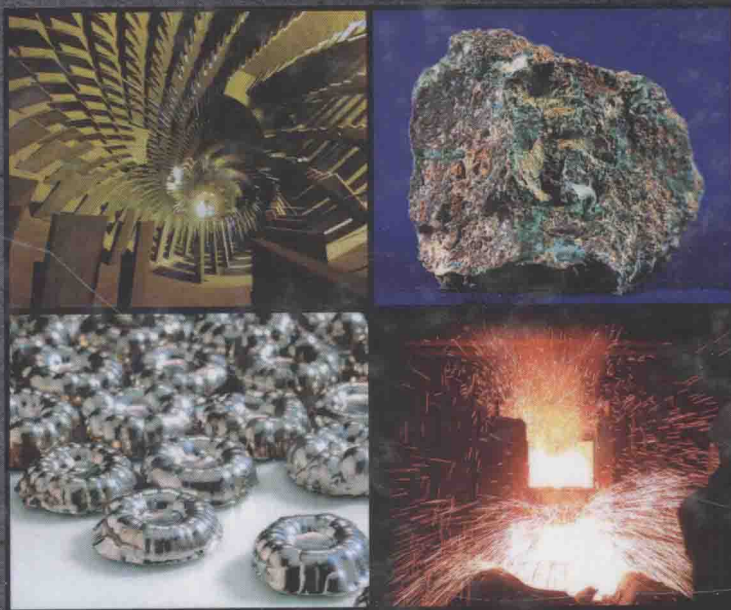


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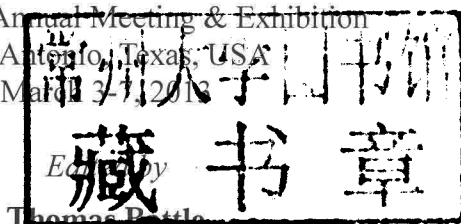
Thomas Battle

Michael Moats • Violina Cocalia • Harald Oosterhof
Shafiq Alam • Antoine Allanore • Rodney Jones
Nathan Stubina • Corby Anderson • Shijie Wang

Ni-Co 2013

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Michael Moats • Violina Cocalia
Harald Oosterhof • Shafiq Alam
Antoine Aulanore • Rodney Jones
Nathan Stubbs • Corby Anderson
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Preface

The physical and extractive metallurgy of nickel and cobalt have been a focus of much activity in TMS over the years. For many years, indeed, a Cu-Ni-Co Committee existed in the Extraction and Processing Division, before their efforts were taken over by the Pyrometallurgy and Hydrometallurgy/Electrometallurgy Committees. These committees have conducted extensive programming in Ni-Co metallurgy, including physical metallurgy in cooperation with the High Temperature Alloys Committee and other committees in other divisions of the society. Many of the larger symposia in this area were organized in collaboration with our partners in The Metallurgy and Materials Society of the Canadian Institute of Mining, Metallurgy and Petroleum (MetSoc). TMS-led symposia included Extractive Metallurgy of Ni and Co in 1988, and the International Laterite Ni Symposium in 2004. MetSoc has organized successful symposia on Ni Co in 1997 and 2005.

Soon after the 2005 conference, the two societies decided to collaborate on future programming in this area. The contract we've signed guarantees a series of symposia in coming years, organized by both societies, with the two organizations alternating in the lead. The first of this new sequence was held by MetSoc as the keystone of their Conference of Metallurgists in 2009 in Sudbury, Ontario. The 2013 symposium in San Antonio is the first in the sequence with TMS as the lead organizer.

Following are presentations and papers representing all eight of the sessions organized in this symposium: a four-paper plenary session, one session on Ores and Processing, two sessions each on Pyrometallurgy and Hydrometallurgy, one on Electrometallurgy, and one on Applications and Recycling. We also have a short course on Ni-Co, and a number of exhibitors to support the success of this conference.

Special thanks are due to MetSoc for their assistance and advice, including three members of the organizing committee: Nathan Stubina, Shafiq Alam, and Ron Schonewille. In addition, there is a strong core of TMS organizers representing all aspects of Ni-Co metallurgy: Violina Cocalia, Corby Anderson, Mike Moats, Harald Oosterhof, Phil Mackey, Xingbo Liu, and Shijie Wang, with assistance from long-time members Norbert Piret and Ram Ramachandran. The affiliations of all organizers, as well as logos of the many co-sponsoring organizations, can be found elsewhere in this book's frontmatter.

I also wish to acknowledge the co-sponsoring organizations for this symposium: MEI (Minerals Engineering International), GDMB (German Society for Mining, Metallurgy, Resource and Environmental Technology), MMIJ (The Mining and Materials Processing Institute of Japan), SF2M (Societe Francaise de Metallurgie et de Materiaux), SME (Society for Mining, Metallurgy, and Exploration), SAIMM (Southern African Institute of Mining and Metallurgy), High Temperature Materials Committee of the Chinese Society for Metals (CSM), ALTA Metallurgical Services,

ABM (Brazilian Association for Metallurgy, Mining, and Materials), and the Cobalt Development Institute.

We hope you find this proceedings volume a useful review of previous work, summary of the state-of-the-art, and reference for the future.

Thomas Battle, lead organizer

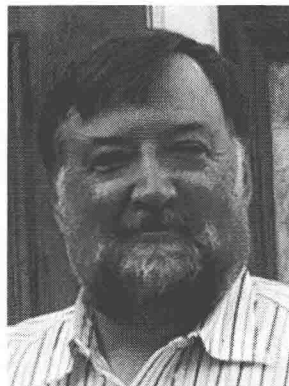
Senior Metallurgist

Midrex Technologies

Pineville, North Carolina

Editors/Organizers

Thomas Battle is currently a Senior Metallurgist at Midrex Technologies in Pineville, North Carolina. He has undergraduate degrees in Materials Engineering and Astronomy from the University of Michigan, a Master's in Metallurgical Engineering from the Colorado School of Mines, and a Doctorate in Materials and Metallurgical Engineering from the University of Michigan. After a time as a Post-Doctoral Research Fellow in the Centre for Numerical Modelling and Process Analysis at Thames Polytechnic, he spent 18 years at various positions with the White Pigments and Mineral Products business at DuPont (now known as DuPont Titanium Technologies). He has spent the last four years as a senior metallurgist at Midrex Technologies, focusing on iron ore pelletizing technology and the direct reduction of iron.



Tom has been active with TMS for more than 20 years, holding a number of volunteer positions, both technical and administrative, mainly for the Extraction and Processing Division. This culminated in a three-year term as chair of the division, and a position on the society's Board of Directors. He is a founding member of the North American Extractive Metallurgy Council.

Michael Moats is an associate professor of Metallurgical Engineering within the Department of Materials Science and Engineering at the Missouri University of Science and Technology. He has published more than 60 papers on various hydro- and electro-metallurgical topics with a particular emphasis on industrial surveys of copper and zinc operations, copper electrowinning and electrorefining and gold leaching. He is a co-author of *The Extractive Metallurgy of Nickel, Cobalt and Platinum Group Metals*. He has been employed in industry, academia, and consulting.



Violina Cocalia holds a Ph.D. in Inorganic Chemistry from the University of Alabama. She has experience in coordination chemistry, solvent extraction, hydrometallurgy, and ionic liquids. She is currently leading the R&D Metal Extraction Products Group at Cytec Industries Inc.



Harald Oosterhof graduated as chemical engineer from the group of Prof. Van Swaaij at Twente University (The Netherlands) in 1994. In the same year, he assumed a position as researcher at Delft University of Technology (The Netherlands) where he worked in the Laboratory for Process Equipment that was headed by Prof. Van Rosmalen. The research that focussed on anti solvent crystallization of well-soluble salts was rewarded with two patents and a dozen publications.



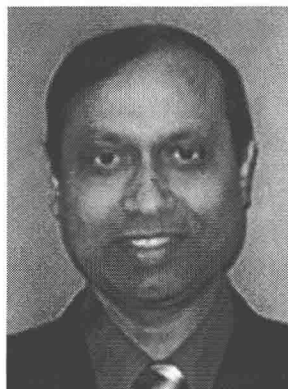
After receiving his Ph.D. in Industrial Crystallization and Precipitation from Delft University in 1999, Harald started working at Umicore, a global materials technology group that is based in Belgium. During his first assignment as Project Leader Hydrometallurgy, he focussed on the refining of cobalt, nickel, and germanium.

Since 2011, Harald has worked as Scientist in the group "Recycling and Extraction" at Umicore's Central R&D department. His main competence areas are:

- Special metals hydrometallurgy (In, Se, Te)
- Recycling and refining of rare earth metals
- Base metals recycling and hydrometallurgy
- Recycling and refining of spent rechargeable batteries (NiMH and Li-ion)

In his current job, Harald is frequently involved in business development of scarce metals recycling and he is heading a team of hydrometallurgical specialists.

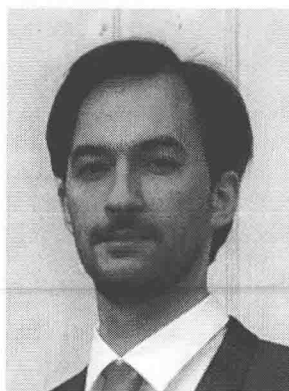
Shafiq Alam is an Associate Professor at Memorial University of Newfoundland, Canada. In 1998, he received his Ph.D. degree in Chemical Engineering from Saga University, Japan. From 1999–2001, he was appointed as a post-doctoral research fellow at the University of British Columbia and the University of Toronto, Canada.



Before joining Memorial University in 2006, he has worked with many different companies, such as, Shell, Process Research ORTECH Inc. (Mississauga, Ontario), Fluor Canada Ltd. (Vancouver), and the National Institute of Advanced Industrial Science and Technology (AIST), Japan. Dr. Alam is highly experienced in the area of extractive metallurgy. He is the lead researcher of the Hydrometallurgy lab at the INCO Innovation Centre (IIC) at Memorial University. He possesses two patents and has over 70 publications in the area of hydrometallurgy.

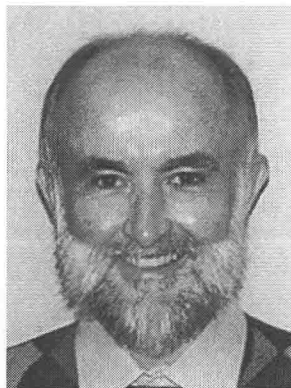
Dr. Alam is a registered professional engineer and has worked on projects with many different mining companies including Xstrata, Phelps Dodge, INCO Ltd. (Vale), and Barrick Gold Corporation. He is an Executive Committee Member of the Hydrometallurgy Section of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM), and is actively involved with the committee in organizing different international conferences, such as, the Conference of Metallurgists (COM) in Canada; Ni-Co Symposium at TMS 2013 in Texas, USA; and the Copper 2013 Conference in Chile.

Antoine Allanore is Assistant Professor of Metallurgy at the Massachusetts Institute of Technology (Cambridge, Massachusetts), in the Department of Materials Science and Engineering where he currently holds the Thomas B. King Chair. He earned a chemical engineering degree from the Ecole Nationale Supérieure des Industries Chimiques de Nancy and a M.Sc. and Ph.D. in chemical engineering from the Institut National Polytechnique de Lorraine. Prior joining MIT, he worked as a research engineer at ArcelorMittal R&D on the development of new electrolytic processes for primary steel production.



Dr. Allanore was a TMS Extraction and Processing Division Young Leader Professional Development Award winner in 2011, and co-recipient of the Vittorio de Nora Prize awarded at TMS 2012.

Rodney Jones has worked in the Pyrometallurgy Division at Mintek since 1985. He holds a B.Sc. (Eng) degree in chemical engineering from the University of the Witwatersrand (Wits) in Johannesburg, a B.A. degree in logic and philosophy from the University of South Africa, and a M.Sc. (Eng) degree in metallurgy from Wits University. He is a registered Professional Engineer, a Fellow and Vice President of the Southern African Institute of Mining and Metallurgy (SAIMM), a Fellow of the South African Institute of Chemical Engineers (SAIChE), and a full member of the Computer Society of South Africa (CSSA). He was a Visiting Professor at the Center for Pyrometallurgy, University of Missouri-Rolla, during July and August 1996, and in 2002 and 2003 also lectured in pyrometallurgy at Murdoch University, Perth, as an Adjunct Associate Professor. The National Research Foundation rated him in 2009 as an "Internationally Acclaimed Researcher." SAIMM awarded him an Honorary Life Fellowship in 2010. Rodney is also a member of the Board of Trustees for OneMine.org.



Nathan Stubina earned a B. Eng in Metallurgical Engineering from McGill University and a Ph.D. in Metallurgy and Materials Science from the University of Toronto. He started working for Falconbridge in 1987 and joined Noranda in 1999. While with those companies he worked at several sites including Sudbury, Norway, Sweden, Belgium and Rouyn-Noranda. Nathan has a mix of plant and R&D working experience.

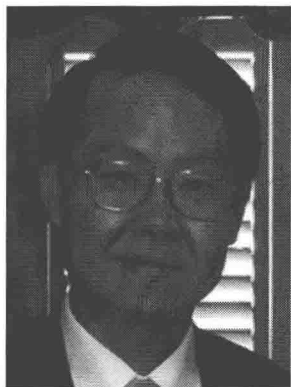
Nathan joined Barrick Gold in 2005 where he is the Manager of the Barrick Technology Centre. He is a member of the Professional Engineers of Ontario. Nathan is currently VP International for the CIM, is a member of the CIM's Board of Directors, was Chair of the 2009 Conference of Metallurgists (COM) in Sudbury and is a MetSoc Past-President. He is a founding member of NAEMC (North American Extractive Metallurgy Council), is a trustee for the Harold A. Steane Memorial Scholarship, and sits on the board of the Strathcona BIA (Business Improvement Association) for Vancouver's Downtown Eastside. Nathan is the author of over 30 technical papers and patents, and he is a co-editor of the MetSoc commemorative book titled *The Canadian Metallurgical & Materials Landscape (1960 to 2011)*.



Corby Anderson has over 33 years of global experience in industrial operations, management, engineering, design, consulting, teaching, research, and professional service. His career includes positions with Morton Thiokol, Key Tronic Corporation, Sunshine Mining and Refining Company, H. A Simons Ltd., and Montana Tech. He holds a B.Sc. in Chemical Engineering and an M.Sc. and Ph.D. in Metallurgical Engineering. He is a Fellow of the Institution of Chemical Engineers and the Institute of Materials, Minerals and Mining. He currently serves as the Harrison Western Professor in the Kroll Institute for Extractive Metallurgy as part of the George S. Ansell Department of Metallurgical and Materials Engineering at the Colorado School of Mines. In 2009 he was honored by SME with the Milton E. Wadsworth Extractive Metallurgy Award for his contributions in hydrometallurgical research.



Shijie Wang received his B.Sc. in Mineral Processing from China and his Masters and Ph.D. in Metallurgical Engineering from the University of Nevada at Reno. Dr. Wang has experience working at the Beijing General Research Institute for Non-Ferrous Metals, ASARCO Inc., and Phelps Dodge Corporation. He is currently Principal Advisor at Rio Tinto Kennecott Utah Copper. Dr. Wang has been active in extractive metallurgy and has experience in metallurgical process development and existing operation optimization as well as troubleshooting. He is copper and precious metals refining subject matter expert.



Dr. Wang has been a TMS member since 1991 and is currently Chair of the Hydrometallurgy and Electrometallurgy Committee of TMS.

TABLE OF CONTENTS

Ni-Co 2013

Preface	ix
About the Editors	xi

Plenary

Laterites - Still a Frontier of Nickel Process Development	3
<i>A. Taylor</i>	
Cobalt ('the Technology Enabler'): CDI Review & Future Challenges	25
<i>D. Weight</i>	
The Recycling of Cobalt from Alloy Scrap, Spent Batteries or Catalysts and Metallurgical Residues—An Overview	53
<i>C. Ferron</i>	

Ni Laterite Hydrometallurgy

Acid Leaching of Nickel Laterites with Jarosite Precipitation	75
<i>D. White, and J. Gillaspie</i>	
Extraction of Nickel, Cobalt and Iron from Laterite Ores by Mixed Chloride Leach Process	97
<i>V. Lakshmanan, R. Sridhar, R. DeLaat, J. Chen, M. Halim, and R. Roy</i>	
Reductive Leaching of Limonitic Laterites Using Ferrous Sulphate	107
<i>M. Zuniga, and E. Asselin</i>	
Sulfuric Acid Leaching Characteristics of Ni-Doped Goethite	117
<i>G. Li, W. Cai, M. Rao, Q. Zhi, and T. Jiang</i>	
Characteristics of Nickel Laterite Crushed Ore Agglomerates	125
<i>A. Janwong, N. Dhawan, T. Vethsodsakda, and M. Moats</i>	

Electrometallurgy

Acid Mist Abatement in Base Metal Electrowinning	143
<i>T. Robinson, D. White, and R. Grassi</i>	
Boleo Cobalt Electrowinning Development	155
<i>J. Lu, D. Dreisinger, and T. Gluck</i>	
Comparison of Intercell Contact Bars for Electrowinning Plants	177
<i>C. Boon, R. Fraser, T. Johnston, and D. Robinson</i>	
High Current Density Electrowinning of Nickel in EMEW [®] Cells	191
<i>J. Robinson, I. Ewart, M. Moats, and S. Wang</i>	
Helm Tracker [™] Cathode Current Sensing Technology	201
<i>R. Fraser, T. Johnston, J. Yesberg, S. Nolet, and C. Boon</i>	

Pyrometallurgy: Solid-State Processing

Cobalt Recovery through Sulphating Roast of Cu/Co Concentrate of Katanga Mining	213
<i>K. Adham</i>	
Experimental Study on Reduction-Magnetic Separation Process of Low-Grade Nickel Laterite Ore	221
<i>F. Chen, B. Zhang, W. Li, Q. Wang, and X. Hong</i>	
State of the Art Refractory Corrosion Test Work for the Nonferrous Metals Industry	231
<i>D. Gregurek, A. Ressler, V. Reiter, A. Franzkowiak, A. Spanring, B. Drew, and D. Flynn</i>	

Ores and Processing

Mineralogical Characterization of Cobaltic Oxides from the Democratic Republic of Congo	243
<i>Y. Vanbrabant, C. Burlet, and P. Louis</i>	
PolyMet Mining Corporation's NorthMet Process Development	255
<i>D. Dreisinger, M. Ounpuu, D. Imeson, and N. Verbaan</i>	

Talvivaara Nickel Mine - from a Project to a Mine and Beyond	269
<i>M. Riekkola-Vanhanen, and L. Palmu</i>	
The Sintering Character of Limonitic Nickel Laterite	279
<i>C. Wu, H. Li, Y. Chen, C. Li, and Z. Zhang</i>	

Pyrometallurgy: Smelting

Nickel, Cobalt and Copper Recovery from Sea Nodules by Direct Smelting Process	291
<i>K. Sahu, S. Agarwal, D. Mishra, A. Agrawal, N. Randhawa, K. Godiwalla, and R. Jana</i>	
Alternative Coolants and Cooling System Designs for Safer Freeze Lined Furnace Operation	299
<i>M. Kennedy, P. Nos, M. Bratt, and M. Weaver</i>	
Outotec's Ausmelt Top Submerged Lance (TSL) Technology for the Nickel Industry	315
<i>R. Andrews, R. Matusewicz, L. Aspola, and S. Hughes</i>	
Processing of PGM Containing Ni/Cu Bulk Concentrates in a Sustainable Way by Outotec Direct Nickel Flash Smelting Process.....	325
<i>S. Jyrkonen, K. Haavanlammi, M. Luomala, J. Karonen, and P. Suikkanen</i>	
Nickel-Chromium-Boron Alloys Production by Aluminothermic Processes ...	335
<i>O. Yilmaz, M. Alkan, and O. Yücel</i>	

Applications & Recycling

Numerical Simulation of Temperature Field in Directional Solidification of Turbine Blade by Liquid Metal Cooling Method	343
<i>N. Tang, Q. Xu, and B. Liu</i>	
Influence of Thermomechanical Treatment on Structure and Properties of a Cobalt Based Superalloy.....	353
<i>P. Sarkar, S. Prasad, M. Chatterjee, and M. Rao</i>	
Effect of Processing Conditions on Structure, Properties and Performance of a Nickel Base Cast Superalloy for High Temperature Applications	357
<i>M. Chatterjee, A. Kishore, P. Sarkar, and M. Rao</i>	

Development of Nickel Boron Alloys for Brazing Materials	365
<i>K. Tasyürek, M. Alkan, and O. Yücel</i>	

Ni and Co Hydrometallurgy

Continuous Co-Precipitation Behaviour and Stability of Arsenic(V) from Fe(II,III)-Al(III)-Ni(II) Sulphate Effluent Solutions.....	371
<i>C. Doerfelt, and G. Demopoulos</i>	

Hydrochloric Acid Regeneration via Calcium Sulfate Crystallization for Non-Ferrous Chloride Leaching Processes.....	379
<i>T. Feldmann, and G. Demopoulos</i>	

Hydrometallurgical Nickel Laterite Processing: A Review of Current SX Flowsheets and Industry Trends	391
<i>A. Fischmann, S. Wiggett, T. Bednarski, V. Cocalia, and C. Bourget</i>	

Studies on Refining Cobalt Salt Solution by Extraction Chromatography to Prepare High Purity Cobalt.....	405
<i>C. Song, Z. Li, L. Shuling, C. Zhenping, and W. Lijun</i>	

The Starved Acid Leaching Technology (SALT) for Recovery of Nickel and Cobalt from Saprolites and Caron Plant Residues	413
<i>D. Dreisinger, and J. Clucas</i>	

Selective Production of Co and Ni Powders Through Hydrothermal Reduction of Leach Solutions of a Synthetic Matte Containing Cu-Ni-Co-Fe-S.....	425
<i>D. Mishra, K. Park, K. Sahu, A. Agrawal, and C. Nam</i>	

Author Index	435
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Subject Index	437
---------------------	-----

Ni-Co 2013

Plenary

Session Chair

Thomas Battle