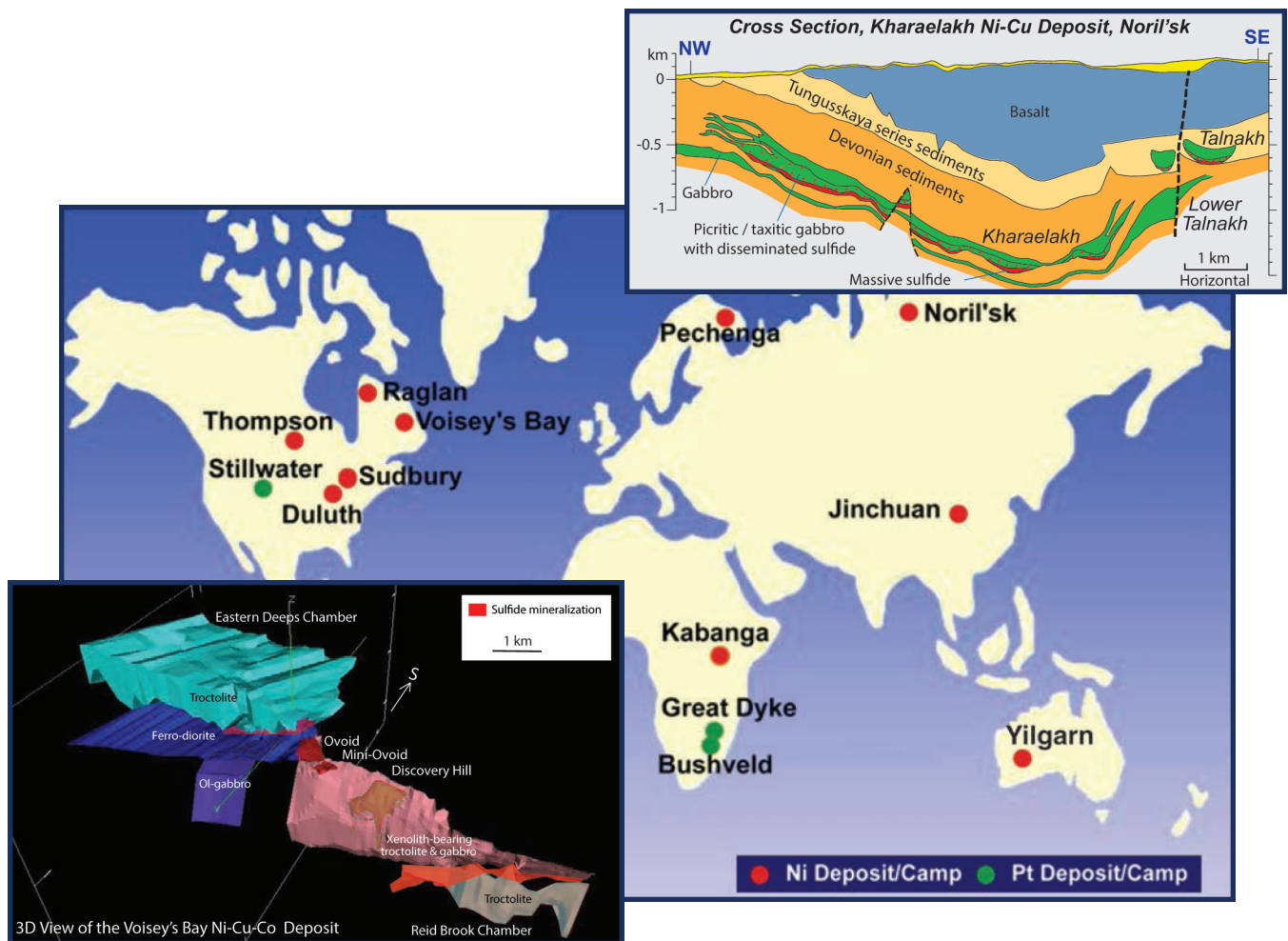


# MAGMATIC Ni-Cu AND PGE DEPOSITS: GEOLOGY, GEOCHEMISTRY, AND GENESIS



Editors

C. Li and E.M. Ripley

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## Preface

As the world continues to develop and advance with new technologies, the need for natural resources increases in concert. Nickel, copper, and platinum-group elements (PGEs) are but a few of the critical materials that are in demand the world over. We hope that this review of the genesis of several types of magmatic ore deposits will be of benefit to those involved in the research of and exploration for nickel, copper, and PGE resources.

We dedicate this collection of papers to Professor Tony Naldrett, whose pioneering efforts laid the groundwork for so much of our current understanding regarding the genesis of magmatic Ni-Cu-PGE deposits. Tony's students are involved in virtually every aspect of the Ni and PGE industries. He has served as mentor to many of the authors of the chapters contained in this book, and his willingness and desire to share his vast knowledge of magmatic ore deposits is a mark of the educator and the gentleman that Tony is. He has had a deservedly celebrated career and has been awarded both the Society of Economic Geologists' Silver Medal and Penrose Gold Medal. Tony continues to be actively involved in both research and consulting; his enthusiasm and zest for life are inspirational to us all.

We wish to thank the authors of the chapters in this volume for their contributions and attention to production schedules. We are particularly grateful to the following reviewers of the chapters—without their willingness to serve this volume would not have been possible: James Brenan, Jim Mungall, Rebecca Sproule, Wouter Bleeker, Steve Barnes, Nick Arndt, Andy Tomkins, Peter Lightfoot, Sarah-Jane Barnes, Gerhard Brüggemann, Steve Beresford, Tony Naldrett, Jim Miller, Rais Latypov, Andy Saunders, Dave Evans, Iain McDonald, Wolf Maier, Chris Harris, Judith Kinnaird, Martin Prendergast, Marian Tredoux, Dave Good, and Iain Samson. We are grateful to Rich Goldfarb for his suggestion to produce this book and for his support during the process.

Finally, we are indebted to our corporate sponsors whose contributions helped to finance the production of this book. Many thanks go to Anglo American, Magma Metals, North Central Mineral Ventures, Quaterra Resources, Rio Tinto, Stillwater Canada, and Vale.

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**STEVE BARNES** is currently leader of the Geology and Geochemistry Group in CSIRO's Division of Earth Science and Resource Engineering. He has a B.Sc. degree from Cambridge University (1977), and M.Sc. (1979) and Ph.D. (1983) degrees from the University of Toronto. He has been with CSIRO since 1985, and has also worked as a postdoctoral fellow at the NASA Johnson Space Center in Houston, and in the mining industry in platinum exploration in Australia and the United States. Dr. Barnes has published more than 60 peer-reviewed journal papers on nickel sulfide deposits, komatiites, spinel mineralogy, and chromium geochemistry, and on the geochemistry of the platinum group elements. He was the recipient of the 2011 Gibb Maitland Award from the Geological Society of Australia for services to Western Australian geology.

**O. MARCUS BURNHAM** obtained his bachelor's degree from Cambridge University in 1988. After a brief spell in mineral

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**MARCO FIORENTINI** is an associate professor at The University of Western Australia (UWA), where he is also deputy director of at the Centre for Exploration Targeting (CET). Since completing his Ph.D. degree in economic geology at UWA in 2005, Marco has successfully led numerous industry-funded research initiatives through federal and state funding agencies and has also liaised and worked efficiently with key national and international academic and governmental institutions. His studies on the genesis of Ni-Cu-PGE systems, evolution of the early Earth's mantle, lithosphere, and hydrosphere-atmosphere have been published in international journals. In 2008, Marco was awarded the highly prestigious Australian Postdoctoral Industry fellowship.

**TAFADZWA SHARON GOMWE** works for InnovExplo as a consultant geologist in the Abitibi region. She worked as a geologist on Ni-Cu sulfide deposits at Raglan, Quebec, and Kabanga,

## BIOGRAPHIES (continued)

Tanzania, from 2006 to 2008. She completed Ph.D. studies on the Roby and Twilight zones of Lac des Iles Complex in 2008 under the direction of Prof. S-J. Barnes at the Université du Québec à Chicoutimi. Dr. Gomwe received her M.Sc. degree in 2002 for her study of the Uitkomst Intrusion in South Africa, carried out under the direction of Prof. W.D. Maier at the University of Pretoria. She obtained her B.Sc. (Hons) degree in geology from Rhodes University in 1999.

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is also active in nonlinear numerical modeling and fractals of oscillatory zoning patterns in minerals. Most recently, he and his graduate students have been applying these new microanalytical techniques to the analysis of fish otoliths in areas impacted by mine tailings and in the Arctic, where contaminant dispersal has major implications for indigenous subsistence fisheries.

**DAVID HOLWELL** is currently a lecturer in Applied and Environmental Geology at the University of Leicester in the UK. He holds a B.Sc. (Hons) degree in geology from Durham University, an M.Sc. degree in mining geology from Camborne School of Mines, a Ph.D. from Cardiff University and was recipient of the Barrick-SGA Young Scientist Award in 2009. With a number of years experience in the exploration industry involved in projects across the globe and in a range of commodities, his current research area is focused on the nature and genesis of precious metal deposits associated with magmatic intrusions. In particular, this includes the Bushveld Complex of South Africa and the Paleogene intrusions of east Greenland, including the Skaergaard Intrusion.

**MICHEL G. HOULÉ** obtained B.Sc. and M.Sc. degrees in geology from Laval University (Québec City) in 1997 and 2000, respectively, and a Ph.D. (earth sciences) from the University of Ottawa in 2008. His studies focused on the Cr-PGE mineralization associated with an ultramafic-mafic layered intrusion (Menarik Igneous Complex) and on the physical volcanology and metallogeny of komatiites in the Abitibi greenstone belt. From 2003 to 2009, as senior geoscientist with the Ontario Geological Survey, he conducted regional bedrock mapping and mineral assessments for Ni-Cu-(PGE) sulfide mineralization in the Abitibi greenstone belt. He is currently a research scientist with the Geological Survey of Canada, since 2009, where he his interests are focused on the nature and origin of ultramafic-mafic complexes and/or flows in Canada and especially the understanding of the genesis of nickel-copper, platinum-group elements, and chrome mineralization related to those volcanic and/or igneous rocks.

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**THOMAS OBERTHÜR** studied at the University of Cologne in Germany and obtained a diploma in mineralogy with a thesis on Ni and Cr mineralization in the Finero Complex of the Alps in 1978. Subsequently, he was employed in South Africa working on various Witwatersrand gold mines. His Ph.D. thesis on the gold mineralization of the Carbon Leader Reef, Witwatersrand, was completed at the University of Cologne in 1983. Afterward, as an assistant at the Institute of Mineralogy and Geochemistry, University of Cologne, he worked on BIF-hosted gold deposits in southern Africa. In 1988, he joined the Federal Institute for Geosciences and Natural Resources (BGR) in Hannover, Germany. He headed the project "Metallogenesis of Gold in Africa" with his own emphasis on deposits in Ghana and Zimbabwe. Since 1989, he has been head of the Ore Deposit Research section at the BGR, which currently concentrates on mineral deposits of rare metals, mainly in Africa, and the "fingerprinting" of conflict

minerals such as "coltan" (columbite-tantalite). Research activities on platinum-group element mineralization centered on the Great Dyke in Zimbabwe and have lately been focused on placers worldwide and the mineralization (primary and oxidized ores) of the Bushveld Complex in South Africa.

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**RICHARD J. WALKER** is a professor in the Department of Geology at the University of Maryland. He utilizes radiogenic isotopes and trace elements to conduct research in several areas of geo- and cosmochemistry, including the chemical evolution of Earth's mantle, the formation and crystallization histories of early solar system planetesimals, the origin of ore deposits and the accretional and differentiation histories of the Earth, moon, and Mars. He received a Ph.D. in geology from the State University of New York at Stony Brook in 1984 and did postdoctoral work at the U.S. National Bureau of Standards, the Carnegie Institution of Washington Department of Terrestrial Magnetism, and the U.S. Geological Survey. He became a member of the faculty of the University of Maryland in 1990. Dr. Walker was the 1990 recipient of the Clarke Medal of the Geochemical Society and is a fellow of

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