CELEBRATING THE MEGASCALE
Proceedings of the Extraction and Processing Division Symposium on Pyrometallurgy in Honor of David G.C. Robertson

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CELEBRATING THE MEGASCALE
Proceedings of the Extraction and Processing Division Symposium on Pyrometallurgy in Honor of David G.C. Robertson

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Edited by:
Phillip J. Mackey | Eric J. Grimsey
Rodney T. Jones | Geoffrey A. Brooks
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PREFACE

This volume contains the proceedings of the symposium, *Celebrating the Megascale: Proceedings of the Extraction and Processing Division Symposium on Pyrometallurgy in Honor of David G.C. Robertson*, held at the 2014 TMS Annual Meeting & Exhibition in San Diego, California. Dr. David G.C. Robertson, Professor Emeritus of Metallurgical Engineering at the Missouri University of Science and Technology, has devoted his career to the education of metallurgical professionals and to the science of all types and sizes of pyrometallurgical processes.

During the 2011 TMS Annual Meeting in San Diego, an informal gathering of colleagues and ex-students of Dr. Robertson began discussing the idea of holding a special symposium as a tribute to his significant contributions in pyrometallurgy. Support was strong, and Dr. Adrian Deneys played a key role in piloting this idea through TMS and identifying the venue, selected to be the TMS 2014 Annual Meeting. It was during these early discussions that Dr. Mark Schlesinger of Missouri University of Science and Technology coined the working title of the symposium: “Celebrating the Megascale”. This was in recognition of Dr. Robertson’s work across different fields that have contributed to the understanding of pyrometallurgical processes, in this way contributing to the successful scale-up of ferrous and non-ferrous metallurgical processes to the unprecedented levels seen today.

As discussed in one of the papers at the symposium\(^1\), when David Robertson began his career in metallurgy (in the 1960s), the output of a well-running iron blast furnace was about 2,000 tonnes of pig iron/day, while the typical equivalent of the best copper reverberatory furnace was about 300 tonnes of Cu/day. Today, single furnaces run at up to 4 to 5 times these rates, that is, of the order of 10,000 tonnes of pig iron/day, and for copper, the equivalent of about 1,500 tonnes of Cu/day – truly the “mega-scale”.

Dr. Robertson’s own contribution to the development of realistic theories for describing the kinetics of processes has been particularly influential, and has assisted understanding to enable the scale-up of processes to what is referred to now as the “mega-scale”. Through his work, Dr. Robertson has contributed to the understanding of many of the big developments in extractive metallurgy over the last half century; these include the large, modern blast furnace which remains a critical component of the world iron and steel industry, steel making technologies, the Noranda Process for copper smelting, the Outokumpu Flash Furnace, Top Submerged Lance technology and the large electric furnace for ferro-alloy production, to name a few.

With a symposium topic and venue identified, an organizing committee consisting of Kent Peaslee, Phillip Mackey, Eric Grimsey, and Rodney Jones was established. Sadly, Kent Peaslee passed away on May 17, 2013. We express condolences for the untimely

\(^1\) P.J. Mackey, “Evolution of the Large Copper Smelter - 1800s to 2013”, this symposium volume.
loss of our colleague, who was also a Past President of the Association for Iron & Steel Technology, a sister organization to TMS. Subsequently, the organizing committee invited Professor Geoff Brooks, AIST 2013 John F. Elliott Award recipient, to join the organizing committee.

The contribution of Dr. Brooks is gratefully acknowledged as is the guidance and help provided by Dr. Robertson throughout the planning process. The organizing committee developed an outline of topics both reflecting the interests of Dr. Robertson and which would also enable a review of the present state and practice of extractive metallurgy, covering both ferrous and non-ferrous metallurgy.

The outcome is the present symposium volume which contains almost 70 papers covering the important topics and issues in pyrometallurgy today including papers as follows: eight keynote papers including a tribute to Dr. Robertson, workforce skills needed in the profession going forward, copper smelting, ladle metallurgy, process metallurgy and resource efficiency, new flash iron making technology, ferro-alloy electric furnace smelting and on horizontal single belt casting for aerospace applications. Topics then covered in detail in this volume include ferro-alloys (seven papers), non-ferrous metallurgy (nine papers), iron and steel (eight papers), modeling (eight papers), education (eight papers, including papers related to sustainability in the metals industry, with particular reference to pyrometallurgy), and fundamentals (17 papers); there are also two papers as posters. We are indebted to all authors who have contributed to this volume.

The editors would like to express their appreciation to all the TMS staff for their help and dedication to this project. In particular, we would like to thank Louise Wallach, Trudi Dunlap, Patricia Warren, Joni Zychowski Minehart, and Diana Grady for their contributions.

Thanks are also given to all authors for their contributions and thanks to the session chairs who contributed to the reviewing of the manuscripts in their respective sessions.

Phillip J. Mackey
Eric J. Grimsey
Rodney T. Jones
Geoffrey A. Brooks
ABOUT THE EDITORS

LEAD EDITOR

Phillip J. Mackey is a consulting metallurgical engineer and specialist in non-ferrous metals with more than 40 years of international experience in all aspects of the non-ferrous and ferrous metals business. Dr. Mackey is originally from Australia where he received his Ph.D. in metallurgical engineering from the University of New South Wales studying under Professor N.A. Warner, one of the innovative leaders of his time. He carried out his graduate work at the same time as David Robertson. With his degrees, Dr. Mackey was armed to take on his first challenge at Noranda Mines in Canada. There he played a leading role in the development of the Noranda Process, the world’s first commercial continuous copper smelting and converting process and one of the important copper technologies developed in the twentieth century. He was later responsible for the marketing of this technology to a number of other companies worldwide. His role in introducing the Noranda Converter, a new continuous converting process, was recognized by the Noranda Inc. Technology Award given in 1998. Active in the copper world, he co-founded the Copper/Cobre series of international conferences, with the first one held in Chile in 1987. He was also involved in a number of major nickel sulphide and nickel laterite projects around the world. Dr. Mackey worked in senior positions for many years with Xstrata (formerly Falconbridge/Noranda) before retiring at the end of 2009 to start his own consulting company. He presently acts in a consulting role for a number of Canadian and international mining and metallurgical companies. He has authored and co-authored more than 100 publications covering many aspects of nonferrous metallurgy. Dr. Mackey is a Metallurgical Society of CIM Past-President (1984–1985) and a fellow of both CIM and TMS. A recipient of several professional awards in Canada and the United States, he also received the 2007 TMS Distinguished Service Award, the Selwyn G. Blaylock Medal of the CIM in 2010, and the Airey Award of the Metallurgical Society of CIM in 2012.
Eric J. Grimsey is an extractive metallurgist who obtained a Ph.D. from the University of Queensland in 1975. He has extensive experience as a university educator, administrator, researcher, and industry consultant. His publications and expertise are mainly in the field of non-ferrous pyrometallurgical processes, encompassing heat and mass balances, thermodynamics, slag/metal interactions, and process modelling. He has also written extensive materials for the courses he has taught in pyrometallurgical fundamentals and pyrometallurgical processes.

Dr. Grimsey is a fellow of the Institution of Engineers Australia and the Australasian Institute of Mining and Metallurgy. He is a former Vice President of The AusIMM, a Director of Curtin University’s Western Australian School of Mines (WASM), and a recipient of the AusIMM President’s Award from his contribution to the institute and minerals education. He is currently an emeritus professor of minerals engineering with Curtin University and has a continuing involvement with AusIMM as chair of the institute’s Ethics Committee.

Dr. Grimsey is pleased to have the opportunity to serve on the organizing committee to celebrate the work of Dr. David Robertson, who has been a friend and colleague since they met at the University of Missouri-Rolla in 1989.

Rodney T. 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 senior vice president of the Southern African Institute of Mining and Metallurgy (SAIMM), and a fellow of the South African Institute of Chemical Engineers (SAIChe). 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 in South Africa rated him in 2009 as an “Internationally Acclaimed Researcher.”
The SAIMM awarded him an Honorary Life Fellowship in 2010. Rodney is also a member of the Board of Trustees for OneMine.org.

Geoffrey A. Brooks has been a professor in the Faculty of Engineering and Industrial Sciences at Swinburne University of Technology since 2006, where he leads the High Temperature Processing research group. Previously, he was a senior principal research scientist at CSIRO (2004–2006), an associate professor in materials science and engineering at McMaster University (2000–2004), and a senior lecturer at the University of Wollongong (1993–2000). In the 20 years since completing his Ph.D. at University of Melbourne, he has published more than 140 papers and run many research projects with funding from companies and government agencies. Dr. Brooks is currently active in steelmaking, aluminum production and refining, and solar thermal research. He has been a key reader for *Metallurgical and Materials Transactions* since 1998 and is a fellow of the Institute of Engineers (Australia). In 2013, he received the John Elliott Lectureship from the Association for Iron & Steel Technology (AIST), acknowledging his contribution to research and training in steelmaking. Dr. Brooks has been a TMS member since 1990.
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The committee received guidance and help from Adrian Deneys of Praxair, Lloyd R. Nelson of Anglo American Platinum Limited, Quinn Reynolds of Mintek, and Dr. David Robertson.
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CELEBRATING THE MEGASCALE
Proceedings of the Extraction and Processing Division Symposium on Pyrometallurgy in Honor of David G.C. Robertson

Keynote Session
DAVID GORDON CAMPBELL ROBERTSON:  
A BIOGRAPHICAL SKETCH

J.B. See¹

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Keywords: Biography, Education, Research, Pyrometallurgy

Emeritus Professor David Robertson of the Missouri University of Science and Technology was born in Dublin Ireland on 29 December 1941. His father was a merchant navy Captain who served during WWII and during David’s early years his family lived in Dublin and Donegal where David went to the local elementary school. In 1954 he moved to London with his parents and attended Highgate School before commencing metallurgy at the Royal School of Mines, Imperial College, London in 1960.

David graduated in 1963 with a BSc(Eng) with first class Honors in Metallurgy having also been awarded the Imperial College Charles Salter Prize for excellence in metallurgy. The distinguished faculty at Imperial College included Professors Richardson, Bradshaw, Alcock, Hills and Dr Julian Szekely. Rod Guthrie, now of McGill University, was among David’s fellow classmates. Upon graduation, on Professor Richardson's recommendation, David decided to study for his doctorate at the University of New South Wales (UNSW) in Sydney, Australia arriving in Sydney just before Christmas 1963.

David’s thesis advisers at UNSW were Dr Alex Jenkins and Dr Noel Warner. David was a Teaching Fellow in 1964 and a Broken Hill Proprietary (BHP) Scholar from 1965 to 1968 and hence had extensive contact with then Director of BHP Research, Dr Robert G Ward, author of the textbook The Physical Chemistry of Steelmaking.
UNSW was then a major world centre for university research in pyrometallurgy. Alex Jenkins, and his students Bruce Harris and Les Baker, had perfected the use of levitation melting to study the reactions of metal drops in gases whilst Noel Warner, a chemical engineer, was a pioneer in the application of heat and mass transfer principles to pyrometallurgical processes. In addition David’s fellow PhD students at UNSW included Dr Phillip Mackey, a co-editor of this volume and a well-known and respected industrial metallurgist in North America.

David’s PhD thesis topic was “Heterogeneous Reactions between Liquid Metals and Gases,” an investigation of the kinetics of the reaction of iron alloy drops in pure oxygen and a topic of great interest in steelmaking research even today. On graduating with his PhD from UNSW in 1968 David accepted an appointment as a Lecturer back at Imperial College. As David has since bemoaned; “So I left one of the world’s most beautiful cities for cold grey London - that was before the days of global warming!” Professors Richardson, Bradshaw and Hills became very supportive colleagues together with Jim Jeffes who had joined the faculty in the interim. David also interacted with then graduate students the late Professor Keith Brimacombe and Dr Amit Chatterjee, now an international authority in the area of iron and steel. David also worked closely with Professor Paul Grieveson, who joined Imperial College in 1977.

David remained a faculty member at Imperial College from 1969 to 1985 after being promoted to Reader in 1982 and supervised 17 PhD theses and 6 other higher degree theses - M Phil and DIC - on a wide range of topics in pyrometallurgy. In 1985 he accepted the position of Professor of Metallurgical Engineering at the University of Missouri-Rolla (now Missouri S&T) and, from 1985 to 1996, was also the Director of the Generic Mineral Technology Center for Pyrometallurgy. He worked closely with the first Director, Dr. Art Morris, and was responsible for all aspects of running this national center for university-based research, funded through the United States Bureau of Mines and with a budget of about $1,000,000 per annum. This appointment allowed David to interact closely with pyrometallurgical researchers from all over the US when their projects were funded by the Center.

Dr Robertson organized two successful international conferences sponsored by the Center - in 1986 at Purdue University on “Gas-Solid Reactions in Pyrometallurgy”, and in 1988 at the University of Utah on “Flash Reaction Processes.”

When the Center for Pyrometallurgy closed in 1996, with the demise of the United States Bureau of Mines, David remained at the University as a Professor. He retired in 2008 and was awarded the title of Professor Emeritus.

In his role as Professor, David supervised 7 PhD theses and 10 MS theses. One of his most distinguished graduate students in this period was the late Dr. Kent Peaslee, initially an organiser of this conference, who passed away recently.

David has travelled frequently to be a thesis examiner, give lectures, teach short courses, take part in conferences, and visit companies as a consultant. In 1995, he spent a period of six months on development leave at Mintek in South Africa, working on a major project on fuming zinc from lead blast furnace slags. In 2006 he worked at BHP Billiton’s Technical Marketing Group in Australia for six months and he was a Visiting Professor at Tohoku University for four months in 2008 and at IIT Kanpur for five months in 2010. He is currently a Visiting Professor at Chongqing University.