



REVIEWS IN ECONOMIC GEOLOGY

Volume 8

VOLCANIC-ASSOCIATED MASSIVE SULFIDE DEPOSITS: PROCESSES AND EXAMPLES IN MODERN AND ANCIENT SETTINGS

in cooperation with with the Mineral Deposits Division (MDD)
of the Geological Association of Canada (GAC)

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Editors

C.T. Barrie and M.D. Hannington

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C.T. Barrie and M.D. Hannington, Editors

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PREFACE

Volcanic-associated massive sulfide (VMS) deposits are predominantly stratiform accumulations of sulfide minerals that precipitate from hydrothermal fluids at or below the sea floor in a wide range of ancient and modern geological settings. They occur within volcano-sedimentary stratigraphic successions, and are commonly coeval and coincident with volcanic rocks.

The understanding of ancient, land-based VMS deposits has been heavily influenced by the discovery and study of active, metal-precipitating hydrothermal vents on the sea floor. During the last three decades, excellent descriptions of sea-floor sulfides and related vent fluids and hydrothermal plumes have provided modern analogs for the land-based VMS deposits. Conversely, the geology and mineralogy of land-based deposits have provided insight into the plumbing systems and sulfide mineral paragenesis of sulfide deposits relevant to sea-floor hydrothermal systems. This volume capitalizes on the complementary nature of ancient, land-based VMS deposits and active, metal-precipitating hydrothermal systems on the sea floor, and draws equally from land-based and sea-floor VMS research.

The volume attempts to provide a balanced view of VMS systems, with descriptions of the processes involved in VMS formation and important examples representing a variety of VMS deposits and districts in modern and ancient settings. The contributions are divided into two parts, with a classification scheme given as an Introduction. In Part I, reviews of the most significant geological, physical, and chemical processes involved in the formation of land-based and sea-floor VMS deposits are presented. It is not meant to be a comprehensive review;

rather, it presents a spectrum of current ideas based on research over the last 20 years. The papers have been written to be understood by a fourth-year undergraduate or graduate student, and will be a valuable reference for the practicing mineral deposits economic geologist.

The papers presented here stem from a short course held May 17–18, 1997, at Carleton University, Ottawa, Canada. The volume is co-sponsored by the Mineral Deposits Subdivision (MDD) of the Geological Association of Canada and the Society of Economic Geologists (SEG).

We thank the following scientists who have reviewed one or more of the manuscripts in this volume: Jean Bedard, Larry Cathles, Ron Cook, Brian Cousens, Al Coutts, Earl Davis, Udo Fehn, Al Galley, Katherine Gillis, Wayne Goodfellow, Peter Herzig, Dave Huston, Ian Jonasson, Maurice Lambert, Craig Leitch, Dave Lentz, John Lydon, Curtis Manley, Suzanne Paradis, Jan Peter, Mark Reed, Gwillim Roberts, Steve Scott, Tom Setterfield, John Slack, Ed Spooner, Geoff Thurlow, Bob Turner, John Valley, Robert Varga, Anthony Williams-Jones. A number of other individuals have been helpful in the production of this volume, including Hannah Barrie, Alice Bouley, Dick Brown, Bob Cathro, Louise Corriveau, Al Galley, Steven and Daniel Hannington, Anne Labelle, Rachelle Lacroix, Lisa Laird, Mike Leshner, Dave Moore, Patsy Muntean, Kim Nguyen, Jennifer Shaw, John Thoms, Gary Sidder, Scott Swinden, and Dave Watkinson.

Tucker Barrie
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February 15, 1999

BIOGRAPHIES

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TIMOTHY J. BARRETT received B.Sc. (1972) and M.Sc. (1974) degrees in geology from the University of Toronto, and a D.Phil. from Oxford University (1979), with studies focusing on atypical ophiolites and deep-sea sediments in the northern Apennines. Following a NATO postdoctoral fellowship in Germany, where his work was related to the Deep Sea Drilling Project and on-land ophiolites, Barrett returned to the University of Toronto from 1982 to 1986; as a university research fellow, he continued work on these topics and participated in three oceanic research cruises to the Southern Explorer Ridge. During that period, his work also included study of Precambrian iron-formations and turbidites on the Canadian Shield. At McGill University (1986–1992), through IREM-MERI, he was involved in a study of volcanogenic massive sulfide (VMS) deposits in the Noranda camp in Quebec. From 1993 to 1996, Barrett was at the University of British Columbia with the Mineral Deposit Research Group, as research coordinator for a major project on VMS deposits of the British Columbia Cordillera. His current fields of interest are volcanic stratigraphy, litho-geochemistry, and hydrothermal alteration associated with VMS deposits, and sea-floor transport and deposition of metals. He is currently working as a consultant to the mining and exploration industry through Ore Systems Consulting (with partner W.H. MacLean).

C. TUCKER BARRIE (B.Sc., University of Michigan, 1979; M.Sc., University of Texas at Austin, 1984; Ph.D., University of Toronto, 1990) has worked as an economic geologist for Exxon Minerals, BP Resources Canada, Falconbridge, and Noranda, and is currently a visiting scientist at the Geological Survey of Canada. His interests are in igneous petrology and geochemistry as applied to ore-generating magmatic and hydrothermal systems, and in heat and fluid-flow modeling of hydrothermal systems.

DELFIN DE CARVALHO received a LIC. degree in geology from the University of Lisboa, Portugal, in 1965, and took postgraduate courses in economic geology at the University of Arizona, 1971 to 1972. He worked as an exploration geologist and research scientist in a team of the Servico Fomento Mineiro (1967–1978) which discovered or contributed to the discovery (Neves-Corvo) of several mineral

deposits, especially in the Iberian pyrite belt. From 1978 to 1992 he was Director of the Geological Survey of Portugal. Carvalho's research has been concerned largely with the geology, structural control, and hydrothermal alteration of VMS-type deposits. He was national delegate in the EC committee for the research in mineral deposits and raw materials from 1989 to 1991. De Carvalho has taught economic geology as invited associate professor in the New University of Lisbon since 1995. He has been Vice-President of the EDM Group, which includes Somincor, since February 1998, and is a Fellow of the SEG and member of several other scientific societies.

ALAN G. GALLEY received a Ph.D. degree in geology from Carleton University, where his studies were concentrated on the Ansil volcanogenic massive sulfide deposit in the Archean Noranda camp. He joined the Mineral Resources Division of the Geological Survey of Canada in 1984, and has since been involved in the study of Precambrian epigenetic gold and modern/ancient VMS deposits. This has included work on VMS deposits in Cyprus and Oman. His present interest is the study of subvolcanic intrusive complexes in modern and ancient submarine environments and their relationship to VMS-related hydrothermal systems.

HAROLD L. GIBSON received his degrees from Queen's University (B.Sc.) and Carleton University (M.Sc. and Ph.D.). After a successful 12-year career with several Canadian mining companies—most notably Corp. Falconbridge Copper and Falconbridge Limited—as an exploration, mine, and research geologist, he joined the Department of Earth Sciences at Laurentian University in 1990. Since then, Gibson and his students have undertaken research projects in Canada (Sudbury, Timmins, Noranda, and the Northwest Territories), Brazil, Ecuador, Peru, Oman, and Turkey. His research involves: (1) the study of VMS deposits, with particular emphasis on the volcanic environment and attendant alteration associated with “giant” VMS deposits and constraints on their formation and location; (2) development of architectural and depositional models and volcanic facies relevant to VMS and diamond exploration; (3) the petrology and igneous geochemistry of Precambrian and younger (Cretaceous and Tertiary) volcanic rocks; (4) subaqueous explosive volcanic processes, mechanisms, and deposits; and (5) the trace element geochemistry of gold and associated sulfide minerals in Archean, iron formation-hosted lode gold deposits.

WAYNE D. GOODFELLOW is a senior research scientist in the Mineral Resources Division, Geological Survey of Canada, and an adjunct professor in the Geology Department, University of Ottawa. He received his B.Sc. degree in geology from Mount Allison University and a Ph.D. from the University of New Brunswick. In 1975, Goodfellow joined the Geological Survey of Canada; since then, he has worked on projects in North America, Germany, Australia, France, and China. His research interests include the genesis of modern and ancient sea-floor hydrothermal sulfide

BIOGRAPHIES (continued)

deposits, the genetic and temporal relationship between continental rifting, magmatism, and hydrothermal activity, the evolution of oceans through time, and the role of anoxic bottom waters in the formation of base metal deposits. He has authored or co-authored more than 200 papers, reviews, and technical reports, mostly in the area of economic geology and geochemistry. Goodfellow is currently the leader of the EXTECH-II multidisciplinary project on massive sulfide deposits in the Bathurst Mining Camp, New Brunswick.

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GREGORY HARPER received a B.S. degree with honors in geology from the University of Nebraska in 1975, and a Ph.D. degree from the University of California, Berkeley, in 1980. He has worked extensively on the Jurassic regional geology and tectonic evolution of the western United States, on oceanic faulting, hydrothermal metamorphism, serpentinization, and igneous petrology of the Josephine ophiolite, and on the structure of ocean crust. Harper participated in Leg 148 of the Ocean Drilling Project, which had as its goal the deepening of the deepest hole in the ocean crust, Hole 504B. He has also worked on oceanic faults preserved in the northern Apennine ophiolites, as well as on a possible Archean ophiolite in the Wind River Range, Wyoming. His current research focuses on the structure, petrology, and tectonic origin of the Coast Range ophiolite, California-Oregon.

DAVID L. HUSTON is a research scientist at the Australian Geological Survey Organisation. He received his B.Sc. degree from the Colorado School of Mines in 1982, his M.Sc. degree from the University of Arizona in 1984, and his Ph.D. from the University of Tasmania in 1990. Prior to joining AGSO, he was a research fellow—first at the University of Tasmania, and then for the Geological Survey of Canada. Huston has studied VHMS deposits ranging in age from the Paleoproterozoic to the Permian, including deposits from most states in Australia and the provinces of Ontario and Manitoba in Canada. He has documented the geological setting,

spatial and mineralogical distribution of gold and silver, hydrothermal geochemistry, alteration zonation, and isotope geochemistry of these deposits. He has authored more than 25 papers in refereed journals, most of which are on aspects of VHMS ore genesis.

RANDOLPH A. KOSKI is a geologist at the U.S. Geological Survey. He is currently chief scientist for the Mineral Resources Program, Western Region Team, located in Menlo Park, California. Since receiving his Ph.D. in geology from Stanford University in 1978, his primary research interests have been focused on hydrothermal systems and mineral deposits located on sediment-free (southern Juan de Fuca Ridge) and sediment-covered (Escanaba trough, southern Gorda Ridge) spreading axes in the northeast Pacific Ocean. The results of his detailed studies of the setting, composition, and growth processes of sulfide mounds and chimneys on the modern ocean floor have been applied to investigations of fossil analogs, including volcanogenic massive sulfides in ophiolites in Oman, Cyprus, and the western United States.

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