



SEG
www.segweb.org

BARRICK

Special Publication Number 23

Geology of the World's Major Gold Deposits and Provinces

Richard H. Sillitoe, Richard J. Goldfarb,
François Robert, and Stuart F. Simmons, Editors

Special Publication Number 23
Commemorating the 100th Anniversary of
The Society of Economic Geologists, Inc.

Special Publications of the Society of Economic Geologists

Special Publication Number 23

Geology of the World's Major Gold
Deposits and Provinces

Richard H. Sillitoe, Richard J. Goldfarb,
François Robert, and Stuart F. Simmons, Editors

First Edition 2020

Printed by
Allen Press, Inc.
810 East 10th St.
Lawrence, Kansas 66044
www.allenpress.com

Additional copies of this publication can be obtained from
Society of Economic Geologists, Inc.
7811 Shaffer Parkway
Littleton, CO 80127
www.segweb.org/store

ISSN
1547-3112 (Print)
2639-1910 (Online)

ISBN
978-1-629493-12-1 (Print)
978-1-629496-42-9 (Online)

© 2020 Society of Economic Geologists, Inc.

On the cover: Front cover photo displaying high-grade Timiskaming conglomerate hosting folded carbonate-pyrite-quartz veins with visible gold, Dome mine (see paper by Dubé et al.); photo on the back cover is the Grasberg mine, taken in 2015, looking northeast and showing the ~2.5-km-diameter open pit and the surrounding area (see Leys et al.).

SPONSOR

BARRICK

The Society of Economic Geologists Publications Board thanks
Barrick Gold Corporation for generous financial support of this volume.



SEG Publications Board

Shaun L.L. Barker, *Chair*
Pilar Lecumberri Sanchez
Patrick Mercier-Langevin

Elizabeth R. Sharman
Ross L. Sherlock

Brian G. Hoal, *Executive Director, ex officio*
Lawrence D. Meinert, *Editor, Economic Geology*
J. Bruce Gemmill, *Editor, SEG Discovery*

SOCIETY OF ECONOMIC GEOLOGISTS, INC.
Special Publication Number 23

Contents

*Papers and Appendices are on the flash drive attached to the
inside back cover of this publication*

Sponsor		iii
Forward		ix
Preface		xi
Introduction		
1	Gold Deposit Types: An Overview	<i>Richard H. Sillitoe</i> 1
Precambrian Gold Deposits		
2	Metallogeny of the Neoproterozoic Malartic Gold Camp, Québec, Canada	<i>Stéphane De Souza, Stéphane Perroudy, Benoît Dubé, Patrick Mercier-Langevin, Robert L. Linnen, and Gema R. Olivo</i> 29
3	Gold Deposits of the World-Class Timmins-Porcupine Camp, Abitibi Greenstone Belt, Canada	<i>Benoît Dubé, Patrick Mercier-Langevin, John Ayer, Jean-Luc Pilote, and Thomas Monecke</i> 53
4	Hemlo Gold System, Superior Province, Canada	<i>K. Howard Poulsen, Rodney Barber, and François Robert</i> 81
5	The Low-Grade, Neoproterozoic, Vein-Style, Carbonaceous Phyllite-Hosted Paracatu Gold Deposit, Minas Gerais, Brazil	<i>Nicholas H.S. Oliver, Brian Thomson, Flavio H. Freitas-Silva, and Rodney J. Holcombe</i> 101
6	The Super-Giant, High Grade, Paleoproterozoic Metasedimentary Rock- and Shear Vein-Hosted Obuasi (Ashanti) gold deposit, Ghana, West Africa	<i>Nicholas H.S. Oliver, Andrew Allibone, Michael J. Nugus, Carlos Vargas, Richard Jongens, Richard Peattie, and Vaughan A. Chamberlain</i> 121
7	Paleoproterozoic Gold Deposits of the Loulo District, Western Mali	<i>Andrew Allibone, David Lawrence, John Scott, Mark Fanning, James Lambert-Smith, Paul Stenhouse, Reinet Harbidge, Carlos Vargas, Rose Turnbull, and Joel Holliday</i> 141
8	The World-Class Gold Deposits in the Geita Greenstone Belt, Northwestern Tanzania	<i>P.H.G.M. Dirks, I. V. Sanislav, M. R. van Ryt, J-M Huizenga, T. G. Blenkinsop, S. L. Kolling, S. D. Kwelwa, and G. Mwazembe</i> 163
9	Orogenic Gold Deposits of the Kibali District, Neoproterozoic Moto Belt, Northeastern Democratic Republic of Congo	<i>Andrew Allibone, Carlos Vargas, Etienne Mwandale, Justus Kwibisa, Richard Jongens, Sarah Quick, Nathan Komarnisky, Mark Fanning, Philip Bird, Doug MacKenzie, Rose Turnbull, and Joel Holliday</i> 185
10	Olympiada Gold Deposit, Yenisei Ridge, Russia	<i>A. M. Sazonov, K. V. Lobanov, E. A. Zvyagina, S. I. Leontiev, S. A. Silyanov, N. A. Nekrasova, A. Y. Nekrasov, A. B. Borodushkin, V. A. Poperekov, V. V. Zhuravlev, S. S. Ilyin, Yu.A. Kalinin, A. A. Savichev, and A. S. Yakubchuk</i> 203

11	The Telfer Gold-Copper Deposit, Paterson Province, Western Australia	<i>Alan J. Wilson, Nick Lisowiec, Cameron Switzer, Anthony C. Harris, Robert A. Creaser, and C. Mark Fanning</i>	227
12	Geologic Setting and Gold Mineralization of the Kalgoorlie Gold Camp, Yilgarn Craton, Western Australia	<i>Jordan A. McDivitt, Steffen G. Hagemann, Matthew S. Baggott, and Stuart Perazzo</i>	251
13	Boddington: An Enigmatic Giant Archean Gold-Copper (Molybdenum-Silver) Deposit in the Southwest Yilgarn Craton, Western Australia	<i>Stephen J. Turner, Graeme Reynolds, and Steffen G. Hagemann</i>	275
Phanerozoic Gold Deposits			
14	The Brucejack Au-Ag Deposit, Northwest British Columbia, Canada: Multistage Porphyry to Epithermal Alteration, Mineralization, and Deposit Formation in an Island-Arc Setting	<i>Warwick S. Board, Duncan F. McLeish, Charles J. Greig, Octavia E. Bath, Joel E. Ashburner, Travis Murphy, and Richard M. Friedman</i>	289
15	Goldstrike Gold System, North Carlin Trend, Nevada, USA	<i>Paul J. Dobak, François Robert, Shaun L.L. Barker, Jeremy R. Vaughan, and Douglas Eck</i>	313
16	Giant Carlin-Type Gold Deposits of the Cortez District, Lander and Eureka Counties, Nevada	<i>Mark A. Bradley, L. Page Anderson, Nathan Eck, and Kevin D. Creel</i>	335
17	Epithermal Gold Deposits Related to Alkaline Igneous Rocks in the Cripple Creek District, Colorado, United States	<i>Karen D. Kelley, Eric P. Jensen, Jason S. Rampe, and Doug White</i>	355
18	Geology of Round Mountain, Nevada: A Giant Low-Sulfidation Epithermal Gold Deposit	<i>David A. Rhys, Nadia St. Jean, Rodolfo Lagos, David Emmons, George A. Schroer, and Richard Friedman</i>	375
19	The Peñasquito Gold-(Silver-Lead-Zinc) Deposit, Zacatecas, Mexico	<i>Omar Dromundo, Sigfrido Robles, Thomas Bissig, Claudio Flores, Maria del Carmen Alfaro, and Lorenzo Cardona</i>	399
20	The Pueblo Viejo Au-Ag-Cu-(Zn) Deposit, Dominican Republic	<i>Jeremy Vaughan, Carl E. Nelson, Guillermo Garrido, Jose Polanco, Valery Garcia, and Arturo Macassi</i>	415
21	Geology of the Fruta del Norte Epithermal Gold-Silver Deposit, Ecuador	<i>Stephen Leary, Richard H. Sillitoe, Jorge Lema, Fernando Téliz, and Diego Mena</i>	431
22	Gold Deposits of the Yanacocha District, Cajamarca, Peru	<i>Richard Pilco and Sean McCann</i>	451
23	Alteration, Mineralization, and Age Relationships at the Kışladağ Porphyry Gold Deposit, Turkey	<i>T. Baker, S. Mckinley, S. Juras, Y. Oztas, J. Hunt, L. Paolillo, S. Pontual, M. Chiaradia, A. Ulianov, and D. Selby</i>	467
24	Muruntau, Uzbekistan: The World's Largest Epigenetic Gold Deposit	<i>Reimar Seltmann, Richard J. Goldfarb, Bo Zu, Robert A. Creaser, Alla Dolgoplova, and Vitaly V. Shatov</i>	497
25	The Sukhoi Log Gold Deposit, Russia	<i>G. L. Vursiy, I. A. Zibrov, S. G. Lobov, and A. S. Yakubchuk</i>	523
26	Geology of the Hishikari Gold Deposit, Kagoshima, Japan	<i>Takayuki Seto, Yu Yamato, Ryota Sekine, and Eiji Izawa</i>	545

27	Geology of the Porgera Gold Deposit, Papua New Guinea	<i>Jonathan P. Hay, Mark M. Haydon, and François Robert</i>	559
28	Lihir Alkalic Epithermal Gold Deposit, Papua New Guinea	<i>David R. Cooke, Stephanie Sykora, Erin Lawlis, Jacqueline L. Blackwell, Mathieu Ageneau, Nicholas H. Jansen, Anthony C. Harris, and David Selley</i>	579
29	Grasberg Copper-Gold-(Molybdenum) Deposit: Product of Two Overlapping Porphyry Systems	<i>Clyde Leys, Adam Schwarz, Mark Cloos, Sugeng Widodo, J. Richard Kyle, and Julius Sirait</i>	599
30	Geologic Evolution of Late Ordovician to Early Silurian Alkalic Porphyry Au-Cu Deposits at Cadia, New South Wales, Australia	<i>Anthony C. Harris, David R. Cooke, Ana Liza Garcia Cuison, Malissa Groome, Alan J. Wilson, Nathan Fox, John Holliday and Richard Tosdal</i>	621
Gold Provinces			
31	Geologic Evidence of Syngenetic Gold in the Witwatersrand Goldfields, South Africa	<i>Hartwig E. Frimmel and Glen T. Nwaila</i>	645
32	Gold Deposits of the Archean Abitibi Greenstone Belt, Canada	<i>Benoît Dubé and Patrick Mercier-Langevin</i>	669
33	Neoproterozoic Eastern Goldfields of Western Australia	<i>Gerard I. Tripp, Richard M. Tosdal, Thomas Blenkinsop, Jamie R. Rogers, and Scott Halley</i>	709
34	The Paleoproterozoic (Rhyacian) Gold Deposits of West Africa	<i>Nicolas Thébaud, Andrew Allibone, Quentin Masurel, Aurélien Eglinger, James Davis, Anne-Sylvie André-Mayer, John Miller, Morou François Ouedrago, and Mark Jessell</i>	735
35	Gold Deposits of the Jiaodong Peninsula, Eastern China	<i>Kun-Feng Qiu, Richard J. Goldfarb, Jun Deng, Hao-Cheng Yu, Zong-Yang Gou, Zheng-Jiang Ding, Zhao-Kun Wang, and Da-Peng Li</i>	753
36	Carlin-Type Gold Deposits in Nevada: Geologic Characteristics, Critical Processes, and Exploration	<i>John L. Muntean</i>	775
37	Giant Placers of the Upper Kolyma Gold Fields, Yana-Kolyma Province, Russian Northeast	<i>N. A. Goryachev, A. S. Yakubchuk, I. S. Litvinenko, A. V. Lozhkin, Yu. V. Pruss, and V. N. Smirnov</i>	797
Epilogue			
38	Hydrothermal Gold Deposition in Epithermal, Carlin, and Orogenic Deposits	<i>Stuart F. Simmons, Benjamin M. Tutolo, Shaun L.L. Barker, Richard J. Goldfarb, and François Robert</i>	823



Foreword

Mark Bristow Ph.D.

*President and Chief Executive
Barrick Gold Corporation*

Discovery is the source of real value creation in the gold mining industry, which makes exploration our equivalent of a pharmaceutical company's research and development department: the foundation of the business as well as the driver of its growth.

The 100th anniversary of the SEG is an opportune occasion to highlight the critical role of geology in the complexity of modern mining, both as an essential pioneering endeavor and as the provider of the research, analysis, and modeling that will determine the viability of a new discovery and then point the way for its optimal development. At a time when greenfields discoveries are becoming scarcer, it plays an equally important part in extending known asset bases.

For Barrick and for me as a geologist, it is a great pleasure to sponsor this landmark volume, thereby continuing our long association with exploration's foremost professional

organization. Barrick and our legacy company, Randgold, have a long history of exploration success—we contributed to seven of the 29 deposit descriptions featured in these pages—while I have always been committed to putting the geosciences at the core of our operations.

This special volume gives geology its deserved due and provides a timely insight into the world's major gold deposits and provinces. It will be a highly valuable, long-lasting reference for all geoscience practitioners of this and future generations.

I would like to express my appreciation to the editors, Richard H. Sillitoe, Richard J. Goldfarb, François Robert, and Stuart F. Simmons, and to thank the authors for their contributions, along with Brian G. Hoal, Alice Bouley, and Mabel Peterson of the Society of Economic Geologists. In conclusion, I also want to pay tribute to the men and women who walk the hills in search of their next discovery.



Geology of the World's Major Gold Deposits and Provinces: Preface

For economic geologists, be they from academia or industry, gold is an important and fascinating commodity that demands a great deal of their collective research and exploration attention. The metal accounts for roughly half of the world's nonferrous exploration activity, which equates to corporate expenditure on the order of US\$5 billion annually. Although present-day research and exploration employ a myriad of specialized tools and techniques, the basic geologic features of gold deposits—lithologic and structural controls, alteration zoning, lithogeochemistry, and mineralogy—provide the foundation stones for both laboratory studies of and search for gold deposits, and will undoubtedly continue to do so.

It is for this reason that successive SEG Publications Board chairs, Stuart Simmons and Rich Goldfarb, promoted the idea of a volume focused on basic geologic descriptions of the world's major gold deposits and provinces as an ideal contribution to the Society's 100th anniversary celebrations. Selection of the deposits and provinces for inclusion in the volume—SEG Special Publication 23—was no easy task, but total gold content and high average gold tenor were the most influential parameters. Although a number of abandoned deposits, including Homestake in the United States, Kolar in India, and Morro Velho in Brazil, are historically important, it was decided to focus on currently or soon-to-be producing mines and provinces. Some of these (Cripple Creek, Kalgoorlie, Obuasi, Timmins, Witwatersrand) have long and illustrious histories whereas others, including all the low-grade deposits, entered production in the last few decades. Indeed, Fruta del Norte came on stream since the paper was written and Sukhoi Log, although long known, is still at the feasibility stage. Orogenic gold deposits and provinces dominate the volume's content, in keeping with their preeminence for global gold endowment. Nonetheless, the geology of the world's largest gold concentration, the Witwatersrand goldfields of South Africa, also features prominently. It could be perceived that epithermal and porphyry deposits are somewhat under-represented, given their worldwide abundance, the reason being the relatively small size and low grade, respectively, of many of them.

The volume is introduced with a series of thumbnail sketches that attempt to give a general flavor of the principal currently recognized gold deposit types, several of them insufficiently important globally to merit representation, and concludes with a consideration of gold transport mechanisms relevant to the major deposit types. The meat of the volume, however, is in the 29 deposit descriptions and seven province overviews. Each description summarizes exploration history and regional and local geologic settings preparatory to synthesizing the salient lithologic, structural, alteration, and mineralization features of the deposit itself. The province papers address terrane-scale geologic parameters and their controls on the localization, styles, and timing of gold mineralization.

As editors of the volume, we have enjoyed the disparate challenges presented over the past three years and would like to express our appreciation to the authors of the papers—compliant and recalcitrant alike—for their contributions, many prepared during serious competition with corporate duties. We are also indebted to the 63 specialists, listed below, who peer reviewed the manuscripts in timely fashion, to Alice Bouley, Managing Editor of SEG publications, for overseeing production of the volume, to Mabel Peterson, for careful copyediting, and to Laura Doll and Vivian Smallwood, for meticulous handling of layout. Last but not least, the Society offers its sincere thanks to Barrick Gold Corporation for generous sponsorship of the volume.

The Editors

Richard H. Sillitoe
Independent consultant, London

Richard J. Goldfarb
*China University of Geosciences, Beijing and
Colorado School of Mines, Golden, Colorado*

François Robert
Independent consultant, Montreal

Stuart F. Simmons
*Hot Solutions Ltd., Auckland and
University of Utah, Salt Lake City, Utah*

Reviewers of SEG Special Publication 23

Andrew Allibone
Tim Baker
Marc Bardoux
Dave Boden
Dave Braxton
Patrick Browne
Graham Carman
Rob Chapman
Odin Christensen
Tony Christie
Dave Crow
Stéphane DeSouza
Lluís Fontboté
Louis Gauthier
Lynnette Greyling
David Groves
Steffen Hagemann
Scott Halley
Jeff Hedenquist
Ken Hickey
David John

Imants Kavalieris
Steve Kesler
Doug Kreiner
Bruno Lafrance
James Lambert-Smith
Ross Large
Bernd Lehmann
Shoufa Lin
Robert Linnen
Rael Lipson
Tony Longo
James MacDonald
Quentin Masurel
Peter Megaw
Cam McCuaig
Lawrie Minter
Robert Moritz
Jim Mortensen
John Muntean
Miguel Nassif
Evgeniy Naumov

Gema Olivo
Pepe Perelló
Stéphane Perroudy
Franco Pirajno
Howard Poulsen
Stewart Redwood
Mike Ressel
Dave Rhys
Robbie Rowe
Norman Russell
Ross Sherlock
Mike Skead
Sachihiro Taguchi
John Thompson
Tommy Thompson
Steve Turner
Peter Vikre
Yasushi Watanabe
Willy Williams-Jones
Wally Witt
Roberto Xavier