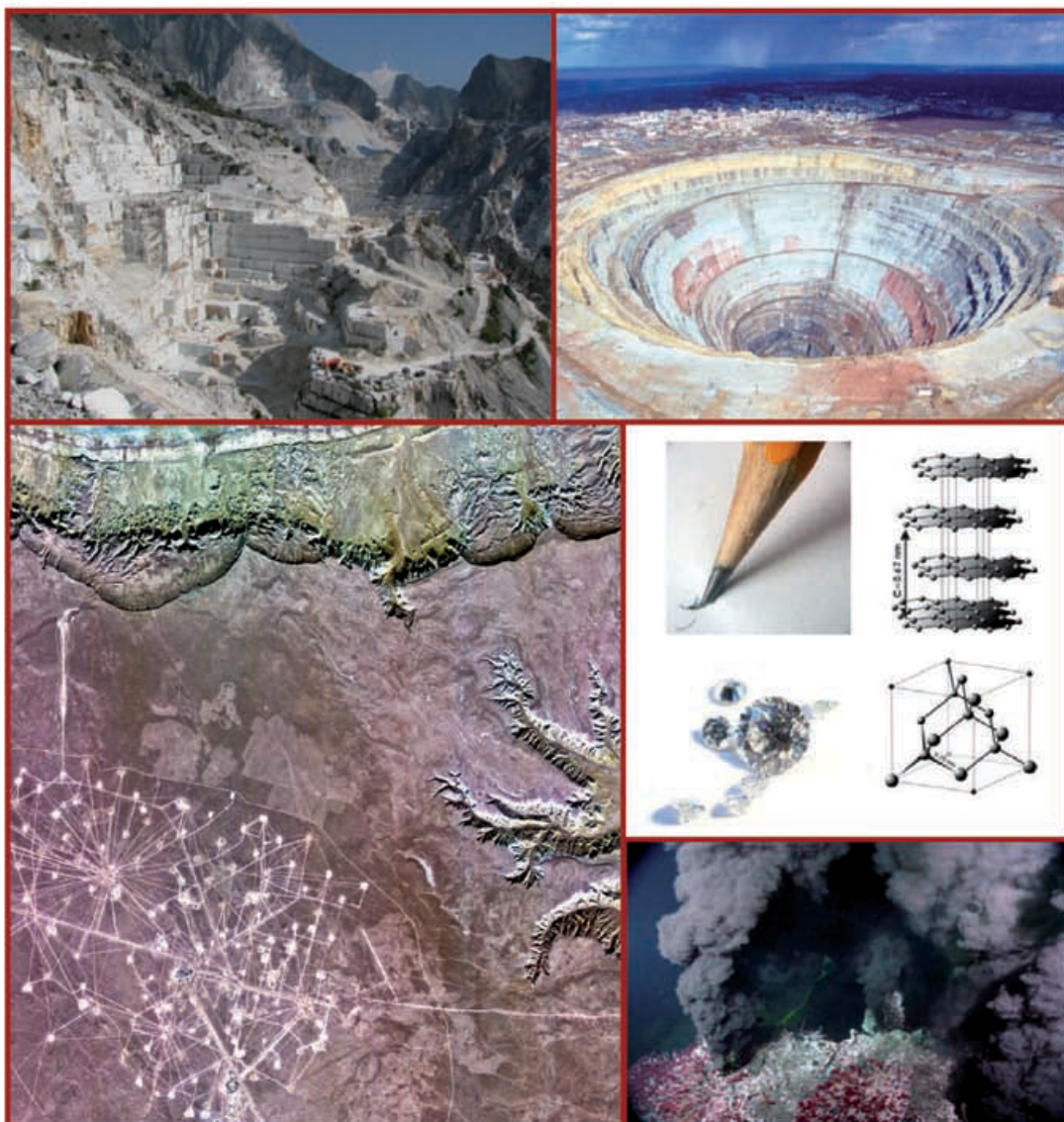




# European Geosciences Union

## GIFT – Geosciences Information For Teachers



*GIFT WORKSHOP- 2015*

*MINERAL RESOURCES*

*Vienna, Austria, 12-15 April 2015*

Images from the cover:

Apuane marble quarry

<http://scempioapuane.blogspot.it/2013/01/cave-del-bacino-di-torano-sopra-carrara.html>

Diamond mining

<http://www.911metallurgist.com/blog/15-largest-mines-on-earth>

Space image of Kazakhstan

[http://www.esa.int/spaceinimages/Images/2013/05/The\\_treasure\\_peninsula\\_of\\_Kazakhstan](http://www.esa.int/spaceinimages/Images/2013/05/The_treasure_peninsula_of_Kazakhstan)

Deep Sea mining polymetallic sulfides

<http://www.deepseaminingoutofourdepth.org/deep-sea-mining-out-of-sight-out-of-mind/>

Diamond/graphite

<http://education.mrsec.wisc.edu/212.htm>

Dear Teachers,

Welcome to the 11th GIFT workshop of the European Geosciences Union!

This year the workshop will unite 76 teachers from 21 different countries around the general theme "Mineral Resources".

The expansion of the world population from 6 to 9.6 billion in 2050, the rapid industrialization of highly populated countries combined with an overall higher standard of living are expected to intensify global competition for natural resources and exert additional pressure on the environment, both on land and at sea. It is a fact that reserves of minerals are being exhausted, and worries about access to raw materials, including basic and strategic minerals, are increasing.

The rise in the price of several important metals, for example copper, has prompted some industrialized countries to initiate concerted activities to ensure access to strategic minerals, and Europe has launched several initiatives over the last years in the attempt to solve the issue.

Europe, in particular, depends on imports for many of these materials that it needs for construction and for its heavy and high-tech industries. Recycling, resource efficiency and the search for alternative materials are essential, but most specialists agree that this will not suffice and that there is a need to find new primary deposits.

Politicians and business leaders are concerned because deposits are often found in areas with poor access, barring modern exploration technology, and because of the investment required. Exploration requires substantial capital, rare expertise and leading edge technologies in order to secure the lowest extraction costs.

The GIFT 2015 workshop will gather experts of exploration, extraction, policy making, in the field of future mineral resources, including the deep-sea frontier. Conventional hydrocarbons will not be addressed in this Workshop.

As in every GIFT Symposium, contributions by the attending teachers on particular "off-the-program" activities that they may have had in their classrooms are particularly welcomed, in the poster session (Science in tomorrow's classroom) associated with the workshop, even if their subject is not directly related to the theme of the workshop.

Also, a first step will be a guided visit to the Vienna Museum of Natural Sciences, on Sunday afternoon, April 12, 2015, after which teachers will still be in time to participate to the "Ice breaker party" at the Austria Center where the General Assembly of EGU and the GIFT workshop will take place.

The GIFT workshop is sponsored not only by EGU, but also by several science organizations. We would like to continue to offer teachers the opportunity to attend GIFT and similar workshops, but this depends upon us being able to show our sponsors that teachers have used the new GIFT information and science didactics in their daily teaching, or as inspiration for new ways to teach science in their schools.

Therefore, we ask you

**1.** To fill in the evaluation forms as soon as possible and email them back to us,

**2.** Make a presentation of your experiences at GIFT to a group of your teaching colleagues sometime after you return from EGU, and

**3.** Send us reports and photographs about how you have used the GIFT information in your classrooms. We also encourage you to write reports on the GIFT workshop in publications specifically intended for geosciences teachers.

Information on past GIFT workshops is available on the EGU homepage:

<http://www.egu.eu/media-outreach/gift/gift-workshops.html>

where you can find the brochures (pdf) and also the slides of the different presentations given at the GIFT workshops for the last 8 years. Beginning in 2009, we have also included web-TV presentations, which may be freely downloaded and used in your classrooms.

We know that bringing together 80 teachers in Vienna is not enough to spread scientific information as widely as we would hope. For this reason, the EGU Committee on Education has inaugurated in 2012 an annual series of GIFT Distinguished Lectures (for the moment restricted to European countries), to be given by top scientists who have previously participated as speakers in GIFT workshops during the EGU General Assemblies. These lectures are to be included in a well-organized educational event for high school science teachers, in which a minimum of 80-100 teachers will attend. High school teachers, high school directors, educators for teachers are welcome to request a lecture, for which the EGU Committee on Education will cover the travel and subsistence costs of the speaker. Lecturers and topics should be selected among the ones given in the past 5 years in EGU General Assembly GIFT Workshops.

We are looking forward to meeting you in Vienna!

The Committee on Education  
European Geosciences Union



## Acknowledgements

The GIFT-2015 workshop has been organized by the Committee on Education of the European Geosciences Union. EGU has supported the major share of the expenses, but the workshop has also benefited from the generous help of:



The European Space Agency



Istituto Nazionale di Geofisica e Vulcanologia



Westermann Verlag, Braunschweig, Germany



The Geological Survey of Europe



William S. Goree Award

And we thank all the speakers who have contributed to this educational workshop and their institutions.

# European Geosciences Union

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*Program*

*European Geosciences Union – General Assembly*  
*GEOSCIENCE INFORMATION FOR TEACHERS (GIFT) WORKSHOP*  
*Austria Center Vienna, 12-15 April 2015*  
***‘Mineral Resources’***

**Sunday April 12, 2015**

16:00 - 18:00     **GUIDED TOUR OF THE VIENNA MUSEUM OF NATURAL HISTORY**  
Herbert Summesberger and Mathias Harzhauser  
Vienna Museum of Natural History

**Monday April 13, 2015**

08:30 - 08:45     **WELCOME!**  
Günter Bloeschl  
President of EGU  
**PRACTICAL INSTRUCTIONS FOR THE WORKSHOP**  
Carlo Laj  
EGU Committee on Education

*Chairperson: Carlo Laj*

08:45 - 09:20     **MINERAL RAW MATERIALS: SUSTAINABILITY ISSUES FOR THE  
XXIST CENTURY**  
Patrice Christmann  
BRGM, France

09:20 - 10:00     **MINERAL DEPOSITS – WHERE DO THEY COME FROM AND HOW  
DID THEY GET THERE?**  
Laurence Robb  
Department of Earth Science  
University of Oxford, UK

**10:00 – 10:30 COFFEE BREAK**

*Chairperson: Francesca Funiello*

10:30 – 11:15     **ROLE OF ORGANIC GEOCHEMISTRY IN MINERAL DEPOSITS**  
Kliti Grice  
Department of Chemistry  
Curtin University, Australia



- 11:15 - 11:30    **INSTRUCTIONS FOR THE POSTER SESSION EOS02**  
Eve Arnold  
Stockholm University, Sweden
- 11:30 - 11:45    **PRESENTATION OF CD 'Minerals in your life'**  
Claudia Delfini  
Eurogeosurveys
- 11:45 - 12:10    **TEACHERS AT SEA DURING THE CIRCEA CRUISE IN THE SOUTH CHINA SEA (VIDEO)**  
Ana Morante Sanchez and Carlo Laj

**12:10 – 14:15    LUNCH (SANDWICHES)**

*Chairperson: Angelo Camerlenghi*

- 14:15 -18:00    **HANDS-ON ACTIVITIES**
- MINERAL RESOURCES IN MOBILE PHONES - A HANDS-ON TOOL FOR SCHOOLS**  
Britta Bookhagen  
IASS Potsdam, Germany
- THE 'DERRICK SOFTWARE'**  
Erwan Paitel  
Centre International de Valbonne, France
- TEACHING ABOUT SPECIAL MINERAL PROPERTIES**  
Michael J. Passow  
Dwight Morrow High School, Englewood, USA

**Tuesday April 14, 2015**

*Chairperson: Stephen Macko*

- 08:30 - 09:15    **'LIGHTING UP THE SUBSURFACE**  
John Ludden  
British Geological Survey
- 09:15 - 10:00    **THE GEOLOGICAL HISTORY AND MINERAL DEPOSITS IN GREENLAND - A STATUS ON CURRENT PROJECTS**  
Majken D. Poulsen

Geological Survey of Denmark and Greenland (GEUS)  
Nuuk, Greenland

**10:00 – 10:30 COFFEE BREAK**

*Chairperson: Friedrich Barnikel*

- 10:30 – 11:15    **CRITICAL RAW MATERIALS; WHAT, WHY AND HOW?**  
Éimear Deady  
British Geological Survey, Minerals and Waste, Environmental Science  
Centre, Keyworth  
Nottingham, United Kingdom
- 11:15 – 12:30    Free tour to the EGU General Assembly and at the exhibitors stands

**12:30 - 14:00    LUNCH (SANDWICHES)**

- 14:00 – 14:45    **CITIES: TOMORROW'S MATERIAL RESERVOIRS**  
Helmut Rechberger  
Vienna University of Technology, Institute for Water Quality,  
Resource and Waste Management  
Vienna, Austria

**14:45– 15:30    COFFEE BREAK**

*Chairperson: Eve Arnold*

- 15:30 – 19:00    **EOS3 – POSTER SESSION**

**Wednesday April 15, 2015**

*Chairperson: Annegret Schwarz*

- 08:30 - 09:15    **INTERNATIONAL CO-OPERATION AND EXPLORATION OF  
MINERAL RESOURCES**  
Bernhard Stribrny  
Federal Institute for Geosciences and Natural Resources  
Hannover, Germany
- 09:15 - 10:00    **GLOBAL NATURAL RESOURCE USE: IS THE WORLD HEADING  
TOWARDS A "GREEN ECONOMY"?**  
Stefan Giljum  
Institute for Ecological Economics  
Vienna University of Economics and Business, Austria

**10:00 – 10:30 COFFEE BREAK**

*Chairperson: Francesca Cifelli*

**10:50 – 12:00 GENERAL DISCUSSION AND QUESTIONS**

With: The Committee on Education of EGU, Nick Arndt (ISTerre),  
Mickael Passow (NESTA), Margaret Holzer (NESTA), Giuliana  
D'Addezio (INGV), Francesco Sarti (ESA)

**12:00-13:00 LUNCH (SANDWICHES)**

*END OF THE WORKSHOP!*

**14:00 - 15:30 GEOLOGICAL PATHWAY FROM MARIA THERESIA'S MONUMENT  
TO ST. STEPHEN'S CATHEDRAL**

Herbert Summesberger, Vienna Museum of Natural History

*Speakers*

**Patrice Christmann**

Head of Unit Mineral Resources Strategy  
BRGM (French Geological Survey)  
Orléans, France

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Patrice Christmann is a geologist, specialised in economic geology. He owns a Ph.D. in geosciences obtained in 1979 from the University of Grenoble (France) and a master level degree from the Ecole Supérieure de Commerce de Paris, obtained in 1993.

During his studies he worked as a junior geologist with the Ministry for natural resources of Québec (Canada), and did his field work on the Copper Cliff Cu-Au deposit, near Chibougamau in preparation of his Ph.D.

He entered Bureau de Recherches Géologiques et Minières (BRGM) in 1977, and worked eight years in geological mapping and mineral exploration in Iran and Yemen. In its International Directorate, which he joined in 1985, he managed projects development in several world regions.

From 1997 to 2000 he worked three years as a seconded national expert with the European Commission (DG Development), in Brussels, in the mineral resources domain. He returned to Brussels a second time from 2004 to 2009, as the Secretary-General of EuroGeoSurveys, the Association of 33 European geological surveys. He then returned to BRGM to become the head of its Mineral Resources department.

Since September 2010 he is deputy director of BRGM's Corporate strategy directorate, in charge of BRGM's mineral resources strategy. In this position he coordinates BRGM's contribution to the French committee on strategic metals and to the European Commission's raw materials initiative.

Since June 2010, he is a member of the UNEP International Resources Panel ([www.unep.org/resourcespanel](http://www.unep.org/resourcespanel)).

He is a member of the High-Level Group that steers the European Innovation Partnership on Raw Materials.

His areas of interest are public policies related to the sustainable management of natural resources and mineral raw materials economics.



# **MINERAL RAW MATERIALS: SUSTAINABILITY ISSUES FOR THE XXIST CENTURY**

Patrice Christmann  
BRGM  
France

While energy related issues tend to be rather widely known, and receive much and ever growing attention from citizens, researchers, industrialists, investors and policy makers, mineral raw material issues tend to be less known and therefore overlooked in policy making.

This short paper and the presentation given at EGU 2015 are not pretending to provide a detailed overview of the various issues that we all, as citizens of the Anthropocene on our fragile Earth, are facing with respect to non-energy mineral raw materials. It is merely a brief introduction to the topic. A bibliographic selection is given at the end of this paper to encourage the reader to learn more about the realm of issues related to minerals and metals, those ingredients so vital to mankind that some have given their names to major phases of human civilisation: the Stone Age, the Iron and the Bronze ages.

More than ever minerals and metals are ingredients essential to almost every thinkable human community, especially those living in so-called “advanced” economies such as the OECD countries.

While at the beginning of the XXth century our ancestors were essentially using a few elements of the periodic table, such as carbon, gold, copper, iron, lead or zinc, we are using almost every imaginable element of the periodic table. Fig. 1 shows the diversity of elements that are required just for modern energy generation (including the production of energy from renewable sources), storage transport, or saving (for instance rhenium in the superalloy of maximum efficiency aircraft or gas turbines).

Not only did the diversity of the mineral raw materials we use grow at unprecedented pace since the early XXth century, so did also the quantities of the raw materials needed (fig.2). While, between 1919<sup>1</sup> and now the world population grew by a factor of about 5, the total production of 14 widely used minerals and metals grew by a factor of 20. The Compound Annual Growth Rate of production of these minerals was 3.2%. This may seem as a slow growth, but it is not. It means that every year not only reserves of minerals and metals corresponding to those depleted the previous year will need to be ready to go into production, but this amount will grow by an average 3.2%/ year. In other terms, more minerals and metals will need to be produced between now and 2050 than have been produced since the onset of humanity. The demand growth rate could even be higher, as up to the beginning of this millennium, the production of minerals and metals have essentially benefitted the wealthier nations, China having since 2000 joined the group of minerals and metals intensive nations. Fig. 3, taken from a report of the United Nation's International Resource Panel [2] shows the difference, between wealthier and poorer nations, in per capita stocks of some key metals essential to the development of infrastructure and buildings. In simple terms, in 2005-6 the wealthiest 10% of the plant were using about 90% of the minerals and metals produced worldwide (fig. 3).

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<sup>1</sup> The beginning of the USGS Data Series 140 for some minerals and metals, this data source being used to produce fig. 2

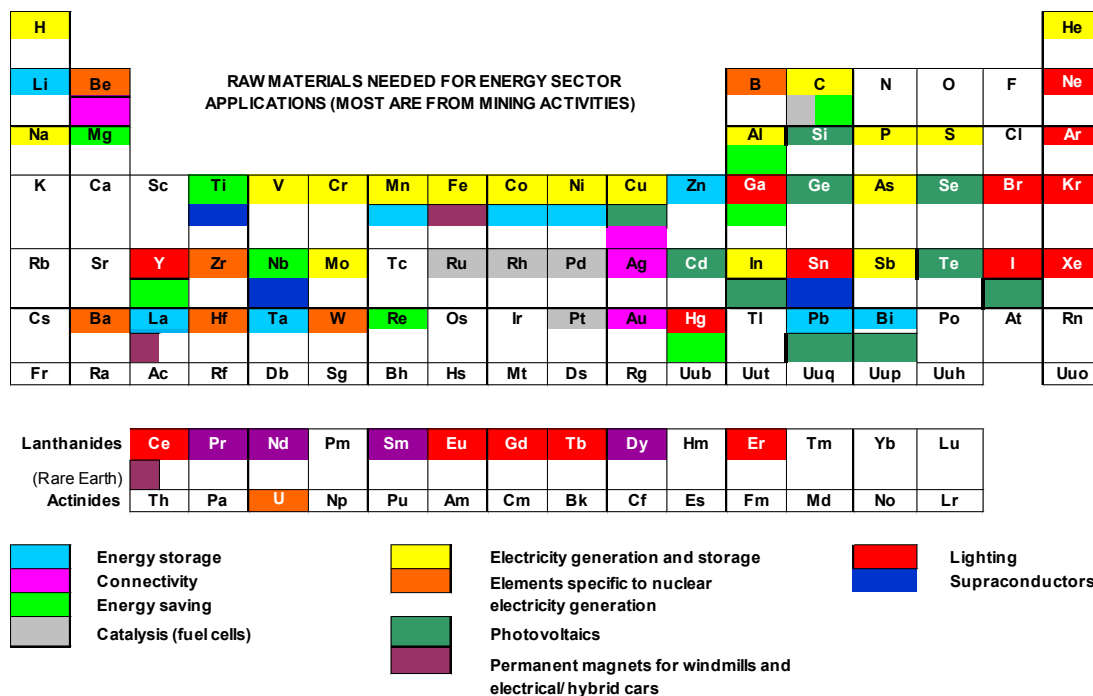


Figure 1- Raw materials needed for energy production, storage, transport and saving

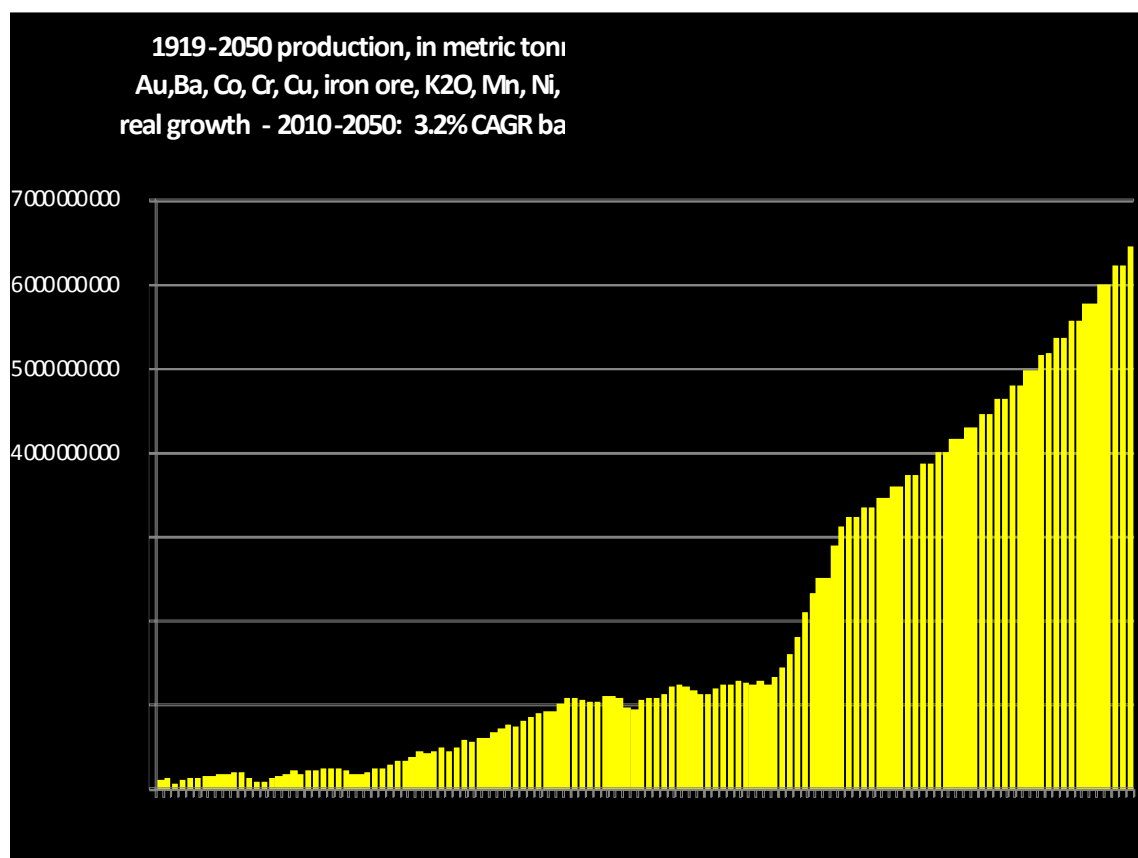


Figure 2 - Trends in minerals and metals production 1919-2050 - Data source: USGS Data Series 140 [1]

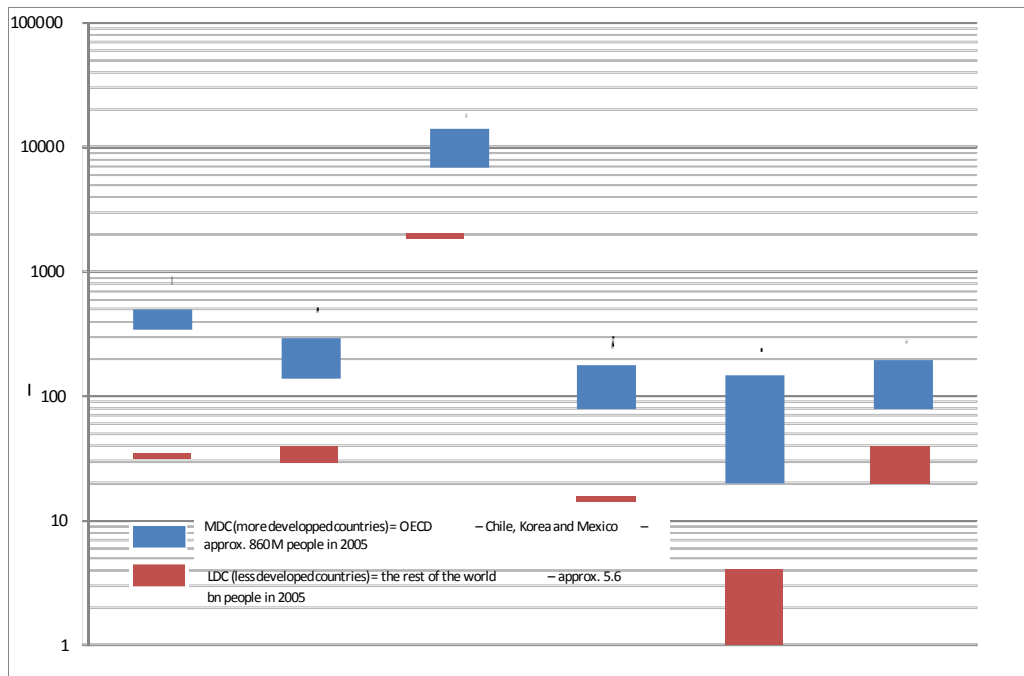


Figure 3 – Per capita metal stocks (in metric tonnes per capita) in developed countries (blue rectangles) and less developed countries (red rectangles). The rectangles reflect differences among the estimates in the data sources used by the authors of the quoted report [2] – Data source: UNEP International Resource Panel.

New technologies, for example to enhance the energy efficiency of cars and/or reduce their demand for fossil fuels, for electricity production from renewable energy sources or in information and communication technologies boost the demand for metals, some produced in very small quantities.

The steel demand by renewable energy generation technologies is particularly high: 115 to 140 000 tons per GW electrical production capacity by means of wind turbines [3] up to 393 000 tonnes for tower concentrating solar power and 650 000 tonnes for parabolic trough concentration solar power generation systems [4]. The demand for copper is equally high: 2 000 t per GW for 2 MWe wind turbines [5]. Moreover, several renewable energies production systems require the use of rare metals such as gallium, indium, selenium or tellurium for specific solar energy production technologies. These figures do not account for the smart grids that will need to connect all these deconcentrated production capacities to the end-users (28 tons of copper are required to manufacture 1 km of a bipolar 1200 MW capacity bipolar cable, for instance [6], they do not account either for the power storage and/or backup systems that will need to be built to ensure continuous power delivery and the management of demand peaks, while the production will be intermittent.

Using the historical world production data from USGS [1], fig. 4 shows the Compound Annual Growth Rate of the world production of a selection of minerals and metals over two periods: 30 years, from 1983 to 2012 and 10 years, from 2003 to 2012. The first period was selected to reflect average annual growth rates through a very long period (30 years), to reduce the impact of the supercycle that started in 2002 due to the rapid growth of the Chinese minerals and metals production. The second period, of 10 years, from 2003 to 2012, not only reflects the Chinese metals production supercycle, it also reflects the

beginning of the transition of energy production from renewable sources, the quest for energy efficiency and the boom of information and communications technologies.

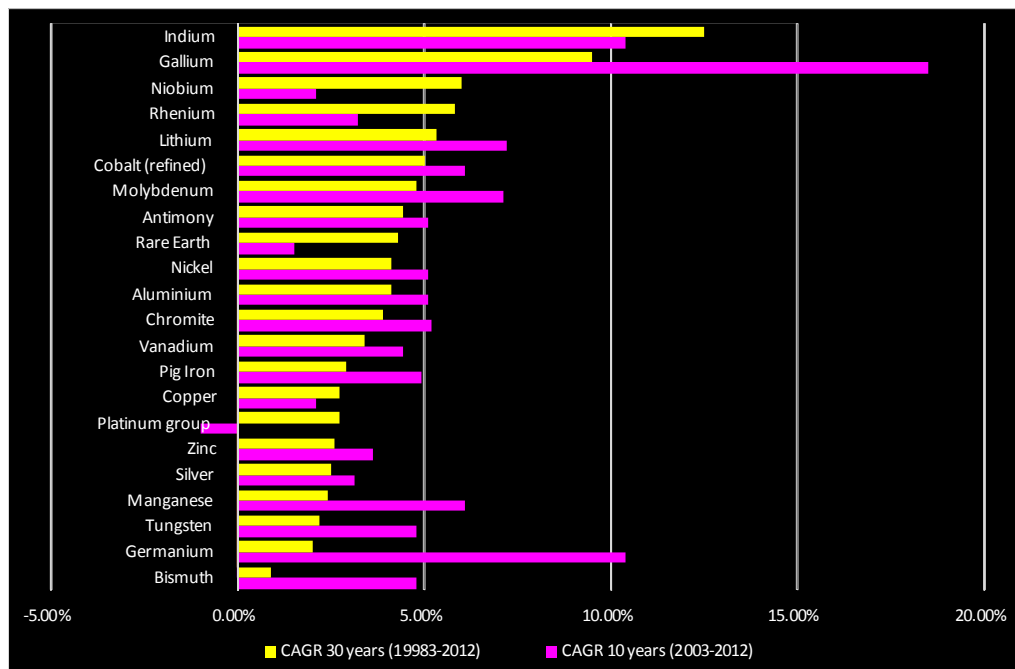


Figure 4 – Compound annual growth rate of the production of a selection of metals, over a 10 years (2003-2013, magenta bars) and 30 years (1983-2012, yellow bars) – Data source: USGS Data Series 140

Quite a number of metals had a 5% CAGR over the last 10 years. If such a trend would persist over a century that would mean an increase in production by a whopping rate of nearly 125 times, quite a challenge as it will require to discover and invest in the launch of the production of a large amount of mineral deposits. However these CAGRs may decline over the coming century, especially if the world population stabilises and once a major part of the world population will have reached a per capital material intensity comparable with the levels currently observed in developing countries. Rising metals prices may also encourage research and innovation in resource efficient product design technologies, allowing to obtain high levels of performance with less use of raw materials per functional unit. Nanotechnologies for instance offer very interesting perspectives in this respect. However, resource efficiently designed products may also be more affordable, leading to a rebound effect with an even stronger growth of the demand, offsetting the gains resulting from eco-efficient product design.

The growing political perception of the manifold issues around natural resources and sustainable development steers the transition towards a circular economy, where an end-of life product would no longer be a worthless waste but a valuable resource, either via the reconditioning and re-use of components (of a car, of a computer, of a washing machine...) in a new product and/or the recycling of the metals contained in the end-of life products.

However, recycling of metals from end-of-life products is far from being an easy task. A UNEP International Resources Panel report [7] has identified the recycling rate of 60

metals<sup>2</sup> in end-of-life products. Fig. 5 shows that most of the rarer metals have recycling rates of less than 1%. Among the



Figure 5 – Recycling rates of 60 metals from end-of-life products – Source: [7]

11 metals shown in fig. 4 with a 2003-2012 CAGR of 5% and more, 4 metals essential to modern technologies (gallium, germanium, indium, lithium) had an end-of-life recycling rate of less than 1%.

Very low recycling rates are the case for almost all rare metals used in electronic applications such as motherboards, integrated circuitry, telecommunications hardware and video screens. This is due to multiple reasons such as:

- the extreme complexity of the assemblages binding the multiple elements (about 60) found for instance in modern electronic appliances;
- the low per ton value of certain of these elements, making their recycling economically unattractive.

Fig. 6 show the difference between a typical lead-zinc ore and a modern motherboard, with its many highly miniaturised electronic components.

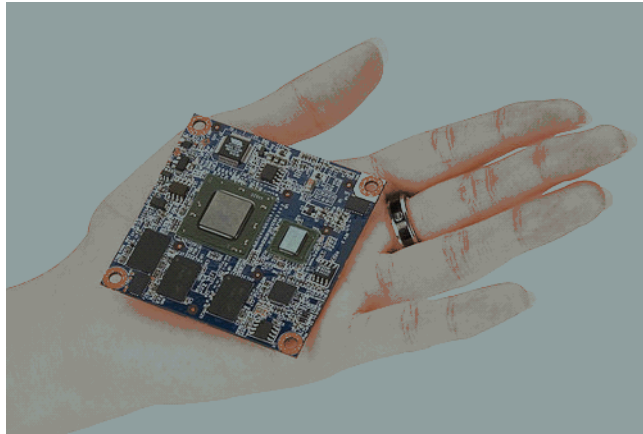
Progressing in the recycling of the rarer metals requires an important investment in research and innovation and the development of recycling-friendly design of modern products, which may prove difficult or impossible in a number of cases.

<sup>2</sup> The elements investigated in that report were not all “metals” in the usual chemical definition, but also metalloids. The radioactive actinides and polonium were excluded from the assessment.





A lead-zinc ore ( greyish-blue lead sulfide and dark brown shiny zinc sulfide crystals ) on a quartz matrix. Common polymetallic ores are assemblages 5 to 10 minerals and may contain up to 10 elements



A modern highly integrated motherboard may comprise 60 different elements in very complex assemblages and miniaturised components, a man-made « ore » of much higher complexity than natural ores. ( Here : VIA Mobile -ITX Board – Image from ViaGallery , Creative Commons Licence)

*Figure 6 – Differences between natural man-made ores*

Reuter et al. [8] have described in detail the opportunities and the limits of metal recycling in an International Resource Panel report providing a detailed insight in the related issues. There are many hurdles to overcome to make an economically viable use of the huge metals and minerals stocks contained in “urban mines” made of our waste and our built infrastructure.

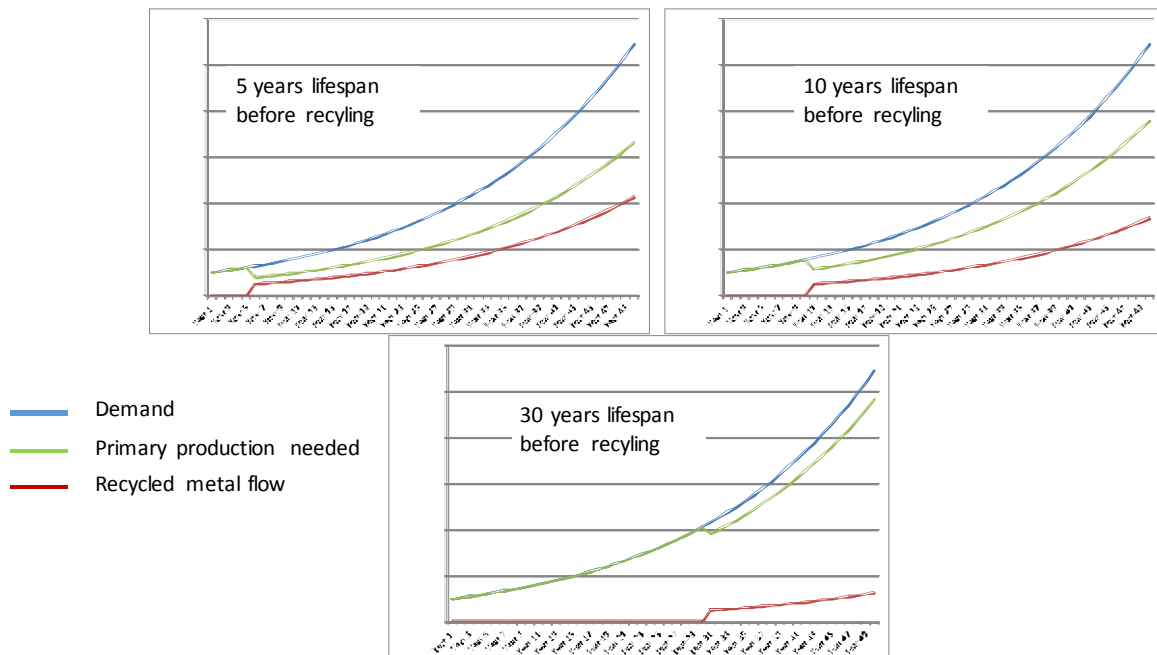
While recycling of metals allows resource efficiency gains (less use of non-renewable primary resources, less energy and water needed for the production of one ton of recycled metal) of importance from a sustainable development perspective, it cannot secure our needs in a context of a rapidly growing demand and of long residence time of minerals and metals in products or infrastructure, before becoming available for end-of-life recycling. While some electronic consumer goods have a short life span (less than 2 years in developed countries for smartphones), many manufactured products have longer life cycles: cars for instance remain in use for over 10 years, washing machines for 14 years. Metals and minerals used in infrastructure will remain “locked in” their applications for even longer times. The lifespan of windmills is rated at about 20 years, copper wiring in buildings may stay in use for over 50 years.

Fig. 7 shows the impact of recycling on the demand of a given primary metal (extracted from an ore deposit) having a 5% CAGR, considering a 50% recycling rate from end-of-life products and 3 different lifespans for these products: 5, 10 and 30 years. The figures clearly show that recycling only postpones for some years the demand for primary resources, the gain rapidly fading away as the lifespan of a metal in a product in use grows. With a 30 years lifespan and a 5% CAGR the gain is almost negligible.

In conclusion, to overcome the XXIst mineral raw materials demand challenges action is needed at the broad international level on multiple levers, both at the levels of research and innovation, and of policy making:

- to foster resource governance, based on transparency and quadruple sustainable development reporting (on economic, environmental, governance and social performance);

**IMPACT OF RECYCLING, AT A 50% RECYCLING RATE, ON THE DEMAND FOR PRIMARY METAL HAVING A 5% CAGR, FOR 3 DIFFERENT PRODUCT LIFESPANS (5,10, 30 YEARS LIFESPAN)**



*Figure 7 – Impact of “in use” lifespans on recycling and the demand for primary resources*

- through limiting the use of metal hedging to professionals;
- to foster resource efficient minerals through the reduction of harmful chemicals, energy, water consumptions and emissions/ waste harmful to the environment and/or to human health in mining, ore processing and metallurgy;
- to foster the full use of the valuable contents of ores, including co- and by-products;
- to develop a functionality based concept of economy;
- to search for substitutes allowing a similar functionality, or near similar functionality thanks to the use of common minerals and metals rather than rare one;
- through eco-design of products, to facilitate their later re-use and recycling;
- through the further deployment of the industrial ecology concept, linking together economic activities in a way that waste streams of certain activities become resources needed by other activities, therefore enhancing resource efficiency and reducing overall emissions;
- through extending the lifespans of products, facilitating their maintenance;
- through the reconditioning of components of larger systems at end-of life, for use in new systems;
- to foster recycling at end-of-life;
- to develop natural resource education and life-cycle thinking from the youngest age,
- to develop international cooperation and dialogue on mineral raw materials issues.

The European Union has one of the world highest dependences on mineral raw materials imports from beyond its borders. Its situation in this domain is quite comparable on its energy dependence. In 2008 the political perception of the issues at stake led the

European Commission to launch its Raw Materials Initiative<sup>3</sup> and, more recently, its Flagship Initiative for a Resource-efficient Europe<sup>4</sup> combining policy, communication about the issues, research and innovation.

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- [5] Guezuraga B., Zauner R., Pölz W. - 2012 - Life cycle assessment of two different 2 MW class wind turbines - Renewable Energy 37 (2012) 37-44 - Elsevier Science Publishers B. Y. (Amsterdam, Netherlands)
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- [7] UNEP - 2011 - Recycling rates of metals - A Status report. A Report of the Working Group on the Global Metal Flows to the UNEP International Resource Panel - Graedel T.E., Allwood J., Birat J.-P., Reck B.K., Sibley S.F., Sonnemann G., Buchert M., Hagelüken C. - UNEP (Nairobi, Kenya) - [http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metals\\_Recycling\\_Rates\\_110412-1.pdf](http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metals_Recycling_Rates_110412-1.pdf)
- [8] UNEP - 2013 - Metal Recycling: Opportunities, Limits, Infrastructure. A Report of the Working Group on the Global Metal Flows to the International Resource Panel. Reuter, M. A.; Hudson, C.; van Schaik, A.; Heiskanen, K.; Meskers, C.; Hagelüken, C - UNEP (Nairobi, Kenya)- <http://www.unep.org/resourcepanel/Publications/MetalRecycling/tabid/106143/Default.aspx>

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3 Web portal: [http://ec.europa.eu/enterprise/policies/raw-materials/index\\_en.htm](http://ec.europa.eu/enterprise/policies/raw-materials/index_en.htm)

4 Web portal : <http://ec.europa.eu/resource-efficient-europe/>

**Further suggested sources of information:**

**United Nations Environmental Programme (UNEP) International Resource Panel:**  
[www.unep.org/resourcepanel](http://www.unep.org/resourcepanel)

in addition to the already quoted reports:

- UNEP - 2013 - Environmental Risks and Challenges of Anthropogenic Metals Flows and Cycles - A Report of the Working Group on the Global Metal Flows to the International Resource Panel. van der Voet, E.; Salminen, R.; Eckelman, M.; Mudd, G.; Norgate, T.; Hirsch, R. - UNEP (Nairobi, Kenya) - [http://www.unep.org/resourcepanel/Portals/24102/PDFs/Environmental\\_Challenges\\_Metals-Full\\_Report\\_150dpi\\_130923.pdf](http://www.unep.org/resourcepanel/Portals/24102/PDFs/Environmental_Challenges_Metals-Full_Report_150dpi_130923.pdf)

**On critical minerals:**

- Ad-hoc working group on defining critical raw materials - 2014 - Report on Critical raw materials for the EU - European Commission, DG Enterprise (Brussels, Belgium) - available online: [http://ec.europa.eu/enterprise/policies/raw-materials/critical/index\\_en.htm](http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm), with separate complementary documents: Annexes A to D; Study on critical raw materials at EU level with its 2 annexes (Critical raw materials profiles and Non-critical raw materials profiles)
- Gunn G. (Editor) - 2014 - Critical Metals Handbook - Wiley-Blackwell (Hoboken, New Jersey, USA)

**On renewable energies and metals demand:**

- Moss R., Tzimas E., Willis P., Arendorf J., Thompson P., Chapman A., Morley N., Sims E., Bryson R., Pearson J., Tercero Espinoza L., Marscheider-Weidemann F., Soulier M., Lüllmann A., Sartorius C., Ostertag K. - 2013 - Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector - European Commission, Joint Research Centre, Institute for Energy and Transport (Petten, Netherlands) - <http://setis.ec.europa.eu/publications/jrc-setis-reports/jrc-report-critical-metals-energy-sector>

**On research and innovation:**

- Vidal O., Weihed P., Hagelüken C., Bol D., Christmann P., Arndt N. - 2013 - ERA-MIN Research Agenda - ERA-MIN, The European Research Area Network (ERA-NET) on the Industrial Handling of Raw Materials for European Industries - (Coordinator: CNRS - the French Research Council, Paris, France) - <http://hal-insu.archives-ouvertes.fr/docs/00/91/76/53/PDF/roadmap10.pdf>

**Laurence Robb**

Visiting Professor

Department of Earth Science

University of Oxford, UK

[laurence.robbs@earth.ox.ac.uk](mailto:laurence.robbs@earth.ox.ac.uk)

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**EDUCATION**

University of the Witwatersrand, Johannesburg, South Africa

1981: PhD

1977: MSc

**AFFILIATIONS**

Fellow of the Royal Society of South Africa

Fellow of the Geological Society of South Africa

Fellow of the Society of Economic Geologists

Fellow of the Geological Society of London

Chartered Geologist

European Geologist

**CAREER**

1997-2005: Pavitt Professor of Economic Geology, University of the Witwatersrand, Johannesburg.

1999-2000: President, Geological Society of South Africa.

2001-2005: Director, Economic Geology Research Institute, University of the Witwatersrand.

2004-2008: Visiting Senior Research Fellow in Economic Geology, University of Oxford.

2008-present: Visiting Professor in Economic Geology, University of Oxford.

**RESEARCH INTERESTS**

I am interested in the geological processes that give rise to the concentration of metals in the Earth's crust and the formation of mineral deposits. My research has been conducted in many of the great mineral districts of the African continent, including the Witwatersrand Basin, the Bushveld Complex and the Central African Copperbelt. At present we are studying the tectonic and metallogenic evolution of Myanmar and Malaysia, in SE Asia.

I have written a major text book in economic geology, entitled 'Introduction to Ore Forming Processes' which was published by Wiley-Blackwell in 2005. A second edition of this book is currently in preparation.



## MINERAL DEPOSITS – WHERE DO THEY COME FROM AND HOW DID THEY GET THERE?

Laurence Robb

Department of Earth Sciences, University of Oxford, UK

With a global population in 2014 of close to 7 billion people, and this figure set to increase to some 9 billion by 2040, it is apparent that the world's economies are under growing pressure to sustain an increasingly materialistic life-style for its peoples. The unprecedented growth of human population over the past century has resulted in a dramatic increase in demand for, and production of, natural resources - it is therefore evident that understanding the nature, origin and distribution of the world's mineral deposits remains a vital and strategic topic. The discipline of "economic geology," which covers all aspects pertaining to the description and study of mineral resources, is therefore one which traditionally has been, and should remain, a core component of the university earth science curriculum. An understanding of the natural resource cycle is also a subject that school learners should be exposed to as early as possible.

There is a multitude of processes that give rise to the concentration of metals in the Earth's crust and the formation of mineral deposits. For the purposes of this presentation I have selected only four processes, very different from one another, that nevertheless provide a useful and informative insight into how metals are concentrated and where mineral deposits are likely to occur. These are:-

### Exhalative activity on the sea-floor

Cold sea water is known to circulate through the oceanic crust and in so-doing becomes heated to temperatures as high as 350°C. As it passes through the oceanic crust this fluid dissolves metals such as Cu, Zn, Pb, Ag, Au and Ba and carries them in solution until the point on the ocean floor where the water vents back into the ocean and the metals are precipitated. These vent sites have been described from many different parts of the World's oceanic basins



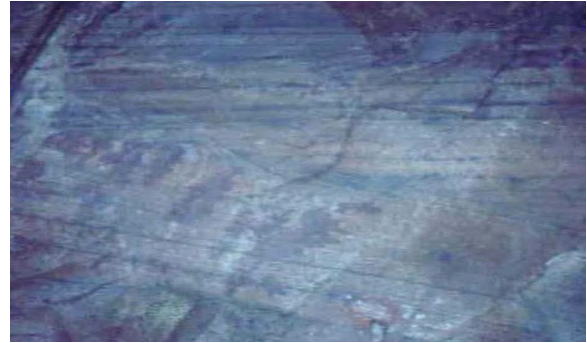
Black smokers and sulphide chimneys at an exhalative vent on the ocean floor

and point to processes that have resulted in very significant concentrations of metals in preserved portions of the oceanic crust. There are many examples of massive sulphide Cu-Zn-Pb deposits around the World (for example, Troodos, Cyprus; Red Dog, Alaska; Broken Hill, Australia) that have formed by processes similar to these.

### Metals at the 'redox' interface in sediments

Some metals, such as Cu, Co and U, are relatively soluble in oxidized waters but are insoluble in more reduced environments. Others, such as Fe and Mn, exhibit the opposite tendency. Many sedimentary environments comprise basinal fluids that are oxidized and are, therefore, able to dissolve certain metals encountered whilst circulating through the sediment pile. These metals are subsequently precipitated as soon as these fluids interact with more reduced strata, resulting in ore concentrations at the redox interface. One area where this has occurred on a massive scale is in the Central African Copperbelt that straddles a 400km long stretch of the Katanga Basin in northern Zambia and the southern Congo.

*Cross-bedded sandstone with concentrations of Cu and Co along foresets representing a redox interface, Mufulira Mine, Zambia*



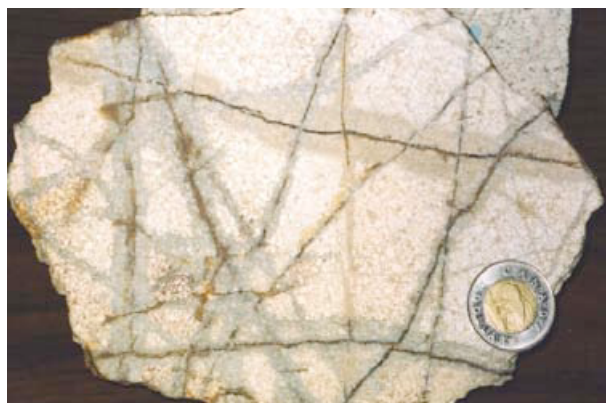
Another example is the 'Kupferscheifer' in eastern Europe. In the Central African Copperbelt most of the stratiform Cu-Co deposits occur stratigraphically beneath a major glacial diamictite unit (the Grand-Conglomerat) that has been correlated with the Sturtian 'Snowball Earth' event. It is suggested that the basin-wide transition from oxidized to reduced conditions that was responsible for metal precipitation and concentration was promoted by global glaciations and anoxia at this particular interval.

#### Granite formation and mineralization along subducting plate margins

The Earth's surface is made up of rigid plates that move relative to one another. Plate tectonic processes provide the framework for understanding many ore-forming processes. When dense oceanic crust in one plate collides with less-dense continental crust in another (such as along the western edge of present-day South America) the oceanic material is subducted beneath the continental material, resulting in rock deformation and magma formation. The granite magmas that form along subducting plate margins are hosts to major Cu-Mo deposits (known as 'porphyry coppers') that form only 1-3 km below the surface, and also to high-level (or 'epithermal') Au-Ag deposits that typically form in or near to volcanic vents. The water that emanates from these magmas, known as a hydrothermal fluid, carries chlorine and sulphur, that assists in the dissolution of metals such as Cu and Au, the latter themselves derived from the magma.



*Magmatic hydrothermal fluid precipitating native in the vent of a volcano, Kyushu, Japan*



*Network of intersecting veins cutting a granite porphyry – the sulphur veins represent the fossilized pathways of hydrothermal fluid*

These hot, metal-charged hydrothermal fluids circulate in and around the granitic intrusions and react with the country rocks through which they pass. The alteration of the country rocks changes the properties of the hydrothermal fluid causing the metals being transported in solution to precipitate out. For this reason granites forming adjacent to

subducting plate margins, such as in Chile, are highly prospective around the World for porphyry style Cu-Mo deposits and epithermal Au-Ag mineralization.

#### Basaltic magmatism and fractional crystallization

A very substantial proportion of the World's platinum group element (PGE) and chromium reserves are extracted from mines that occur within the Bushveld Complex in South Africa. The Bushveld Complex is the largest known intrusion of basaltic magma, emplaced some 2050 million years ago and underlying an area of >60 000 km<sup>2</sup>. The intrusion forms a large, 7000m thick composite sill that cooled very slowly allowing the sequential crystallization of rock-forming minerals to take place. This process, known as fractional crystallization, allows certain minerals, such as olivine and orthopyroxene, to form and settle at the base of the magma chamber before others such as plagioclase feldspar and clinopyroxene. Fractional crystallization results in the formation of igneous layering within the intrusion, with the composition and mineralogy of the layers evolving progressively in an upward direction. Basal layers, made up of rocks such as peridotite and harzburgite, are overlain by more fractionated layers of gabbro, norite and anorthosite.



*The UG1 chromitite layer, Bushveld Complex, South Africa*

Perturbations in the normal crystallization sequence, related to events such as the injection of new magma into the existing chamber, periodically occur in the Bushveld Complex. The lower portions of the sequence contain numerous layers of chromite rich rocks, known as chromitite seams, many of which are mined for chromium from layers that extend laterally for hundreds of kilometres. Higher in the sequence magnetite layers also occur and these represent rich resources of Fe, Ti and V that are used in specialized steel industries. Injection of new magma also results in the separation of immiscible sulphide globules that settle to form sulphide-mineral rich layers. In the Bushveld Complex one such layer, the Merensky Reef, hosts the World's largest reserves of PGE, as well as substantial Ni and Cu. The complex crystallization processes that formed the layered intrusion of the Bushveld Complex were extremely efficient at concentrating a wide range of metals into ore deposits that collectively represent one of the most prospective mineral provinces of the World.

To conclude, the formation of mineral deposits occurs in response to the many varied and complex, but otherwise routine, geological processes that accompany the development and evolution of the Earth's crust through time. However, the responsible management and sustainability of the World's finite mineral resource base in the future will need to be carried out by a global population that more fully understands the nature, limits and distribution of its natural resource endowment.

**Kliti Grice**

Department of Chemistry

Curtin University

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[k.grice@curtin.edu.au](mailto:k.grice@curtin.edu.au)

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**Current Position**

Professor of Organic and Isotope Geochemistry, Curtin University – since December 2007

**Professional Employment**

- |                |  |
|----------------|--|
| 2008–current   | Founding Director, Western Australian Organic and Isotope Geochemistry Centre (founding director); Australian Research Council (ARC) Discovery Outstanding Research Award- DORA at Professorial level 2013-2016) |
| 2008 – current | Founding Director, Western Australian Organic and Isotope Geochemistry Centre (founding director); Australian Research Council (ARC) QEII Fellow (II)  |
| 2007           | Professor of Organic and Isotope Geochemistry, Curtin University   |
| 2003           | Associate Professor of Organic and Isotope Geochemistry, Curtin University   |
| 2002–2007      | ARC (QEII) Fellow (I), WA State Centre for Excellence in Applied Organic Geochemistry, Curtin University<br>Leader of the Stable Isotope and Biogeochemistry Research Group                                      |
| 1998–2002      | Senior Research Fellow, John de Laeter State Centre for Excellence in Mass Spectrometry, Curtin University   |
| 1995–1998      | Research Fellow, Royal Netherlands Institute for Sea Research, Texel, The Netherlands  |

**Education**

- |      |  |
|------|--|
| 1995 | Doctor of Philosophy (University of Bristol, UK)                                       |
| 1991 | Bachelor of Science in Applied Chemistry (Honours), University of Kingston, London, UK |

**Awards (last 5 years)**

- 2014: The biennial Australian Organic Geochemistry Lifetime Achievement Medal: First female and youngest awardee
- 2013: Finalist of John de Laeter Science Leadership award, Curtin University
- 2013: Curtin University of John Curtin Distinguished Professor for exceptional service to the University.
- 2013: Geochemical Fellow: Geochemical Society and European Association of Geochemistry
- 2012: RACI Environmental Medal and Lecture
- 2013-2015: Geochemical Society committee member awards
- 2010: VC Award for Excellence and Innovation at Curtin University, Finalist award
- 2009 Faculty Senior Researcher of the Year Award for Science, Curtin University

# **ROLE OF ORGANIC GEOCHEMISTRY IN MINERAL DEPOSITS**

Kliti Grice

Department of Chemistry

Curtin University, Perth, WA, Australia

Many major mineral accumulations contain substantial quantities of organic matter (OM), which plays a critical role in the formation of many deposits. Until recently many questions have remained unanswered on the association between OM and mineral accumulations globally. These include (i) What is the role of OM in the transport and/or precipitation of metal types? (ii) What are the main source(s) of the OM? and (iii) What geological environments (redox conditions, temperatures) have the OM been exposed to? Some examples of very recently published data on OM associated within the mineral matrices of several Australian mineral deposits will be presented. These include the world class 'Here's Your Chance' lead-zinc-silver deposit showing evidence for sulfur-cycling bacteria that led changes in the water chemistry essential for the formation of such a deposit. Other deposits include uranium-rich samples from the Mulga rock, WA. Detailed organic geochemical and stable isotopic analyses shows that the OM associated with the uranium in the deposit is derived from highly aliphatic biopolymers present in a variety of extant organisms. These aliphatic biopolymers break down by radiolysis yielding a unique suite of compounds attributed to radiolytic cracking.

A series of novel analytical instruments have also been developed and have been published, allowing the measurement of compound-specific sulfur isotopic composition ( $\delta^{34}\text{S}$ ) of key organosulfur compounds in mineral deposits. Methods developed to isolate OM inside various minerals. Further, application and development of hydropyrolysis to study highly altered OM from gold deposits will be presented.





## **Britta Bookhagen**

Institute for Advanced Sustainability  
Studies (IASS) Potsdam, Germany  
britta.bookhagen@iass-potsdam.de

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### **Education:**

- 2006 Diploma in Geology at Freie Universität Berlin, Germany
- 2003-2006 Teaching studies in mathematics and physics, Freie Universität Berlin, Germany
- 2002 pre-Diploma in Geosciences at Universität Potsdam, Germany

### **Work Experience**

- since March 2012: Research Associate, IASS Potsdam, Germany
- 2010-2012 Educator/Project Leader, Natural History Museum, Vienna and Austrian Academy of Science, Austria
- 2008-2010 Educator, Boston University School of Medicine, Boston, USA
- 2007-2010 Outreach Manager, Massachusetts Institute of Technology, Cambridge, USA
- 2005-2007 Research and Teaching Assistant, GFZ Potsdam, Germany

### **Publications**

Nordmann, J., Welfens, M.J., Fischer, D., Nemnich, C., **Bookhagen**, B., Bienge, K., Niebert, K. (2014): *Die Rohstoff-Expedition, Entdecke, was in (deinem) Handy steckt*. Springer Spectrum, Didaktik der Naturwissenschaften, Berlin.

**Bookhagen B**, Buchwaldt R, McLean N, Rioux M and Bowring S (2014): *Earthtime: Teaching Geochronology to High School Students..* In: Tong, V. C. H. (ed.), Geoscience Research and Education, Springer, Dordrecht

Welfens, **Bookhagen**, Nordmann, Reimann (2013): *Rückgabe und Nutzung gebrauchter Handys*. SÖF Mitteilungen des BMBF GAIA 22/2 (2013): 128–131

**Bookhagen**, B. (2012) *Rohstoffkoffer: Was steckt im Handy?* LehrerInnenbroschüre. 76 S. Verlag Naturhistorisches Museum Wien, ISBN 978-3-902421-73-9

**Bookhagen, B.**, Buchwaldt R, McLean N, Rioux M and Bowring S (2010): *Lesson plan and activities for teaching U-Pb radiometric dating*, EARTHTIME [http://www.earthtime.org/Lesson\\_Plan.pdf](http://www.earthtime.org/Lesson_Plan.pdf).

# **MINERAL RESOURCES IN MOBILE PHONES**

## **A HANDS-ON TOOL FOR SCHOOLS**

Britta Bookhagen  
IASS  
Potsdam, Germany

### **Find out what's in your cell phone!**

#### **Workshop Description:**

In this hands-on workshop for teachers, mobile phones are used as an example for mineral resources in our daily lives. The interdisciplinary teaching material was developed for students ages 14 and up to raise awareness for our resource-rich lifestyle. More than 90% of students own a mobile phone. This workshop will demonstrate how to engage your students in this up-to-date topic. The teaching box contains eleven raw materials (minerals and ores), which are being used as basic materials for the mobile phone production. A mobile phone will be disassembled and linked to the raw materials from the box. Example exercises from the workshop can be directly transferred to classrooms. Topics covered in this workshop include exercises and discussions about the ecological and social impacts of mining of the raw materials and the distribution of "critical" materials and problems during manufacturing (e.g., working conditions). Also, the energy consumption during the life time of mobile phones is evaluated and the necessity of recycling to preserve our resources („urban mining") will be discussed. Valuable background material about these issues will be provided as well as information on how to make usage of a mobile phone more sustainable.

#### **Facts:**

Interdisciplinary subject for teachers in geography/ earth sciences, chemistry, physics, biology, sociology  
For Students aged 14+

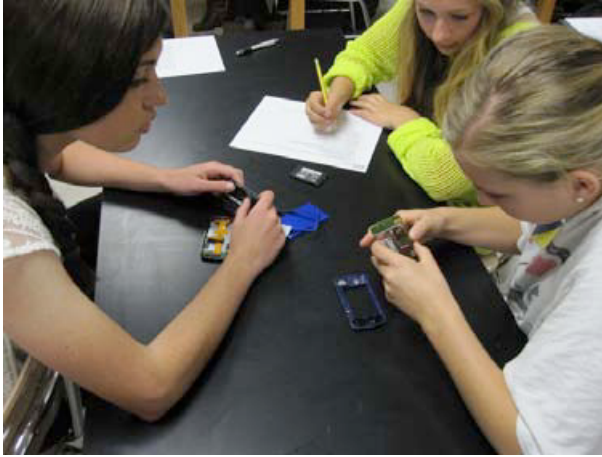
#### **Basic idea:**

- Mobile phones contain up to 45 elements, 30 of which are raw and expensive metals such as gold, silver, palladium. Mining of these ores often is associated with social and ecological problems.
- Teaching-box contains eleven minerals and ores (raw materials), which are being used as basic materials for cell phone production; the provided educational game is used to determine the minerals and sort them to the components of a mobile phone that they are being processed to.
- Fun and experimental, awareness rising without a pointing finger
- makes students also aware about resources in other devices and that everything we use is linked to Earth (where the resources come from)

#### **Examples for interdisciplinary teaching linkages:**

- Biology: impact of mining on environment, animals and humans
- Chemistry: Chemistry of the elements, metals, alloys, technical chemistry and applications
- Physics: conductors, technical use, capacitors

- Geography: physical and industrial geography (formation of lagerstätten, distribution of "critical" materials, prospecting and mining, raw materials/commodities, value chains, geopolitical issues)
- social and political aspects: social-political conflicts arising through mining (child labour, working conditions, security), for example the conflict mineral tantalite („Coltan“) prolonged civil war in DR Kongo



Disassembled mobile phone and the quiz for determining the raw materials contained in it.





## **Erwan Paitel**

High-school teacher

Centre International de Valbonne, France

erwan.paitel@gmail.com

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### Professional experiences

2005-2015:

- High School teacher (Lycée Carnot, Cannes; CIV, Valbonne)
- Professor, genetics and biochemistry (University of Nice-Sophia Antipolis)
- Selection board for Engineer schools in agronomy and Veterinary schools (Agro ParisTech, Paris)
- Professor, Environmental Sciences (Skema Bachelor)

2004-2005 :

- Post-doc position, genetics and molecular biology of neurodegenerative diseases (University of Nice Sophia-Antipolis).

2003-2004 :

- Post-doc position, research on transgenic approaches of neurodegenerative diseases, University of Toronto, Canada.

1999-2002 :

- PhD student, research on prion diseases, Institut de Pharmacologie Moléculaire et Cellulaire, Valbonne.

### Diplomas

2002 : PhD in Life Sciences.

1998 : Agrégation, earth and Life Sciences.

### Publications

Cortical neuronal and glial pathology in TgTauP301L transgenic mice: neuronal degeneration, memory disturbance, and phenotypic variation. Murakami T, Paitel E, Kawarabayashi T, Ikeda M, Chishti MA, Janus C, Matsubara E, Sasaki A, Kawarai T, Phinney AL, Harigaya Y, Horne P, Egashira N, Mishima K, Hanna A, Yang J, Iwasaki K, Takahashi M, Fujiwara M, Ishiguro K, Bergeron C, Carlson GA, Abe K, Westaway D, St George-Hyslop P, Shoji M. Am J Pathol. 2006 Oct;169(4):1365-75.

Primary cultured neurons devoid of cellular prion display lower responsiveness to staurosporine through the control of p53 at both transcriptional and post-transcriptional levels. Paitel E, Sunyach C, Alves da Costa C, Bourdon JC, Vincent B, Checler F., J Biol Chem. 2004 Jan 2;279(1):612-8. Epub 2003 Oct 21.

## **THE 'DERRICK SOFTWARE'**

Erwan PAITEL,  
Centre International de Valbonne, France

Resources stands for what human can get for living and developing into its large ecosystem: the Earth. Since the 19<sup>th</sup> century, humanity has been developing (industrial revolutions). Demography has exploded. The needs have grown exponentially. We are now facing some issues with finding the resources we need to maintain this level of development.

Kids, and more generally students, were born with computers, tablets, cell phones... but do they know what makes them work? Are they aware of the necessity of mineral resources, such as lithium to accumulate energy in that kind of apparatus? Do they know what we do with Uranium in a nuclear plant? Speaking of these issues is pointing the necessity of finding mineral resources.

We designed a software called Derrick, so that students can get into the awareness of the scarcity and the cost of resources. The easy point-and-click interactivity of this software gives us the opportunity to get quickly into the notion of respect and conservation of resources.



## **Michael J. Passow**

Dwight Morrow High School,  
Englewood, NJ 07631, USA  
michael@earth2class.org

### EDUCATION

B.A. (Geology), Columbia University; M.A.T. and Ed.D. (Science Education), M.Ed. (Curriculum & Teaching), Teachers College, Columbia University

### CAREER

Dr. Michael J Passow is a national leader in pre-college geoscience education in the USA. In addition to his 44-year career as a classroom teacher, he promotes excellence in Science Education as the current President of the National Earth Science Teachers Association (NESTA) and the Earth2Class Workshops for Teachers at the Lamont-Doherty Earth Observatory of Columbia University (E2C). In his NESTA role, he has guided efforts to enhance the NESTA website and interactions with other professional societies (such as AGU, GSA, and NSTA) and federal agencies (such as NOAA and USGS) to promote K-12 teaching. E2C is a unique program that provides monthly workshops which connect research scientists, teachers, and students. It is one of the most widely-accessed websites for middle and high school Earth Science teachers and students. Passow has authored more than a hundred articles in science education journals, and is a respected contributor to electronic geoscience teacher networks. He has organized and presented at local, regional, national, and international conferences. He serves as a mentor in many professional development programs, including the American Geophysical Union's Geophysical Workshops For Teachers, the American Meteorological Society's DataStreme courses, the International Ocean Drilling Program's Deep Earth Academy, and others.

### RESEARCH INTERESTS

Earth Science Education, Teacher Professional Development

### SELECTED PUBLICATIONS AND SERVICES

- *Earth2Class Workshops for Teachers at the Lamont-Doherty Earth Observatory of Columbia University*  
<http://www.earth2class.org>
- Kastens, K.A., L. Pistolesi, and M.J. Passow (2014) *Analysis of Spatial Concepts, Spatial Skills and Spatial Representations in New York State Regents Earth Science Examinations*. *Jour. Geosci.Educ.*, v.62, no. 2, pp. 278-289. **doi:** <http://dx.doi.org/10.5408/13-104.1>
- Passow, M, H. Pereira, and L Peart (2013) *A brief history of scientific ocean drilling programs/Breve historica dos programas cientificos*. *Terra Didatica* 9(2), pp. 65-73. <http://ppegeo-local.igc.usp.br/pdf/ted/v9n2/v9n2a01.pdf>

### SELECTED AWARDS AND HONORS

Fellow of the National Earth Science Teachers Association and Science Teachers Association of New York State

Distinguished Service Awards from the National Association of Geoscience Teachers-Eastern Section, New York State Earth Science Teachers Association, and American Meteorological Society Board on Outreach and Pre-College Education.

## **TEACHING ABOUT SPECIAL MINERAL PROPERTIES**

Michael J Passow

Dwight Morrow High School, Englewood, NJ 07631, USA

There are more than 3,000 different minerals, although only a few form most of the rocks of Earth's crust. Each mineral has a definite composition and recognized properties. This hands-on workshop will provide opportunities to learn more about common and unusual mineral properties. One activity will involve making models of crystal structures using toothpicks and raisins. This explains how substitution of atoms of elements can produce different crystal shapes (cubic, hexagonal, etc.) and related minerals, such as calcite ( $\text{CaCO}_3$ ) and dolomite [ $\text{CaMg}(\text{CO}_3)_2$ ]. Another activity will feature fluorescence, the change in color under ultraviolet and normal light. Samples will be provided courtesy of the Sterling Hill Mining Museum in Franklin, NJ, USA [<http://sterlinghillminingmuseum.org/>].

Next, groups of teachers will study lesson plans about other special properties including hygroscopy and dehydration, magnetism, refraction, thermal conductivity, tenacity, density, and color. They will then share the plans with other participants. We will discuss how mineral properties are used to identify ores. Links to web sites useful for learning about minerals will also be provided.

**John Ludden**

Executive Director  
British Geological Survey (BGS)  
Keyworth, Nottingham, UK

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Executive Director at the British Geological Survey and an Executive member of the Natural Environment Sciences Research Council, UK, since 2006, John has held numerous science direction and management posts. Prior to this he was Director of the Earth Sciences Division at the French National Centre for Scientific Research (CNRS) and a Director of Research (classe exceptionnelle) for the CNRS in France, where he also taught at the French National School of Geology (ENSG-Nancy). He has a broad understanding of Earth and environmental sciences and science in general, with specialist knowledge in geochemistry. He has extensive experience in developing the research agendas of universities and the public sector along with experience in translation of research to innovation. He worked as a professor and research scientist at the University of Montreal, Lamont Doherty Earth Institute of Columbia University and with Woods Hole Oceanographic Institution in the USA and holds a doctorate from the University of Manchester, UK. He has visiting and honorary professor status at several universities and is a Foreign Member of the Russian Academy of Sciences and past president of the European Geosciences Union and also EuroGeosurveys. He has published extensively in specialised science journals and also in popular science.

<http://scholar.google.co.uk/citations?user=05oOqAIAAAAJ&hl=en>

## **LIGHTING UP THE SUBSURFACE**

John Ludden

British Geological Survey

Presentation for GIFT – EGU 2015

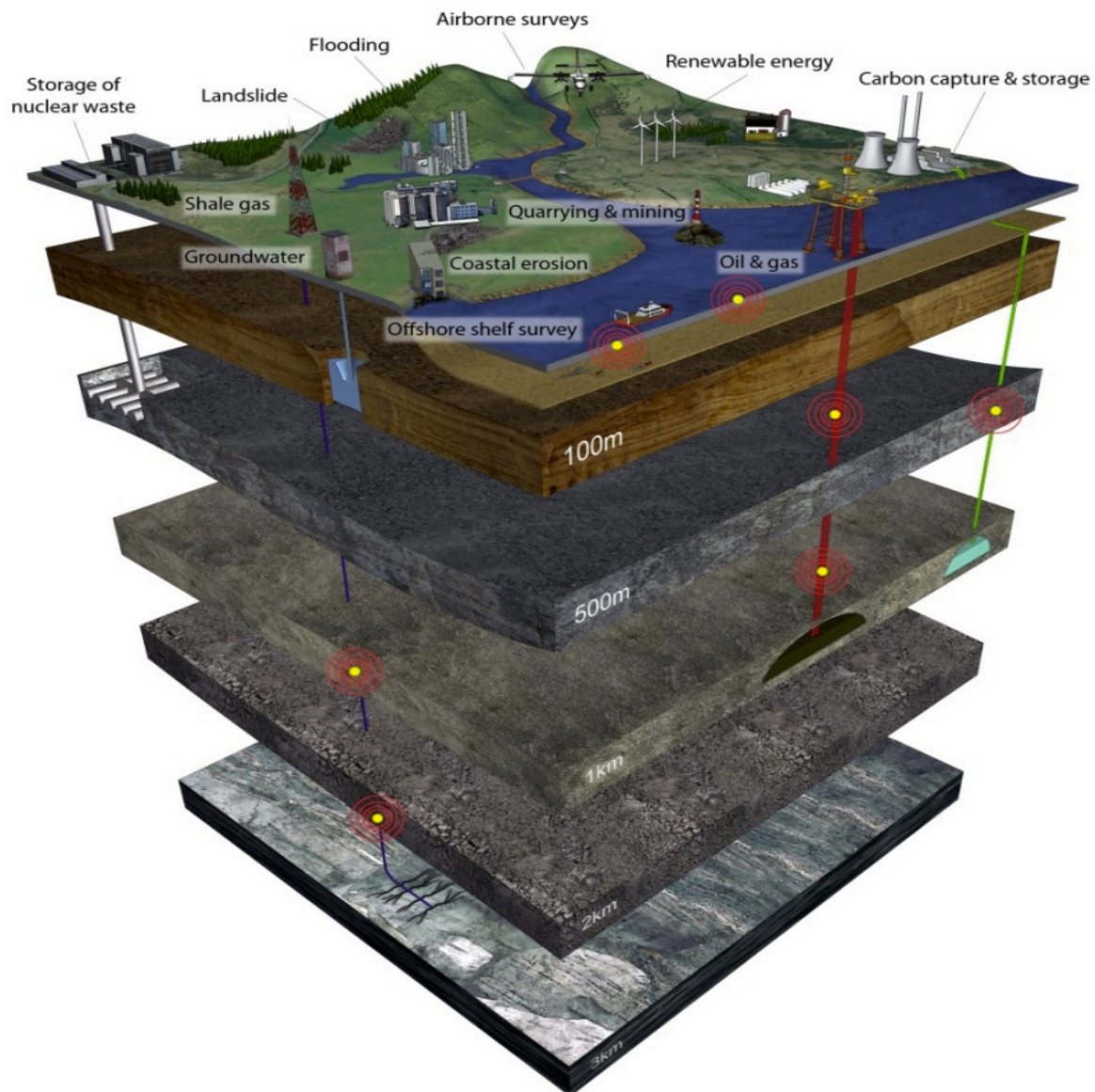
Our future use of the subsurface, particularly for energy (subsurface gas storage, compressed air energy storage, shale gas, coal bed methane, underground coal gasification, enhanced oil recovery, geothermal) and waste disposal relating to energy (carbon capture and storage, radwaste), but also for mineral resources, depends on much greater understanding of subsurface flow and processes. This is particularly pertinent to low-carbon energy because the feasibility of three low carbon energy solutions rely on understanding of subsurface geological containment or flow: carbon capture and storage (CCS), shale gas and radwaste. Mineral deposit development and extraction, particularly near urban areas must be mined responsibly. Lack of understanding and uncertainty feeds through to lack of confidence amongst policy makers and industrial investors, and most of all to lack of public confidence.

We propose an infrastructure “the Energy Test Bed” to allow the subsurface to be monitored at time scales that are consistent with our use of the subsurface, to increase efficiency and environmental sustainability but also to act as a catalyst to stimulate investment and speed new technology energy and mining options to commercialisation.

1. the impact of deep shale gas drilling and hydraulic fracturing on shallow groundwater and surface water, on seismic activity, and on ground stability and subsidence;
2. processes relating to the containment, confinement, and rates of solution and carbonation of subsurface stored CO<sub>2</sub> in carbon capture and storage;
3. processes relating to the containment and confinement of subsurface nuclear and other types of waste; movement of fluids (gas, water, solutes);
4. studies on the impact of coal combustion products on the environment both from surface and subsurface operations (e.g. underground coal gasification);
5. the role of biological mediation in the subsurface in shallow to deep environments;
6. processes at basin and reservoir scale in reservoir stimulation and enhanced oil recovery (EOR);
7. ground deformation and induced seismicity associated with enhanced geothermal systems in hot-rock-dry-rock environments.
8. Large subsurface and open surface mining operations and associated waste management

We will develop a unique package of monitoring capability where monitoring at the surface and in the critical zone will be coupled with deep borehole monitoring of variables such as pressure, temperature, heat flow, seismicity, tilting, strain accumulation, fluid chemistry, pH and biological properties. Monitoring will also include satellite and remote sensed data such as InSAR (Interferometric synthetic aperture radar) and gravity, electrical, spectral and magnetic data.

Infrastructure that underpins research into subsurface activity will make us better at monitoring and managing these new and continuing activities safely and sustainably, including optimising exploration practices. Industry would benefit in being able to access state-of-the-art monitoring data to maximise efficiency of extraction and subsurface management, as well as maximising environmental sustainability.



**Figure 1** Schematic model of the “energy test bed”

The **economic impact** is potentially very large in developing (1) untapped energy resources like shale gas, CBM, UCG, geothermal and new occurrences; (2) methods to sustain fossil fuel reserves e.g. EOR; (3) understanding of storage processes including CCS, gas storage and radioactive waste disposal; and (4) subsurface energy storage such as compressed air energy storage (CAES). Economic value will also stem from management

and minimisation of environmental impacts which will protect the environment, ecosystem services, property and infrastructure.

Greater understanding of subsurface processes, if communicated properly, will also allow better public buy-in to subsurface usage and therefore more efficient, streamlined development.

The **scientific impact** of this new infrastructure will be far reaching, including understanding of subsurface flows, geochemistry and physics of rock matrices, and the interaction of surface carbon and other geochemical cycles and subsurface flows.

The new infrastructure will act as a catalyst for industry both onshore and offshore to stimulate investment and speed new technology options to commercialisation. It will thus act as a bridge from ideas to application and would attract support and possible co-funding from oil and gas companies, mining companies, utilities and energy and environment consultancies.





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### EDUCATION

- Master in Geology-Geoscience in 2013 from Department of Geosciences and Natural Resource Management at University of Copenhagen. Specialized in Geochemistry, Mineralogy and Petrology.
- Master thesis: The explosive Volcanism Succeeding the Eruption of Continental Flood Basalts in East Greenland and the Faroe Islands - a geochemical investigation of the Eocene ash layers from Fur Formation, Denmark.
- Tephra school, Nordic Volcanological Institute course in 2012, Iceland
- Colored Stone Grader from International Gemological Institute in 2014

### CAREER

- Geologist at the Department for Economic Geology and Petrology, GEUS Nuuk, Greenland, August 2013 – present
- Geologist at the Department for Economic Geology and Petrology, GEUS Copenhagen, Denmark, March 2013 – July 2013
- Geology assistant in 2009 for GEUS in Copenhagen
- Geology assistant, 2001-2006 in Greenland  
For the Mineral exploration companies Crew Gold Cooperation A/S, Nuna Minerals A/S, Nanortalik I/S looking for gold, Platinum Group Elements and diamonds for GEUS.
- Geology assistant in 2006 in Greenland. For GEUS on the Galathea 3 expedition along West Greenland on the project: Holocene fjord and shelf processes in West Greenland: a record of environmental and climatic change
- Archaeologist assistant in 2000. Archaeological excavation in old Norse ruins in Herjolfsnæs, South Greenland

### RESEARCH INTERESTS

- Geochemistry, Petrology, Volcanology, Mineralogy, Mineral resources, Gemstones, Public outreach

### PUBLICATIONS AND SERVICES

- Niels Nørgaard-Pedersen, N., Mikkelsen, N., Poulsen, M.D., Simonsen, A.S. (2008): Holocene climate variability in southern Greenland: Results from the Galathea 3 expedition. *Geological Survey of Denmark and Greenland Bulletin* 17, 77–80.
- Poulsen, M.D. & Holm, P.M. (2012): The evolution of the Icelandic hotspot subsequent to the CFB volcanism in East Greenland and the Faroes: a geochemical and petrological investigation of the tuffs in the Eocene Fur Formation, Denmark. Abstract UV3-02 to 30th Nordic Geological Winter Meeting.
- Thorsøe, K., Mate, D. and Poulsen, M.D. 2014: Greenland and Nunavut Geoscience Workshop 2014, Nuuk, Greenland; in Summary of Activities 2014, Canada-Nunavut Geoscience Office. To be published January 2015

# THE GEOLOGICAL HISTORY AND MINERAL DEPOSITS IN GREENLAND: A STATUS ON CURRENT PROJECTS

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## Abstract

Greenland is the largest island in the world and has a total area of 2,166,086 km<sup>2</sup> but the ice free part is ~400,000 km<sup>2</sup> and larger than Germany. The population in Greenland is ~ 57,000 people.

The geological history of Greenland spans over 3.8 billion years, and is one of the oldest continents on Earth. Greenland can be divided into different geological units which have

developed over time with episodes of continental collisions, subduction, volcanism, rifting, uplift and erosion, development of sedimentary basins and lastly by glaciation.

The long geological history of Greenland means that there have been plenty of time to develop many different geological environments and thereby various mineral deposits.

The most advanced project regarding mining operation is the True North Gems Greenland A/S Aappaluttoq ruby project in West Greenland. The company received an exploitation license from the Government of Greenland in March 2014, and has started to build up the infrastructure for the mine. Other advanced mining projects in West Greenland are a large iron ore deposit (ISUA) now owned by a Chinese company and an Anorthosite project owned by Hudson Resources Inc. In South Greenland Greenland Minerals and Energy Ltd. has a project looking for REE and uranium, while Ironbark Zinc Ltd. has a zinc-lead project in Northeast Greenland.

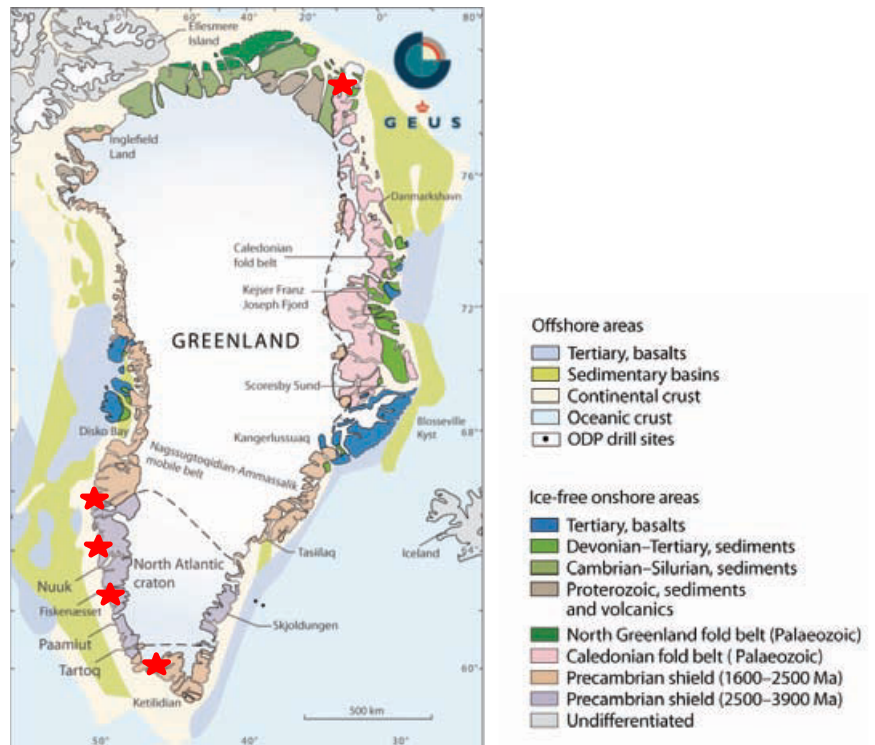


Figure 1. Geological map of Greenland. The red stars refer to the most advanced mining projects in Greenland.



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## EDUCATION

2015- current: part-time PhD student, Camborne School of Mines, University of Exeter, UK  
2010-2011 M.Sc. Mining Geology, Camborne School of Mines, University of Exeter, UK  
2007-2010 B.Sc Geology, University of Edinburgh, UK  
2003-2007 B.A. (Mod) Natural Science – Genetics, Trinity College Dublin, Ireland

## CAREER

Eimear is a minerals resource geologist based at the British Geological Survey since 2013. She is currently a part time PhD researcher working on critical metal mineralisation in South West England. She works on a variety of projects at the British Geological Survey (BGS) both UK based and internationally, she is a key member of the EURARE project team at BGS where she is looking at alternative resources of rare earth elements in Europe, focussing on resources in red mud waste material from alumina processing. She also has a role compiling mineral statistics for global resource production annually and this year has worked with the MINERALS4EU project collating data for mineral production, exploration, resources and reserves in Europe. She has written mineral prospectivity brochures for Nigeria and is currently working on similar brochures for Liberia. Previous to this she worked in the mining industry as an exploration geologist and has worked on a variety of deposit types in Peru, Malawi, Mauritania and Zambia.

## RESEARCH INTERESTS

Critical metal resources with a focus on tungsten, bismuth and antimony.  
Ore mineralogy and petrology.  
Rare earth elements.  
Science communication.

## PUBLICATIONS AND SERVICES

If you are interested in alternative resources of rare earth elements, please see:  
É. Deady, E. Mouchos, K. Goodenough, B. Williamson and F. Wall. "Rare Earth Elements in Karst-Bauxites: a Novel Untapped European Resource?" ERES 1<sup>st</sup> European Rare Earth Resources conference, Milos, Greece, (5-6/09/2014).

## **Critical raw materials; what, why and how?**

Éimear Deady

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In recent years a number of minerals and metals have been designated as 'critical', due to their economic importance and likelihood of supply chain disruption, also termed 'supply risk' (Lusty and Gunn, 2104). Criticality is not necessarily due to a physical shortage of resources but is more strongly influenced by geographical concentration of production in a few countries or even from single mines (Gunn, 2014).

In order to address security of supply the Raw Materials Initiative (RMI) was published in 2008 with the aim of developing the exploration and mining sector in Europe. The RMI led to the first pan-European criticality assessment of raw materials which identified 14 raw materials as 'critical' to the European Union (EU) economy (EC, 2010). This has since been updated leading to an expanded list of critical raw materials to include 20 minerals and metals (EC, 2014). This list includes the rare earth elements (REE), niobium, antimony, phosphate rock, gallium and tungsten. Japan, USA, Canada and Germany have also conducted assessments of materials critical to their economies. A major new policy, the European Innovation Partnership (EIP) on Raw Materials (2014–2020), was launched in 2013 by the European Commission (EC). This aims to improve the security of supply of critical raw materials and their efficient and sustainable management in the EU. The EIP will support research and innovation throughout the minerals value chain, in order to improve the raw materials knowledge base, to develop best practices in extraction and processing and promote international collaboration.

Globally demand for raw materials has been growing over recent decades and we are consuming larger quantities than ever before. Also, as new technologies are developed, we are now using a broader range of metals than previously. In the case of critical raw materials, this is frequently driven by lifestyle choices; green technologies such as electric cars, solar panels, next generation florescent light bulbs, LEDs and wind turbines all contain critical raw materials. For example on average over 300 kg of REE are used in a single 90 metre high wind turbine. Demand for new technologies such as smart-phones, flat-screen displays and nickel-metal hydride car batteries to name just a few, have created unprecedented demand for some critical raw materials. Raw material demand is likely to continue to increase, especially from sectors such as clean energy and medicine. This trend combined with the spread of prosperity in developing countries will lead to further demand for critical raw materials globally.

Europe is largely dependent on imports of raw materials, because, even where deposits of critical minerals are known it is not always economically viable to work them in Europe. Furthermore, it is frequently not socially or environmentally acceptable to utilise these resources. The Peoples' Republic of China is the world's leading producer of many critical raw materials. Comparative analysis of the EC 2014 report with the first EC 2010 report shows further concentration of the production of critical raw materials in the People's Republic of China, hence the need to diversify the supply base. Increasing domestic demand for critical raw material within China also has led to concerns globally regarding future supply from this source.

The designation of certain materials as 'critical' has led to significant new exploration, particularly by junior companies, attempting to develop projects globally and take

advantage of both increasing demand and prices and the awareness of the need for supply diversification.

Recycling has an important role to play in the supply of certain raw materials and reducing the energy used during their production. For example, major benefits of recycling include mitigation of the environmental impact of mining, potential extension of the lifetime of primary resources and diversification of supply. Primary mine production of tungsten is predicted to be overtaken by the use of secondary recycled tungsten raw materials by 2018 (Roskill, 2013). However, recycling can never meet the total demand for raw materials when demand is increasing. Also, in some applications such as in paint, abrasives and fertilisers, the raw materials are dissipated in use and are therefore not available for recycling.

Numerous European programmes of research have been initiated with the aim of securing supply, particularly of the critical raw materials. These projects cover different stages of the material supply chain. For example, the Minerals4EU project is compiling statistics on European raw materials, including exploration activity, production and resources and reserves, in addition to data on material waste streams, recyclability and resource end-use. This objective of this project is to provide the knowledge base to improve understanding of Europe's domestic raw material resources. Additional projects have been established to enhance understanding of the availability of specific commodities in Europe, with a particular emphasis on critical metals. For example the EURARE (European Rare Earth Resources) and ASTER (Systemic Analysis of Rare Earth Elements – flows and stocks) projects are focussed on European REE resources, materials flows and extractive metallurgy. In the UK, the Natural Environment Research Council (NERC) has funded the Security of Supply of Mineral Resources Research Programme, which addresses the "science needed to sustain the security of supply of strategic minerals in a changing environment". The main aims of this Programme are to improve understanding of the mobility of critical metals in the Earth's crust and to develop more effective and environmentally friendly methods of extractive metallurgy.

### **Tungsten – an example of a European critical metal resource**

Critical raw materials are found in a wide variety of geological environments. In recent years there has been a resurgence of interest in the development of tungsten deposits as demand has increased. New discoveries such as the Largo Resources Northern Dancer deposit in Canada and the Ormonde Resources Barruecopardo deposit in Spain (Pitfield and Brown, 2014), are advancing towards new production while elsewhere historical mines are being re-opened, such as the Wolf Minerals Hemerdon deposit in Devon, UK.

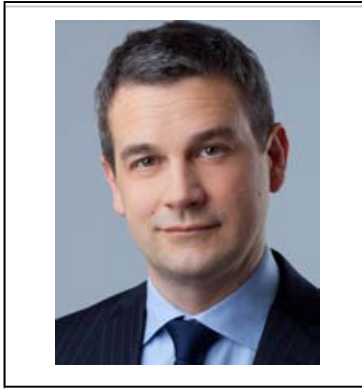
There has been a revival of interest in exploration and mining in South West England as a result of the development of the Drakelands Mine at Hemerdon and recently released regional geochemical and airborne geophysical survey data. Ongoing research at the British Geological Survey (BGS) is focussed on critical metals in South West England.



Figure 1: Wolframite ( $(\text{Fe},\text{Mn})\text{WO}_4$ ); tungsten ore from Cornwall. ©NERC.

This Variscan age (ca. 300 Ma) terrane, was historically a world-class producer of a number of metals, most notably tin, tungsten, copper, arsenic, lead and zinc. BGS research is aimed at understanding the thermal evolution of this globally significant orefield, and the critical metals that may be associated with the base metal and tin-tungsten mineralisation, for example antimony and bismuth.

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- Gunn, G., 2014. Critical Metals Handbook, First Edition. Co-published by Wiley and the American Geophysical Union.
- Pitfield P., and Brown, T., 2014. In Critical Metals Handbook. First Edition. Co-published by Wiley and the American Geophysical Union, pp385-413.
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- Raw Materials Initiative (RMI) [http://ec.europa.eu/enterprise/policies/raw-materials/index\\_en.htm](http://ec.europa.eu/enterprise/policies/raw-materials/index_en.htm)
- European Innovation Partnership (EIP) on Raw Materials, 2014. [http://ec.europa.eu/enterprise/policies/raw-materials/critical/index\\_en.htm](http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm)
- EURARE [www.eurare.eu](http://www.eurare.eu)
- ASTER Systemic Analysis of Rare Earth Elements - flows and stocks [http://www.agence-nationale-recherche.fr/en/anr-funded-project/?tx\\_lwmsuivibilan\\_pi2%5BCODE%5D=ANR-11-ECOT-0002](http://www.agence-nationale-recherche.fr/en/anr-funded-project/?tx_lwmsuivibilan_pi2%5BCODE%5D=ANR-11-ECOT-0002)
- NERC SOS Minerals  
<http://www.nerc.ac.uk/research/funded/programmes/minerals/>
- EUROGEOSURVEYS <http://www.eurogeosurveys.org/>
- Minerals4EU [www.minerals4eu.eu](http://www.minerals4eu.eu)
- MINVENTORY [www.minventory.eu](http://www.minventory.eu)



## **Helmut Rechberger**

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### EDUCATION

- 1994 Master in Process Engineering, Vienna University of Technology
- 1999 PhD in Waste Management, Vienna University of Technology
- 2000 – 2001 Post-doc at Yale University, Centre for Industrial Ecology

### CAREER

- 1994 – 2000 Research Assistant, Vienna University of Technology
- 2001 – 2003 Senior Researcher at ETH Zurich, Chair of Resource and Waste Management
- 2003 – Professor of Resource Management, Vienna University of Technology
- 2008 – Vice-Dean of Studying Affairs, Faculty of Civil Engineering
- 2010 – Head of the Research Centre of Waste and Resource Management

### RESEARCH INTERESTS

Research interests are: further development of evaluation methods and concepts in waste and resource management including statistical entropy; introduction of mathematical-statistical tools to Material Flow Analysis to consider data uncertainty; resource accounting; recovery of valuable substances from ashes and slag; waste characterization; investigation on morphological and chemical composition of urban stocks including dynamics.

### PUBLICATIONS AND SERVICES

Brunner PH, Rechberger H, Practical Handbook of Material Flow Analysis, Lewis Publishers, New York, 2004, pp. 318.

Brunner PH, Rechberger H, Anthropogenic Metabolism and Environmental Legacies. In: Encyclopedia of Global Environmental Change, Causes and Consequences of Global Environmental Change, I. Douglas (Ed.), Vol. 3, Wiley, London, 2002, pp. 54-72.



## CITIES: TOMORROW'S MATERIAL RESERVOIRS

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Vienna University of Technology, Institute for Water Quality, Resource and Waste Management, Austria

The modern anthropogenic metabolism is characterized by exponentially increasing resource consumption. It has been estimated that an average citizen of an industrialized country consumes about 1000 tons of solid materials over his/her life. These goods are mainly building materials and energy carriers (cv. Table 1).

*Table 1: Amount of solid raw materials consumed over an average person's lifetime (BGR, Germany).*

Raw material	Consumption in tons/person's life	Raw material	Consumption in tons/person's life
Gravel and sand	307	Gypsum	8.5
Lignite	158	Industrial sand	4.7
Hard rock	130	Kaolin	4.0
Mineral oil	116	Potash	3.4
Natural gas (1000m <sup>3</sup> )	90	Aluminium	1.7
Limestone, dolomite	72	Copper	1.1
Hard coal	67	Steel refiners	0.9
Steel	40	Sulphur	0.2
Cement	29	Asbestos	0.16
Rock salt	12	Phosphate	0.15

Most of the consumed materials are still in use and stored in long-living products such as buildings and infrastructure networks. It is assessed that statistically each Viennese citizen "owns" a material stock of some 400 to 500 tons, still growing with ca. 15 tons per year. Cities can therefore be considered as hotspots of material resources. Other assessments show that these urban resource reservoirs have similar magnitudes than geogenic ones, therefore, the term "urban mines/mining" has been coined for cities. In order to conserve primary resources and to make regions with insufficient domestic primary resources deposits less dependent on imports these urban mines have to be optimally used, which means, that these materials should be optimally recycled to a high extent again and again. However, currently these urban resource reservoirs are not well characterized. This means that we have only limited knowledge about their magnitude (cv. Figure 1), but this is not a sufficient base for their optimal use and management in future.

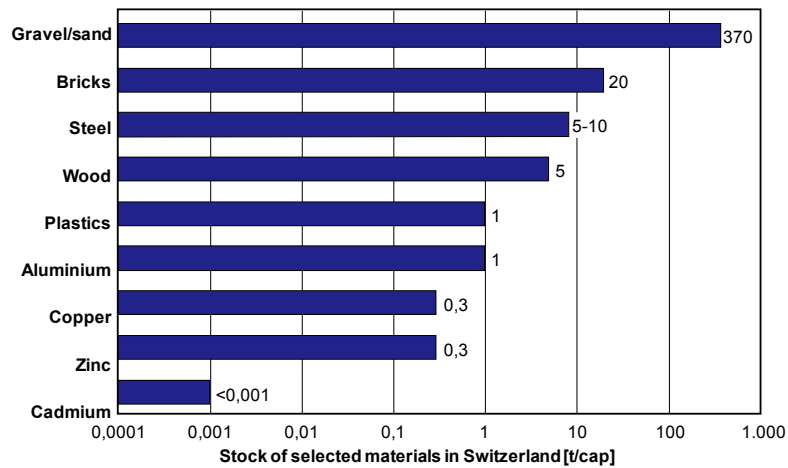


Figure 1: Assessment of materials in the Swiss building stock (Wittmer, 2007). The stock is dominated by mineral materials for construction but also contains significant amounts of metals. Hazardous substances like Cadmium are also contained. If not properly handled such substances can prevent proper recycling if they contaminate recycling products.

Therefore, current research focuses on the development of a scheme to determine urban stocks with regard to quantity, quality, location, and economic extractability. This is done in analogy to the evaluation of primary resources and means that urban material stocks and flows are divided into the economically extractable part (reserves) and the in the future potentially extractable part (resources). In Figure 2 such a classification is shown for selected solid residues from waste incineration with respect to Zinc.

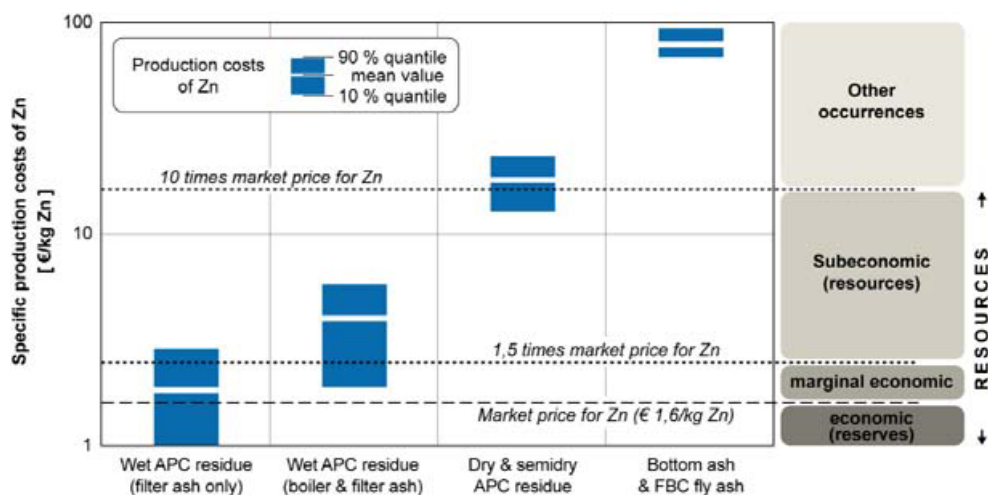


Figure 2: Classification of MSW incineration residues into reserves and resources (Fellner, 2014)

Considerable amounts of Zinc (Zn) are contained in municipal solid waste (MSW) and are concentrated through the incineration process. Depending on the employed air pollution control (APC) technology different Zn containing products can be realized. Figure 2 shows that if only the most concentrated residue (filter ash) is used for Zn recovery this can be done nearly economically today, all other procedures are sub-economic or less.

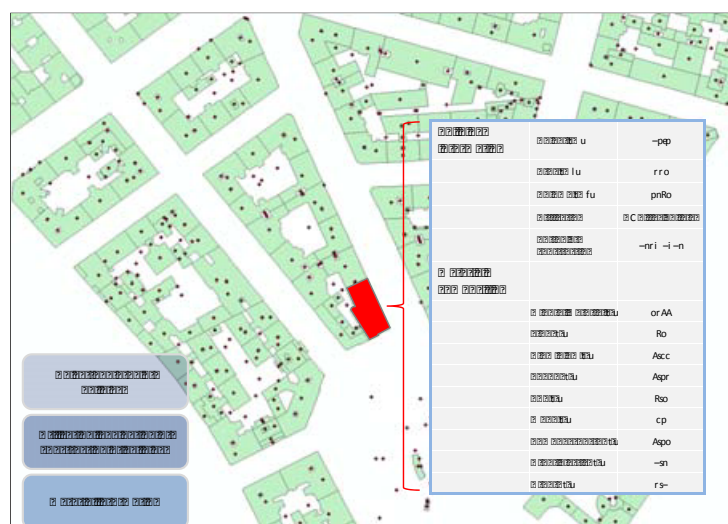
The final goal is to have a regularly up-dated urban resource cadaster as a basis for resource management. This is achieved by investigating the average material composition

of defined categories of buildings resulting in volume-specific material data. Table 2 shows the results of such investigations for buildings of different age and use.

*Table 2: Volume-specific material data (kg/m<sup>3</sup>) for different buildings (Kleemann, 2014)*

Material	B1	B2.1	B2.2	B2.3	B3	B4
Year of construction	1970	1870	1960	2003	1930	1890
Minerals	430	420	410	320	260	450
Steel	7.6	5.1	4.6	8.6	5.8	0.97
Aluminium	0.22	0.049	0.057	0.55	0.03	0.16
Copper	0.11	0.15	0.16	0.24	0.0019	0.062
PVC	0.52	0.19	0.21	0.18	0.0093	0.2
Wood	2.3	4.3	2.2	0.62	3.6	20
Asbestos	1.5	0.04	-	-	0.14	-
Other plastics	1.3	0.16	0.35	4.9	0.14	0.46
Others	1.1	0.54	1.2	0.69	0.43	0.13
Total	440	430	420	340	270	470

The combination of GIS-based data on the built infrastructure and the volume-specific material data leads to a resource cadaster, which is a documentation about the site, quantity and quality of urban resources (cf. Figure 3). Combined with scenarios about future deconstruction and demolition activities predictions about the future availability of secondary raw materials can be made. Such information is instrumental for the recycling industry to plan and provide the required recovery and recycling technologies as well as capacities. Only if this is achieved the goal of a sound and substantial circular economy can be realized.



*Figure 3: Building specific material data is combined with GIS data to quantify the total urban stock (Kleemann, 2014).*



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### UNIVERSITY EDUCATION

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|------|---|
| 1990 | Habilitation and "venia legendi", Goethe-University Frankfurt |
| 1981 | Dr. phil. nat., Goethe-University Frankfurt                   |
| 1978 | Diploma in geology, Goethe-University Frankfurt               |

### CAREER

- |            |   |
|------------|---|
| Since 2012 | Director and Professor and Head of the Division of Geoscientific Information and International Co-operation, Federal Institute for Geosciences and Natural Resources, Hannover, Germany |
| 2007-2009  | Scientific Co-ordinator and Head of the Division of Palaeontology and Historical Geology, Senckenberg Gesellschaft für Naturforschung, Frankfurt  |
| 2005-2006  | President of the Federal Institute for Geosciences and Natural Resources, Hannover  |
| Since 2003 | Honorary Professor of the Albert-Ludwigs-University Freiburg  |
| 2001-2005  | President of the State Geological Survey Baden-Württemberg  |
| 1993-2001  | Director and Professor, Federal Institute for Geosciences and Natural Resources, Hannover   |
| 1991-1993  | Governmental Director, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Bonn  |
| 1990-1991  | Geoscientist, Technical University of Karlsruhe   |
| 1985-1990  | Scientific University Assistant, Goethe-University Frankfurt, Germany   |

### RESEARCH INTERESTS

- Metallogeny and economic geology, raw materials, ore and mineral forming processes.
- Global carbon cycle, paleoclimate, interactions between energy and climate.
- Know-how transfer, scientific advice for decision makers in politics, science and society

### PUBLICATIONS

- Stribrny, B., & Kuch, U. (2009): *Climate change and vector-borne diseases: Using the past to predict the future.*- *Publ. Health Jour.*, **20**, 5-7, *Bayer Environmental Science*
- Stribrny, B., Sonnewald, M., Türkay, M., Uhl, D., Wilmsen, M., & Wolters, S. (2012): *Die Doggerbank – Gerölle erzählen eine Klimageschichte.*- *Natur, Forschung, Museum*, 142, Heft 1/2, 36-43
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- Mosbrugger, V., Brasseur, G., Schaller, M. & Stribrny, B. (Eds: 2014, 2. ed.): *Klimawandel und Biodiversität – Folgen für Deutschland.*- *WBG Darmstadt*, 1-432
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## INTERNATIONAL CO-OPERATION AND EXPLORATION OF MINERAL RESOURCES.

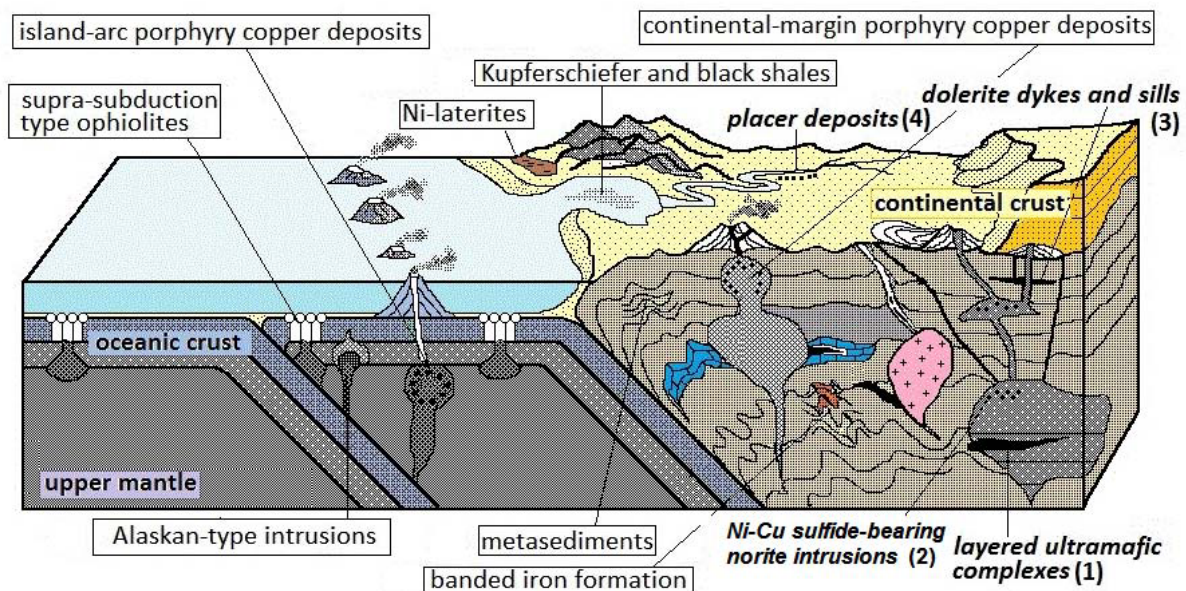
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There would not have been a Stone Age without rocks. More than 7 000 years ago human extraction of rocks and minerals started. Today about 45 billion tons of raw materials are produced each year. 20 % of world population consumes 80 % of the natural resources. People in industrialized countries use about 25 kg of raw material per day on average that is up to ten times more than the population in developing countries.

Minerals have a crystal structure and they are the major components of rocks. Metallic minerals are mined for metal production, for example iron-oxides like hematite and magnetite for smelting of steel. Industrial minerals like halite, feldspar or kaolinite are used in many applications in the chemical, ceramic and paper industry. Construction minerals like sand, gravel and rocks are produced in large quantities and used in form of bricks, concrete or asphalt fillers for the building of houses and infrastructure.

Minerals are mostly formed by dynamic geologic processes. Examples are volcanic ashes, hydrothermal and hot spring sulfide precipitations, chemical sedimentation of carbonates or evaporation and the formation of rock salt in arid regions. So mineral occurrences and mineral deposits are formed in distinct geologic settings (Fig.1).



**Figure 1.** Sketch 3D-diagramm of the geologic setting of conventional PGE deposits (**bold italic**) in (1) layered mafic-ultramafic intrusions, representing 81 % of annual world production, (2) nickel-copper sulfide-bearing norite intrusions (5 %), (3) nickel-copper sulfide-bearing dolerite sills (12 %). (4) placer deposits (1 %) and unconventional PGE mineralizations in the Kupferschiefer and black shales, nickel laterites, banded iron formations, metasediments, ophiolites, porphyry copper deposits and Alaskan-type complexes representing together 1 % of annual world production (Stribny 2013).



Mineral exploration is carried out in order to find these deposits on the surface or even underground. A broad variety of geophysical, geochemical and geoscientific techniques are applied ranging from satellite observations, airborne surveys, field observations down to microscopic laboratory studies (Fig. 2).



**Figure 2.** Inclusion of merenskyite,  $\text{PdTe}_2$ , white spot, in chalcopyrite, yellow, polished section, reflected light, combined with the energy-dispersive X-ray spectrum showing Pd- and Te-peaks, sulfide concentrate Ok Tedi Mine, Papua New Guinea (Stribny 2013).

Finally a number of geologic, geographic, economic, environmental and even political factors are relevant before opening a new mine.

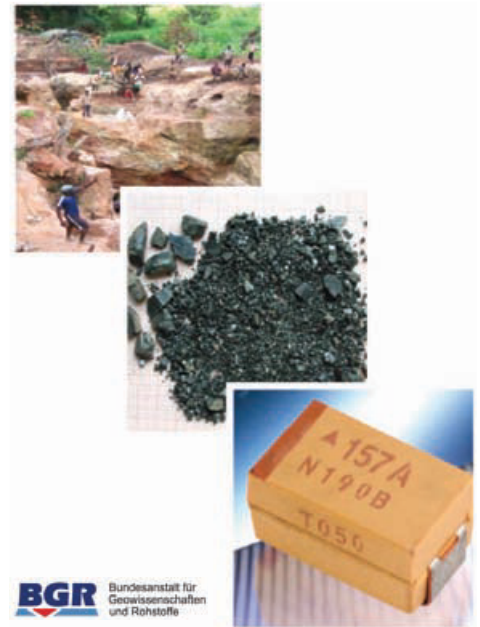
The vast majority of raw materials are produced by national or even international companies. But in up to 50 developing countries small-scale mining is present. More than 17 million men, women and even children are engaged in artisanal mining sectors. The growing global demand for raw materials offers excellent opportunities for resource-rich countries to boost economic growth and revenues. But developing countries are facing complex challenges in managing the mining sector. The so-called “paradox of plenty” describes the fact, that only a small group of people benefits from the use of natural resources, while corruption and mismanagement undermine the positive effects. In the worst case mining revenues are used to fund local war lords and armed conflicts (Fig. 3 a,b).

International cooperation tries to support positive and sustainable developments and to hinder negative processes. Specific concepts and strategies are implemented in order to balance wealth distribution, to introduce effective mining regulations, to improve economic and institutional efficiency and to protect and manage natural resources.

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- Regional certifications system of the Int. Conference of the Great Lake Region
- National certification system for tin, tungsten, tantalum and gold
- Certified trading system for the origin and the ethical quality of minerals



**Figure 3 a.** Regional and national certification systems as well as certified trading chains can be used to certify the origin and ethical quality of minerals by increasing the transparency of their production and trade. **b.** Small scale mining in Africa, tantalum ore concentrate and tantalum-condenser for mobile phones (Hagemann 2013).





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DR. STEFAN GILJUM received an interdisciplinary master in "Human Ecology and Environmental Economics" and a doctoral degree in "Social Ecology" in Vienna. He was visiting scholar at the Universidad de Chile in Santiago and at the University of Keele, UK. Since 1999, he worked as a researcher at the Sustainable Europe Research Institute (SERI), since 2007 was head of the research group "Sustainable Resource Use". In October 2013, he and his team moved to the Vienna University of Economics and Business (WU).

Stefan Giljum is member of several scientific societies and was part of scientific advisory boards for international organisations such as the OECD and UNIDO.

He published extensively in the areas of environmental accounting (in particular, on material flow analysis), economic-environment modelling, as well as on the interlinkages between international trade, environment and development.

#### Selected publications:

Giljum, S., Martinez, A., Bruckner, M., in press. Material Footprint Assessment in a Global Input-Output Framework. *Journal of Industrial Ecology*.

Giljum, S., Dittrich, M., Lieber, M., Lutter, S., 2014. Global patterns of material flows and their socio-economic and environmental implications: a MFA study on all countries worldwide from 1980 to 2009. *Resources* 3 (1), 319-339.

Tukker, A., Bulavskaya, T., Giljum, S., de Koning, A., Lutter, S., Simas, M., Stadler, K., Wood, R., 2014. The Global Resource Footprint of Nations. Carbon, water, land and materials embodied in trade and final consumption, Leiden/Delft/Vienna/Trondheim.

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# GLOBAL NATURAL RESOURCE USE: IS THE WORLD HEADING TOWARDS A “GREEN ECONOMY”?

Stefan Giljum

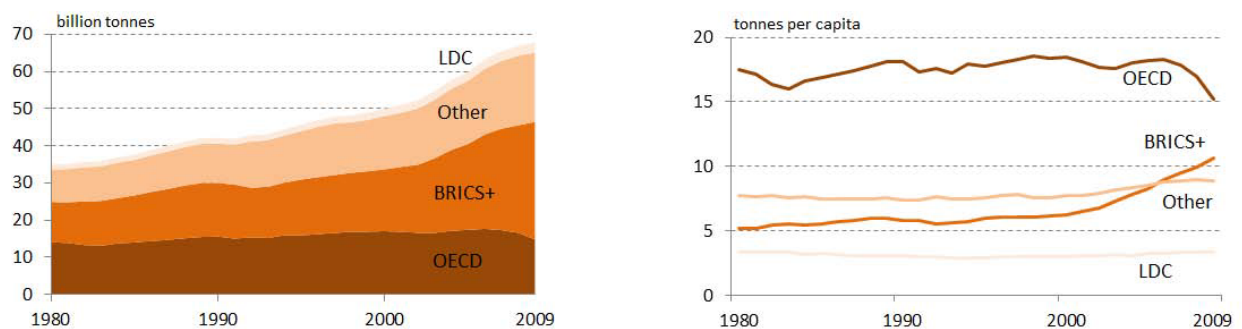
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The concept of a “green economy” is currently intensively debated on the European and international level. A sustainable use of natural resources through a significant increase in resource efficiency is a precondition for realizing a “green economy”. This presentation will feature the most recent data on global raw material extraction, international trade of materials and products as well as material consumption, available for the time period of 1970 to 2012 for all countries world-wide.

Many of the observed trends are alarming (see Figure 1): the rapid increase of global resource consumption, to a large extent driven by demand for mineral resources; the rising per-capita consumption levels in emerging economies such as China, in particular regarding mineral resources related to the building up of infrastructure such as buildings and transport systems; the continued high consumption levels in industrialized countries, who consume far beyond their global “fair share”; and the increasing dislocation of environmental problems related to the extraction and processing of mineral resources through international trade, often with severe negative consequences for the local population in developing countries. Furthermore, decoupling of raw material consumption from economic growth is currently insufficient (see Figure 2).

Figure 1: Material consumption in various world regions, absolute numbers (left) and per-capita numbers (right)



OECD members 1980; BRICS+: BR, RU, IN, CN, ZA, KR, SG, MX; LDC according to UN

Figure 1: Development of GDP (gross domestic production), material consumption, population and material productivity, 1980-2009.

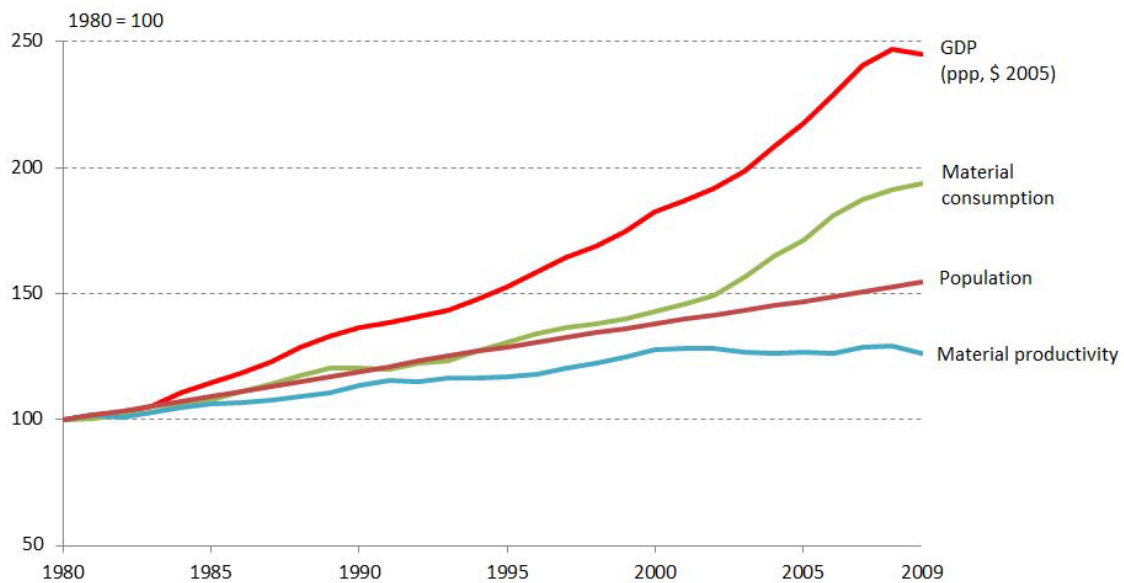


Figure 2: Raw material consumption from economic growth, 1980-2009.

The presentation ends with a plea for the implementation of European and international targets for resource use and resource efficiency. In particular in industrialized countries such as Europe with high per-capita consumption levels an absolute reduction of resource consumption is urgently required. Such a strategy would entail positive environmental and climate effects, but also open up new economic possibilities for Europe in a world characterized by increasing competition for scarce resources.



## European Geosciences Union

**Geological pathway from Maria Theresa's Monument to St. Stephen's Cathedral; Excursion, 15<sup>th</sup> April 2015, 2.00 – 3.30 pm**