

Phytomining Workshop

21-22 July 2014

Brisbane, Australia

By-line: From discovery to full-scale application
Venue: The University of Queensland, St Lucia Campus, Brisbane, Queensland
Organiser: Centre for Mined Land Rehabilitation, Sustainable Minerals Institute

Introduction

Some plants known to be associated with mineral deposits ('metallophytes') have been used for prospecting for hundreds of years. These plants not only have potential to find buried metal ores, but also to reduce risks of metal-contaminated substrates in eventual mine closure via utilisation in a range of phytotechnologies. A subset of the broader category of metallophytes, rare plants that have the ability to actually accumulate very high concentrations (1-6%) of metals such as nickel, cobalt, zinc or copper in their biomass are called 'hyperaccumulators'. These plants can be utilised in 'biogeochemical prospecting' (locating ore-bodies using indicator properties), 'phytoextraction' (cleaning up metal-contaminated soils by capture of metals and removal with biomass), and 'phytomining' (commercially producing metals from biomass). The latter technology entails growing selected hyperaccumulator plants on sub-economic ore bodies or mineral wastes with subsequent harvesting and biomass incineration generating a high-grade bio-ore. The concentration of nickel, for example, in bio-ore (10-25%) is far greater than in current mineable lateritic ores. In essence this is 'metal farming'. In addition, induced phytomining has also been successfully demonstrated for gold. Despite the scientific validation of the concept of phytomining in the last two decades, the mining industry has yet to adopt or test the potential of phytomining at scale. In part, this may be the result of a lack of awareness on the part of the industry of hyperaccumulator plants that occur on mining targets and the scientific advances that have been made in potentially capturing a metal product from plant biomass. This highlights the need to further encourage industry to adopt the application of scientific insights and new technologies that further has the potential to improve the outcomes and opportunities from mine site rehabilitation, especially in the developing countries of tropical regions. The imminent expiry of the main patent protecting phytomining technology (in mid-2015) provides an additional incentive for the minerals industry to start developing phytomining sooner rather than later.

Workshop aims

The workshop is aimed at addressing such questions as: How can hyperaccumulators be used from discovery to application to improve outcomes of mine site rehabilitation? Where lies the greatest potential for phytomining? What is needed for developing large-scale trials and onwards to full commercialization?

Please register your interest by emailing: Antony van der Ent (a.vanderent@uq.edu.au)

The **PHYTOMINING WORKSHOP** takes place in the week following the Australian Institute of Mining and Metallurgy (AusIMM) Life of Mine Conference (LoM) in Brisbane, 16-18 July 2014.
<http://www.lifeofmine2014.ausimm.com.au/>

Tentative program

Monday 21st July 2014 – Discovery and phytotechnologies (10am – 4pm)

Opening and setting the scene	Prof. David Mulligan (University of Queensland, Australia)
Metallophytes, hyperaccumulators and phytotechnologies	Prof. Alan Baker (Universities of Melbourne and Queensland, Australia, and Sheffield, UK)
History of hyperaccumulator plant discovery	Prof. Roger Reeves (Massey University, New Zealand and University of Melbourne, Australia)
Discovery and biogeochemical prospecting	Mr. Antony van der Ent (University of Queensland, Australia)
Rehabilitation of nickel laterite mining wastes	Dr. Bruno Fogliani (L'Institut Agronomique Néo-Calédonien, New Caledonia)

Tuesday 22nd July 2014 – Phytomining and processing of bio-ore (9am – 4 pm)

The agronomics of phytomining operations	Dr. Rufus Chaney (USDA, USA)
Hydrometallurgical processing of nickel ores	Dr. James Vaughan (University of Queensland, Australia)
Production of high-value nickel salts from bio-ore	Prof. Marie-Odile Simonnot (Université de Lorraine, France)
Experiences with large-scale phytomining trials (nickel – Albania)	Prof. Jean-Louis Morel (Université de Lorraine, France)
Experiences with large-scale phytomining trials (induced gold – Indonesia and Brazil)	Dr. Chris Anderson (Massey University, New Zealand)



These images show hyperaccumulator plants with exceptionally high concentrations of nickel metal in tissues and sap (up to 20%). Photos courtesy of Antony van der Ent.

The Phytomining Operation: large scale trials



Growing and harvesting hyperaccumulator biomass on agricultural scale



Incinerating the biomass to produce ash



Arc-furnace smelting of ash to produce nickel metal

These images show a full-scale trial of nickel phytomining using Alyssum spp. in Oregon (USA) in 1998. Dr. Scott Angle holds produced bio-ore. Photos courtesy of Dr. Rufus Chaney.

Expert Panel

Professor Alan J. M. Baker

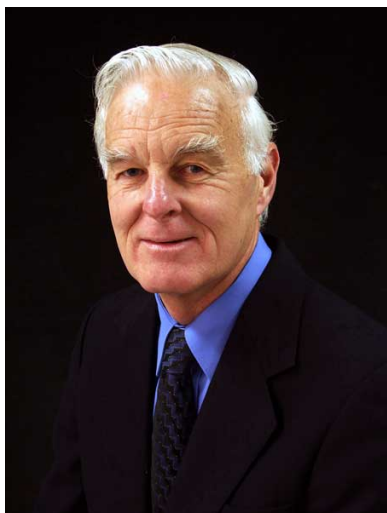
Alan Baker gained a 1st Class BSc (Hons) in Botany (1970) and PhD in Plant Ecology (1974) from Imperial College, London. Subsequently he was appointed Independent Research Worker in the Unit of Comparative Plant Ecology (NERC), University of Sheffield, UK, then Lecturer in Botany 1976-1992, Senior Lecturer in Plant Ecology 1992-1995 and Reader (Associate Professor) in Environmental Science in the Department of Animal and Plant Sciences at the University of Sheffield (1995-2000). He was awarded a DSc degree from the University of Sheffield in 2009. From October 2000 – August 2008, he was Professor of Botany (Ecology and Environmental Science) at the University of Melbourne, Australia where he headed the Applied Ecology Research Group in the School of Botany. His Laboratory was involved in restoration and revegetation projects with the minerals industry and remediation of contaminated land, in addition to carrying out fundamental research on heavy metal uptake and accumulation and on the development of new phytotechnologies. On retirement from the University of Melbourne in 2008 he was made an Honorary Professorial Fellow in the School of Botany and an Honorary Professor in the CMLR, University of Queensland. He is also currently Visiting Professor, School of Life Sciences, Sun Yat-sen University, Guangzhou, PR China and at the Laboratoire Sols et Environnement, University of Lorraine, Nancy, France. He was elected Fellow of the Linnean Society of London (FLS) in 1985 and was a Founder Member of the UK Chartered Institute of Ecology and Environmental Management; elected Fellow 2004 (FCIEEM). In addition to extensive work experience in Europe, Australasia and the USA, he has worked in many developing countries including The Philippines, Thailand, New Caledonia, Sri Lanka, PR China, Democratic Republic of Congo, Brazil, Costa Rica, Cuba and Chile. He is the author of 187 original scientific papers and articles, 33 chapters in books and 230 conference abstracts and holds 3 patents. Professor Baker was Editor-in-Chief (Inorganic Contaminants) of the *International Journal of Phytoremediation* from 1999-2009.

Dr. Rufus L. Chaney



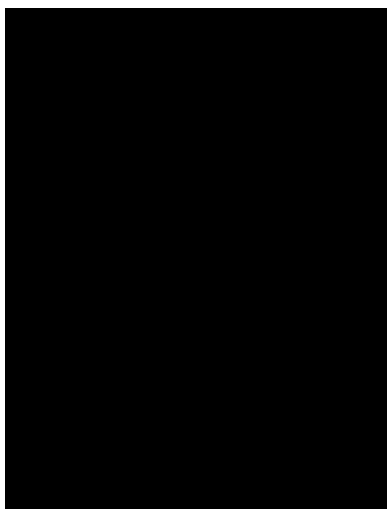
Rufus Chaney is a Senior Research Agronomist in the Environmental Management and By-Product Utilization Laboratory of the US Department of Agriculture-Agricultural Research Service at Beltsville, MD, where he conducts research on the fate, food-chain transfer, and potential effects of soil microelements. The research includes studies on 1) plant uptake of metals and translocation to edible plant tissues; considers plant-soil interactions in microelement phytoavailability; 2) speciation of metals in plants and bioavailability to animals; 3) development of hyperaccumulator crops to phytoextract/phytomine and recycle metals in contaminated soils; 4) bioavailability of lead and other metals in soils, biosolids, and composts directly ingested by animals; 5) development of "Tailor-Made Composts and Biosolids" to remediate Pb, Zn, Cd, Ni and other element contaminated soils including urban gardens; and 6) potential methods to reduce food-chain transfer or toxicity of metals in organic resources and potential regulatory approaches to protect food safety and soil fertility. Since beginning his career in 1969, Dr. Chaney has 447 published papers (301 Peer Reviewed) and 288 published abstracts on these topics. He has cooperated with the US-Environmental Protection Agency, the US-Food and Drug Administration, the Office of Management and Budget, and many States in preparing advice and regulations for utilization of biosolids and remediation of metal contaminated soils.

Prof. Roger D. Reeves



Roger Reeves spent 41 years until 2006 as Lecturer and Professor in Chemistry at Massey University, New Zealand, and more recently has held a position as Honorary Professorial Associate in the School of Botany at the University of Melbourne, Australia. His research interests, and many of his 180 publications, have been centred on (i) trace element analysis and its application to geological and biological materials and environmental problems, and (ii) plant chemistry, particularly with reference to abnormal accumulation of elements such as nickel, zinc and cadmium from naturally metalliferous soils and from soils contaminated by human activity. His work has included field investigations of ultramafic areas and other metalliferous sites in Australia, New Caledonia, Cuba, Brazil, Costa Rica, the northwestern USA, Turkey, and several countries in Europe (including Greece, France, Bulgaria and the UK). With his colleagues, including Alan Baker and the late Robert Brooks, he has been responsible for identifying well over 300 plant species as nickel hyperaccumulators – about 75% of those currently known to behave in this way. Several plant species new to science have also been uncovered through his work.

Prof. Jean-Louis Morel



Jean Louis Morel is professor in environmental biology at the University of Lorraine, where he teaches soil and environmental sciences. His research interests are i) dynamics of pollutants (metals and hydrocarbons) in soil-plant systems, ii) evolution of soils strongly affected by human activities, and iii) applications for soil remediation (phytoremediation, phytomining, soil construction). He created, and led until 2012, the *Laboratoire Sols et Environnement* UMR 1120 INPL-INRA (<http://www.lse.inpl-nancy.fr>) a research group of 40 persons. He leads the GISFI (<http://www.gisfi.fr>), a scientific consortium of 10 research groups devoted to the understanding of the functioning of brownfields, and the development of processes for soil remediation. He is involved in the project LabEx “Ressources21” for the recovery of strategic metals from soils and wastes. He has published 190 papers in international peer-reviewed journals. He was a member of the *Conseil National des Universités* (2004-2012), and vice-president for research of the university (2002-2006). He is now a member of the board of regents of the University of Lorraine (50 000 students, 6 000 staffs). At the national level, he is a member of the scientific council of Ademe, of FRB (Fundation for Research on Biodiversity), of Arvalis, and correspondent member of the French Academy of Agriculture. He chairs the international SUTMA group (*Soils in urban, industrial, traffic, mining and military areas*) of the IUSS, and is invited professor INRS-ETE, Québec (since 2006) and Sun Yat-sen University, Guangzhou (since 2008). He is Associate Editor of *International Journal of Phytoremediation*, and Subject Editor of *Journal of Soils and Sediments*.

Dr. James Vaughan



James Vaughan is Lecturer in the University of Queensland School of Chemical Engineering and leader in the Hydrometallurgy Research Group. He obtained a Bachelor's degree in Metallurgical Engineering at McGill University followed by Master of Applied Science and PhD degrees in Materials Engineering at The University of British Columbia. Before joining UQ James gained valuable experience as a research engineer in industry, working for Placer Dome Mines and BHP Billiton. James is a Member of the Association of Professional Engineers of British Columbia (APEGBC) and the Canadian Institute of Mining, Metallurgy and Petroleum (CIM). His research focuses on the fundamental aspects of leaching; ion exchange, adsorption and precipitation reactions. The potential to apply nanofiltration technology for novel

aqueous phase separations is also being studied. These projects are of interest to the base metals, precious metals and alumina refining industries. Two new nickel processing technologies developed at the University of Queensland are being commercialized. The first is a method to separate nickel from cobalt and manganese contained in hydroxide intermediates by oxidative leaching. The second is a method of extracting nickel and cobalt from process streams using ion exchange resin and recovering the metal to the refinery by selective ammonia elution.

Mr. Antony van der Ent



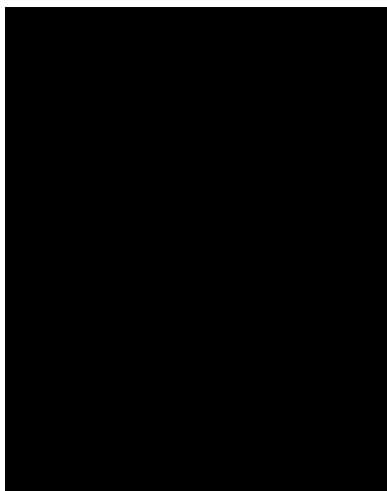
Antony van der Ent obtained a BSc in Environmental Technology (Summa Cum Laude) from Saxion University of Applied Science, The Netherlands, an MSc in Environmental Sciences from Radboud University, The Netherlands (Bene Meritum), and recently his PhD Thesis was accepted at The University Of Queensland, Australia. He is the recipient of competitive scholarships including an International Postgraduate Research Scholarship (IPRS) and an UQ Research Scholarship (UQRS). His scientific interests focus on the soil/plant interface in (natural and anthropogenic) metal-enriched ecosystems, particularly in the tropics. His work has involved leading large expeditions in remote, previously unexplored, rainforests in SE Asia, employing cutting edge synchrotron and nuclear micro-probe techniques to elucidate hyperaccumulator tissue metal speciation and elemental distribution. He has worked extensively as a photographer, which led to writing the book 'Kinabalu' published by Natural History Publications (Borneo). He has won the IJsselland Prijs (1st prize) for university-wide best graduation thesis of the year 2005, the SMI Excellence Award 2010 to support a remote sensing project, the JKtech Innovation Award 2010 for research in geospatial analysis, and the Ornella Vergnano Gambi Award during the International Conference on Biogeochemistry of Trace Elements (ICOBTE) 2011 in Italy, for best presentation in the field of metallophytes: ecophysiology, molecular biology and environmental applications. He has worked in Australia, Netherlands, UK, Belgium, Germany, Malaysia and Indonesia. He is coordinator of the International Serpentine Ecology Society (ISES) and member of the Organising and Scientific Committees of the 8th International Conference on Serpentine Ecology to be held in Sabah 9-13 June 2014.

Prof. David Mulligan



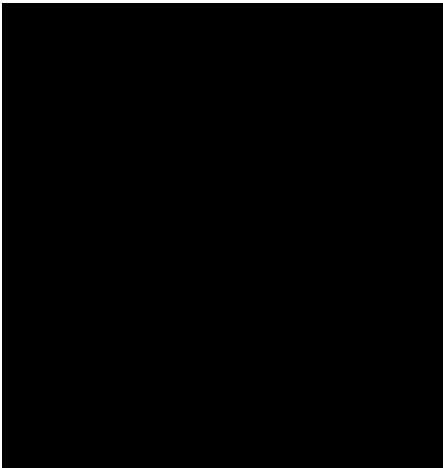
David Mulligan is the Director of the Centre for Mined Land Rehabilitation (CMLR), one of seven research centres in the Sustainable Minerals Institute (SMI) at The University of Queensland. Over the past 20 years, the CMLR has built a reputation for the provision of the scientific research that is necessary to support and underpin the decisions that need to be made to minimise the environmental risks by the mining and mineral processing industries both in Australia and overseas. David is a Fellow of the Australasian Institute of Mining and Metallurgy (AusIMM) and a Life Member of the American Society of Mining and Reclamation. In 1996 he edited the book “Environmental Management in the Australian Minerals and Energy Industries - Principles and Practices” and in 2006, was Chair of the Working Group that developed the “Mine Rehabilitation” handbook as a part of the Australian Government’s ‘Leading Practice in Sustainable Development Program for the Mining Industry’, a handbook he is currently re-writing. He received the Australian Minerals and Energy Foundation Excellence Award for “Outstanding Leadership in Mine Site Rehabilitation Research and Education” in 1998, and in 2011 received a University of Queensland Award for being in the top 10 researchers attracting external grant income to the University. He is the Australian representative to the International Affiliation of Mine Reclamationists (IALR), co-chairs the international biennial ‘Enviromine’ conferences in South America and chairs the AusIMM Life-of-Mine Conference series.

Prof. Marie-Odile Simonnot



Marie-Odile Simonnot has been a Professor of Chemical Engineering at the University of Lorraine (France) since 2003. She is head of i) the research group “Processes for environment, safety and resource valorisation” at the Laboratory “Reactions and Chemical Engineering” (<http://lrgp.univ-lorraine.fr/>), ii) the pedagogic team “chemical engineering” at the EEIGM (www.eeigm.univ-lorraine.fr/), iii) the research axis “pollutant transport and physico-chemical soil clean-up processes” in the research group GISFI (www.gisfi.fr). She has been responsible for different projects with industrial partners (e.g. Brezillon, ICF Environnement, Sita FD, SOLÉO Services, Solvay) and is the scientific head of the LORVER project (Lorraine district-EU Feder 2013-2017). She has been invited Professor at the INRS ETE (Québec, Canada) since 2006 and has partnership with a team of Sun Yat-sen Univ. (Guangzhou, China). She has belonged to different national and international scientific committees. Formerly trained in separation engineering, she has moved to topics as pollutant fate in industrial soils (PAHs, metals), soil clean-up processes (chemical oxidation and reduction) and phytomining. In this field, she has strong partnerships with the Lab. Soil and Environment (Pr. MOREL and ECHEVARRIA); she has co-authored a patent and publications on the synthesis of a nickel salt (ammonium and nickel sulfate hexahydrate, ANSH) from *Alyssum murale* biomass. She has supervised 15 PhD and co-signed *ca* 55 publications, 2 book chapters, 200 communications, 2 patents. In 2013, she has been prize winner of the "National Contest for Assistance to the Creation of Innovative Technology Companies", awarded by the French Ministry of Higher Education and Research and Bpi France for the further creation of a start-up on Ni phytomining. This project is currently in an incubation process.

Dr. Chris Anderson



Dr. Christopher Anderson (Chris) is Senior Lecturer in Soil and Earth Sciences at Massey University in New Zealand. He is based in the New Zealand city of Palmerston North. Chris also holds the position of Adjunct Professor at the Institute of Geochemistry of the Chinese Academy of Sciences and at the NBK Institute of Mining Engineering at the University of British Columbia. He leads an active research group investigating the interactions of trace elements and contaminants with the environment. His projects study heavy metals, organic pollutants such as dioxin, and essential micronutrients. Chris completed his PhD at Massey University in New Zealand under the supervision of Prof. Robert Brooks. During his doctoral research he developed the concept of gold

phytomining, and went on to establish the first company in the world offering commercial gold phytomining services. Today Chris is involved with phytoremediation/phytomining and large scale environmental impact assessment and remediation projects in China, Indonesia, Mexico as well as New Zealand, and contributes to research projects being conducted by colleagues around the world. He has a particular interest in the application of phytomining to the sustainable management of mine tailings at artisanal and small scale gold mining operations. He serves on many editorial and management boards and environmental project steering groups, is a Director of several New Zealand companies, and has an active publication portfolio.

Dr. Bruno Fogliani



Bruno Fogliani is the Deputy Director of the New Caledonian Agronomic Institute, and previously Assistant Professor at the University of New Caledonia. He is involved in the coordination of several research contracts with New Caledonian Institutions as well as with mining industries dedicated to conservation, revegetation and/or ecological restoration. His scientific interests focus on the ecology of seeds used for ecological restoration of mining sites in New Caledonia. He also develops research programs on hyperaccumulator plants to understand their ecophysiology from seed to adult plant. He works on a phytomining project dedicated to the use of hyperaccumulators for revegetation of degraded mining sites and for the utilization of the metal contained in their leaves for green chemistry. He co-organized international workshops in New Caledonia dedicated to "seed ecology" in 2010 and to "the conservation of floristic biodiversity in New Caledonia" in 2012. In 2014, he is a

member of the organizing and scientific committees of the 2nd International Conference of the Society for Ecological Restoration Australasia that will be held in Noumea (17-21 November). He is a member and regional coordinator of ISES as well as a member of the SCB, of the ISSS and of the French Seed Biology Network.