviations

| BIF   | Banded iron formation |
| MORB  | Mid-ocean ridge basalt |
| MVT   | Mississippi Valley Type |
| VMS   | Volcanic-associated massive sulfides (also spelled VHMS) |
| sedex | Sedimentary-exhalational |