Resourcing Future Generations – A Global Effort to Meet the World's Future Needs Head-on

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IUGS
International Union of Geological Sciences

Resourcing Future Generations

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Acknowledgements

A group of us, as listed at page 65, from Australia, Brazil, France, Germany, Greece, Namibia, South Africa, Thailand, the UK and the USA, with diverse backgrounds in geoscience, the environmental and social sciences, met at the Gocheganas Nature Reserve, near Windhoek Namibia, between 25 and 30 July 2015 to discuss how to take forward the International Union of Geological Sciences initiative, Resourcing Future Generations. We wish to acknowledge the financial support from the International Council for Science, the United Nations Education, Science and Culture Organisation and IUGS without which it would not have been possible to meet. We are indebted to Gabi Schneider, Director of the Namibian Geological Survey, who provided invaluable local logistical support, to George Jameson of the Geological Society of London for administrative support and the staff of GocheGanas who made our stay so memorable.

References and notes are identified by numbers in superscript thus [1] and listed at the end of the relevant section of the report

CITATION

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Resourcing Future Generations – A Global Effort to Meet the World's Future Needs Head-on

Context

Mineral resources underpin contemporary society. The 2010 disruption to the supply of rare earth element minerals highlighted the vulnerability of mineral resource supplies. The main focus of the United Nations Conference on Climate Change to take place in Paris in December 2015 will be agreeing on solutions for a low-carbon development strategy, as a direct response to climate change. Here we discuss the common threads between these two separate events, particularly the enormous mineral requirements of a low carbon society, and how resource scarcity may impact on any international agreement to mitigate the effects of climate change.

In 2013, the International Union of Geosciences (IUGS) launched the "*Resourcing Future generations*" (RFG), an initiative that aims to bring world attention to the challenges of sustaining resource supplies and to outline a pathway to the future, including a route to nation-building and poverty alleviation through a sustainable resource development framework. The RFG initiative includes a diverse group of geoscientists, environmental and social scientists, including economists, drawn from a range of institutions with a diverse private and public experience in exploration, mining, processing, environmental protection and sustainable economic development. RFG aspires to be a fundamental service to humankind with the overarching goal of improving the global supply chain for mineral resources, not to vested interest groups in resource development.

Resourcing Future Generations: Framing the Problem

The 20th century was characterised by dramatic improvements in living standards for billions of people. This improvement was underpinned by a dramatic increase in the utilisation of water, energy and mineral resources. However, unconstrained demand should not threaten the well-being of future generations; in other words, mineral requirements of humankind need to be met without compromising the resilience of ecosystems and the ability of future generations to meet their own needs.

With projections of population growth to about 9 billion people by 2050[1], the world needs adequate supplies of mineral raw materials to fulfil the aspirations of this growing population and to meet targets for sustainable development[2] . Access to mineral resources is necessary to both developed and developing countries and thus a concern for all nations. Furthermore, individuals and society need to recognise and understand the direct connection between their consumption patterns and the need for non-renewable resources.

To meet increasing demand production of many commodities has risen dramatically over recent decades. This has been due mainly to technological advances allowing lower grade deposits to be worked in greater volume. The higher costs of many such operations put them at risk from falling commodity prices.

Meeting current demand for mineral resources depends on exploration and production efforts that were conducted mainly in preceding decades. However, taking into account rising demand projections, coupled with declining exploration success, lengthened and more costly discovery-to-production timelines, and increasing tensions about resource development, several challenges on the supply side require attention from the international community.

1. Access to primary mineral resources is necessary for both developed and developing countries (especially for countries building infrastructure), and thus is a concern for all nations. Substitution, recycling (3)and more efficient use of raw materials will contribute to resource supplies, but cannot solve the problem entirely due to population growth, rising standards of living, and locking up of potentially recyclable materials in cars, buildings and other infrastructure.

2. Projections for energy technology, urbanisation and economic growth will dramatically increase the demand for all mineral raw materials (4), and change the mix of needed minerals and metals. For example, increasing world energy production from wind and solar sources, and sequestering carbon from existing fossil fuel production requires greatly increased supplies, not only of critical materials, such as rare earth elements and tellurium, but also more common materials like nickel, copper, steel and aggregate. This will change resource footprints for different countries, technologies and growth scenarios.

3. Mineral deposits are irregularly distributed and their location controlled by geology. Thus, the value of these mineral resources must be recognised and assessed in the contexts of other land uses, such as agriculture, forestry, water resources, habitats for flora and fauna, cultural and natural heritage, as well as land for settlement and infrastructure. Furthermore, the use of materials, energy and water are all interconnected.

4. Environmental protection and social licence are part of sound public policy, including sustainable resource use. Both individual consumers and nations need to be accountable for their resource use, whether produced at home or abroad. Societal accountability and stewardship need to include responsible resource development as a viable land use.

To address the needs of future generations for adequate resources, we outline a series of steps and policy actions to secure sufficient and sustainable supply of raw materials. Action is needed by world leaders and the international community, as well as individual consumers. Action is needed now to address future supply problems that are unpredictable in time and detail, but foreseeable and inevitable.

Summary and Recommendations

In this section we discuss some key themes requiring a globally coordinated approach if we are to meet the resource needs of future generations:

Theme 1: *Balancing resource supply and demand in the 21st century*. This theme discusses the evolution of demand over the next few decades and considers the issues this raises for supply. It is supported by Appendix 1, which outlines how energy security and climate change are altering the demand for metals and minerals.

Theme 2: *The challenge of mineral supply: Accessing new resources from the Earth*. This theme analyses the specific issues in meeting future demand for minerals and metals that primarily come from non-renewable sources in the ground. It is supported by Appendix 2, which presents a summary of developments in the technology for finding, understanding and extracting mineral and metal resources from the ground and Appendix 3, which examines Namibia as a case study of how geological expertise can positively contribute to economic development.

Theme 3: *Building additional capacity to facilitate responsible development in less developed nations*. This theme outlines the opportunity for nation building for resource development if handled effectively. It is supported by Appendix 4, which presents a case study examining the manner in which Brazil has been channelling revenues from resources into economic and social development, including health and education which are powerful drivers of development.

We finish by calling for action on the international stage to ensure adequate and equitable access to resources by future generations, and make four key recommendations:

> *Develop international guidelines for planetary mineral consumption:* Articulate at global and regional levels a vision for future mineral and metal demand (for example, UN Sustainable Development Goals; G7 Resource Efficiency; EU Raw Materials Directive, OECD Sustainable Materials Management, International Union for Conservation of Nature and Natural Resources, United Nations Environment International Resources Panel and on which further groups such as Asia Pacific Economic Cooperation and the African Union could lead based on sufficiency targets

for metals consumption, consistent with sustainable development goals and planetary boundaries.

Raise awareness of the impacts of mineral consumption from source to product: Investigate a system for tracking mineral use from source to product, incorporating as a global chain-of-custody programme similar to the concept of "food miles" or sustainable forestry marking.

Support industry investment and research into new mineral exploration and extraction technologies: New mineral exploration techniques are needed to find remote or deeply buried deposits. Major investment at a scale only realisable through private-public cooperation is needed to develop these techniques. Industry is developing technology to maximise efficiency, minimise waste and reduce the consumption of water. This should be encouraged as it supports economic growth, not only of the resources sector, but also of the service providers and manufacturing sectors supplying the industry. Furthermore, technology offers the potential for opening up previously inaccessible resources.

Developing global best practice for responsible mineral resource development: Technological evolution needs to be reinforced by the development of global practices for responsible resource development that balance the long term value of any mineral assets against alternative land uses, such as biodiversity protection, agriculture and urbanisation. Examples of good environmental practice and co-existence for land use exist on which to model such global guidelines and need to be balanced by asking society to step up to the plate in terms of understanding the consequences of their/our role in consumption.

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Theme 1: Balancing resource supply and demand in the 21st century

Primary mineral resources – rising demand and stagnating supply

Demand for minerals and metals have risen dramatically over the last century, yet the scale and complexity of supplying this demand are under-acknowledged.

The rise in demand results from increasing population and increasing consumption in both developed and developing countries, particularly where essential modern infrastructure is being built (UNEP, 2014(1)). The continuing rise in demand from 1900 to 2010 is shown in Figure 1.

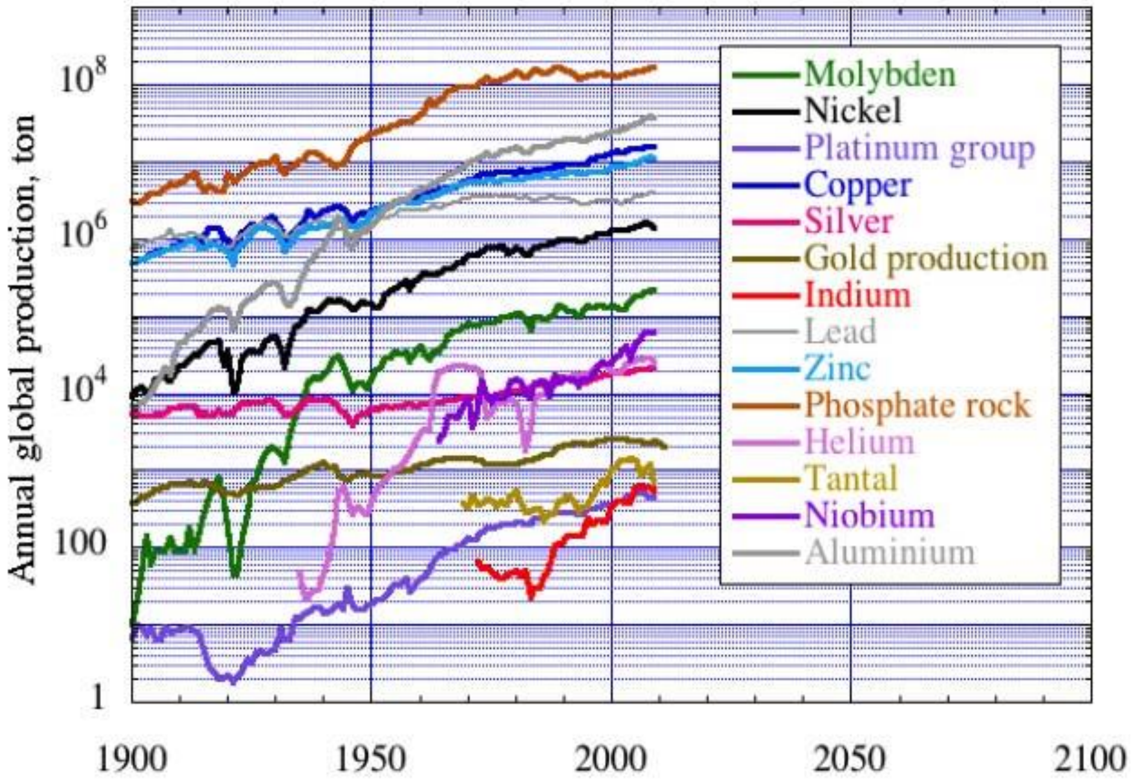
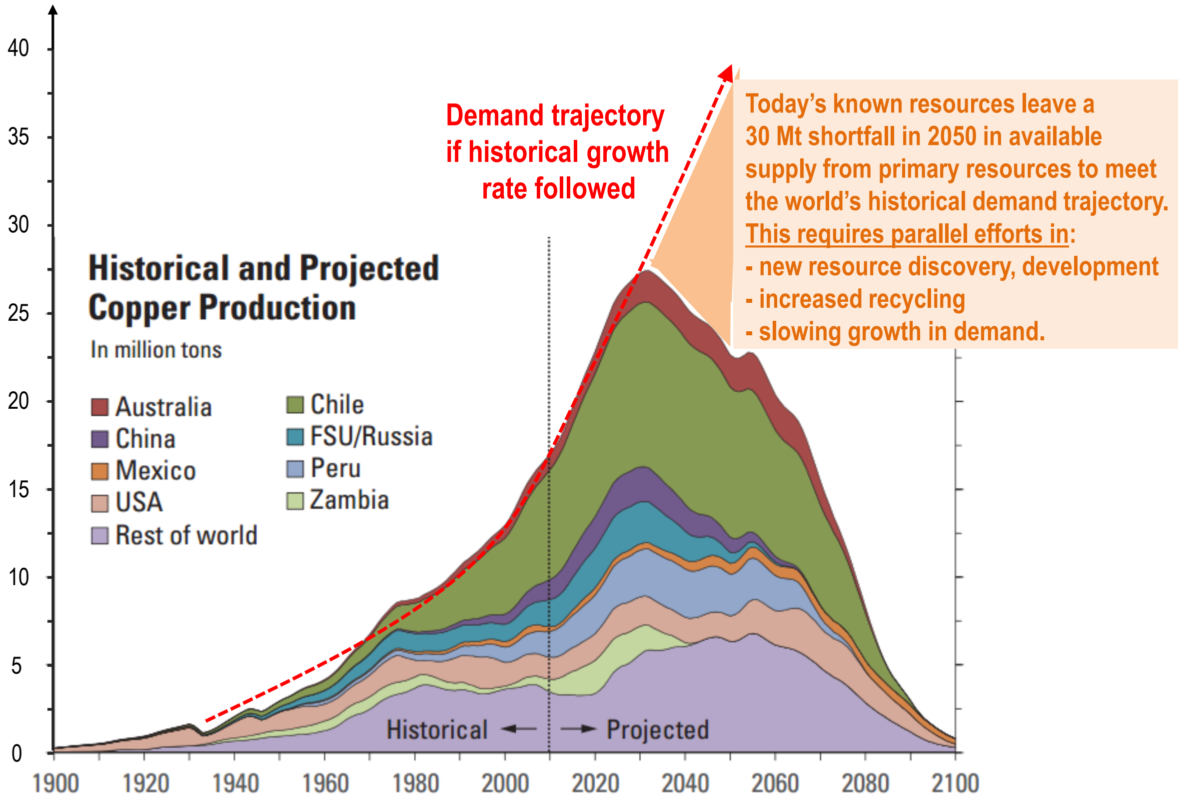


Figure 1: Output from global mining for selected metals and elements (Sverdrup et., al 2013)(1)

There is an almost implicit assumption that future metal demand will be met either by increased recycling or substitution or technological improvements in primary production processes but there are considerable challenges in doing so. Using copper as an example to illustrate the challenge of resourcing future generations this century, the graph in Figure 2 shows declining primary copper production from currently known resources in about 2040.



Demand trajectory if historical growth rate followed

Today's known resources leave a 30 Mt shortfall in 2050 in available supply from primary resources to meet the world's historical demand trajectory.
<u>This requires parallel efforts in</u>:
- new resource discovery, development
- increased recycling
- slowing growth in demand.

Figure 2: Historical and projected primary copper production [Modified from Kerr 2014 and Northey et al 2014)(2)

From about 2050, increasing recycling and lower population and economic growth might offset declining primary production but steps must urgently be taken to assure supply during the coming 2-3 decades. Given that the time from new primary resource discoveries to development and production is usually more than a decade, the imperative to act now is compelling.

The physical basis of our economic activities is raw materials (Ayres, 1978; Tilton, 1996)(2) This can be easy to neglect when global attention has focussed on greenhouse gas pollution, the struggling finance sector and the rise of the service sector (internet and communication, tourism). This may be partly due to the fact that the price of materials has largely declined over the 20th century while our production and consumption systems were physically and socially engineered (UNEP 2010)(3), notwithstanding the periods of higher resource prices during years of strong demand from China.

Technology to the rescue?

Although mineral and metal supply has been a concern throughout history (4), the production of primary raw materials has kept pace so far through technological development in resource discovery and extraction. However, there have always been periods when mineral and metal demand has placed pressure on supply, or supplies have been restricted, leading to fluctuations in prices.

In the 2002-2008 metals boom, metal prices increased, as did monopolies on the supply of metals such as rare earth elements and indium, which put metals scarcity back into the political agenda. Resource economics fall into two distinct schools (Tilton, 1996)(4). The "optimists" argue that technological progress will ensure that supply meets demand into the foreseeable future (See USGS Commodity Statistics and Information) The "pessimists" argue that the use of finite resources and exponential growth of resource extraction is by definition unsustainable, and that the rate of extraction must decrease so as not to limit or curtail the opportunities of future generations (see also Prior et al. 2012(5)). In all cases, social and environmental issues and regulations – in addition to the resource demand and quality of the ore and available technology for processing – impact on the size of mineral resource that it is economic to mine as shown in Figure 3.

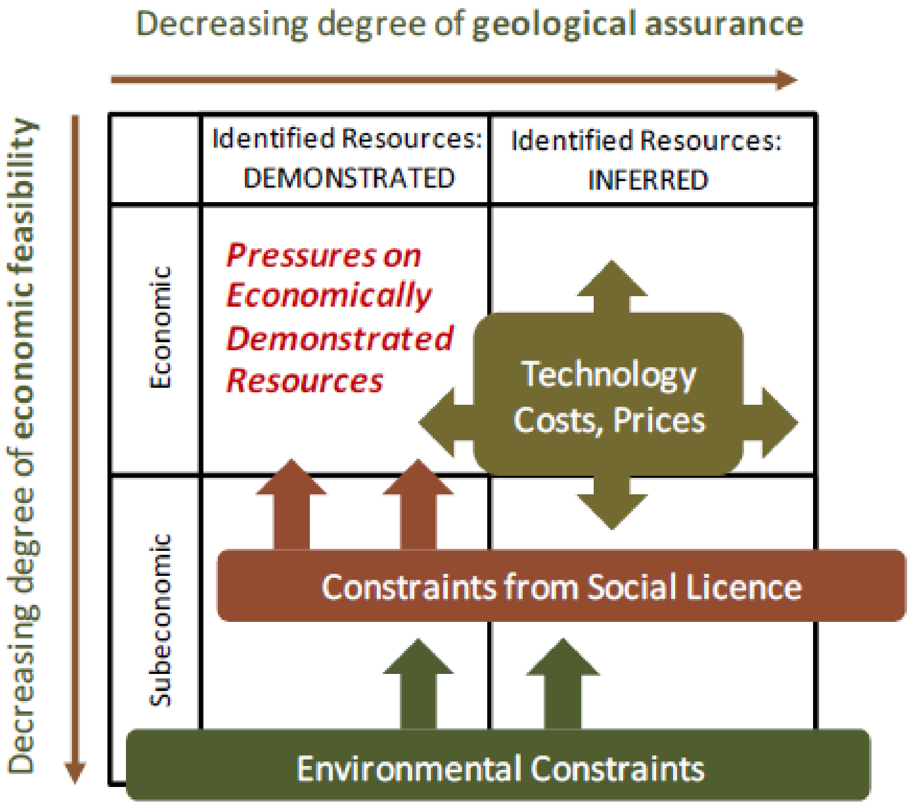


Figure 3: Factors influencing possible production from economically demonstrated resources (Mason et al. 2013)(3)

Technology routes to increased supply do indeed exist but all have inherent limitations:

> *Improving the output from mining and processing:* Technology and innovation to improve the efficiency of extracting raw materials from the ground is a major goal of the resources industry. Appendix 2 outlines some technology developments that will increase the efficiency of supply. However, given socio-economic and environmental requirements for resource development, known accessible resources are limited and even the most efficient operations will not enable an increasing demand for metals, such as copper, to be met solely through technological gains over the next two to three decades (Northey et al. 2014)(6);
>
> *Using better what we already have:* Recycling will contribute to resource supplies but for most metals, less than 25% of metals production currently comes from recycled sources (Graedel et al. 2011)(7). There are considerable economic and energy based challenges in recycling, and considerable quantities of materials are “locked up” for many years or even decades in vehicles, buildings, and other infrastructure. Poor design also limits recycling (Ciacci et al. 2015)(8) The time for the technological and cultural change required to realise a more circular economy with increased recycling is also significant (UNEP, 2013)(9);

Replacing mineral demand with other materials: Substitution of metals by non-metals (i.e. bio-based resources. plastics), or critical metals with more abundant alternatives, is possible in selected cases. However, such sources create their own challenges for sustainable development and are unlikely to meet the rising demand without significant technological innovation.

Finding new resources through exploration: Finally, (and the focus of the Resourcing Future Generations Initiative), new sources of minerals and metal supply can be discovered, but only if sufficient investment and attention is paid to systematic exploration now, so that we can meet needs in a few decades time. This is elaborated in Themes 2 and 3.

A further complication is that the development of technology itself creates demand for new and different mixes of raw materials, the rare earths being the best known but by no means a unique example, – particularly as the planet strives to address the twin issues of climate change and energy security.

The minerals-energy nexus

Raw materials provide 97% of our current energy through fossil fuels, uranium and biomass (IEA 2010)(10). The infrastructure of the energy sector requires the massive use of metals and minerals, in particular (1) steel for ships, pipelines, mining equipment, power plants, refineries and exploration activities, (2) copper for the electricity grid, generators and electric motors, and (3) aluminium, primarily for the electricity grid, and (4) a host of other metals and minerals including phosphorous, potassium and nitrogen for bio mass production.

The remainder of the energy is produced through hydropower, wind and sunlight – which need huge amounts of concrete, steel and specialty metals (Hertwich et al 2015)(11). Global energy demand also continues to rise (IEA, 2014)(12)

It is this low carbon energy supply that global leaders will seek to expand in order to transition to a low carbon society within the coming decades to counterbalance climate change.

There is not only a rapidly rising energy demand but also a change in the raw materials needed to meet this demand in a low carbon future (Kleijn et al. 2011(13); Vidal et al. 2013(14)) as illustrated in Figure 4.

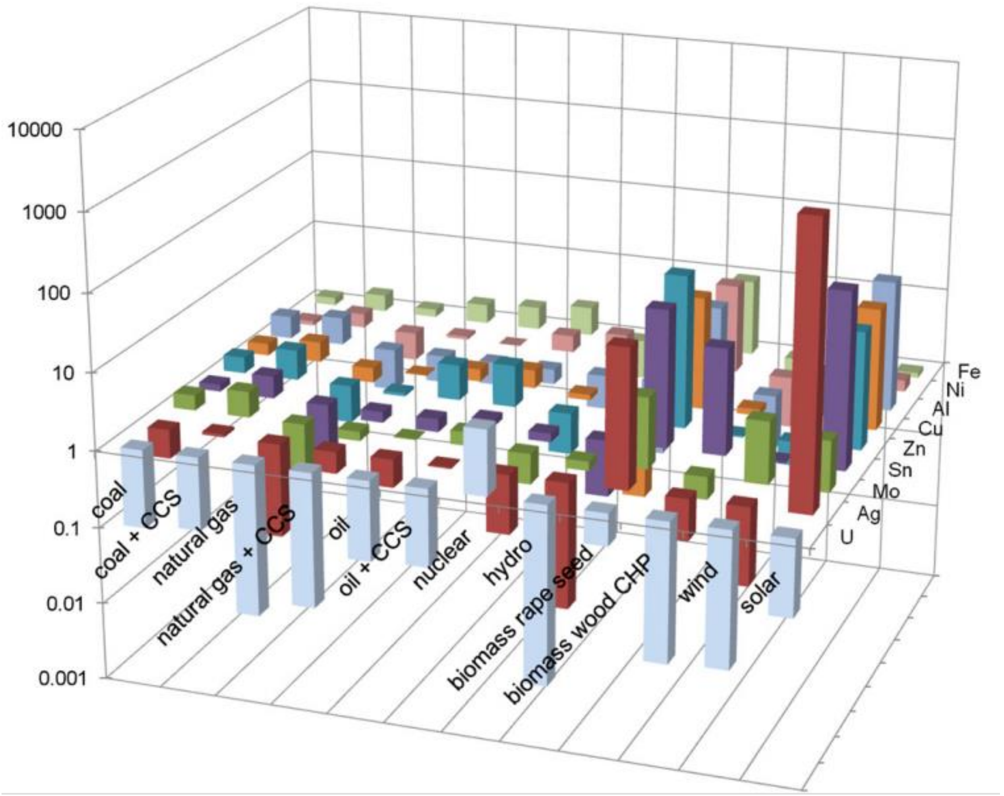


Figure 4: Requirements of selected metals in different power generation technologies relative to the metal demand of the current mix (Kleijn et al. 2011) (4)

The nexus (15) between energy transitions and materials supply is discussed in more detail in Appendix 1.

Acknowledging Societal Accountability for Consumption

The rising consumption of materials and metals occurs to meet societies' needs and expectations. Currently, high rates of metal consumption cause significant and adverse environmental impacts (UNEP, 2010)(16). Yet societal awareness and accountability is low, consumers are often dissociated from knowledge of the origin of the products and infrastructure they use. The low and collectively societal recognition and responsibility for the cumulative global impacts (both at home and abroad) of consumption and its ultimate link to resource development makes addressing the problem more difficult.

A paradigm of sufficiency (in relation to consumption) and decoupling societal prosperity from rising resource use needs greater elaboration, in place of defaulting to the little-questioned notion that unending growth in resource consumption is beneficial. Yet more resources than are used today will be required for future societal prosperity, and they ought to be utilised efficiently and productively and to support sustainable development goals.

Mining is often seen as an undesirable use of land and social conflicts increasingly delay mining operations or prevent them as shown in Figure 5.

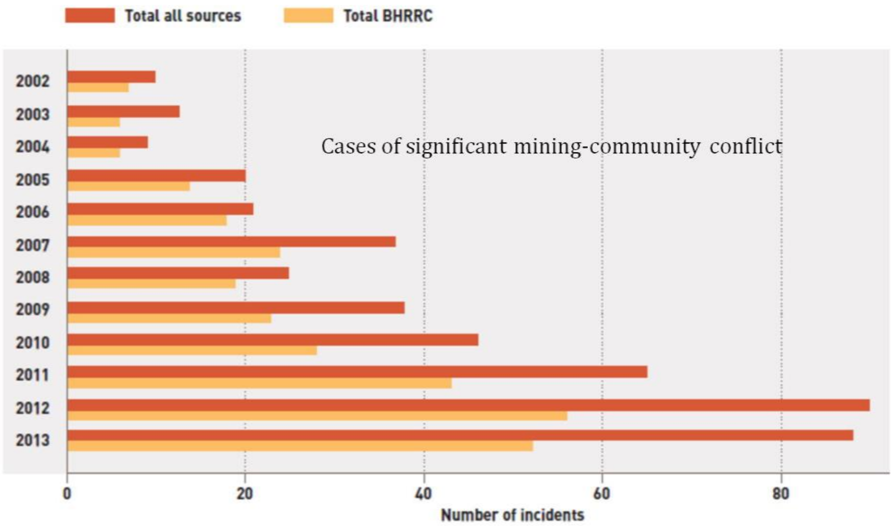


Figure 5: Incidents of company – community conflict (ICMM, 2015) (5)

In seeking to address the global challenge of resource supply for responsible prosperity, not only the risks but also the benefits of resource operations must be weighed against alternative land uses through an evaluation of socio-economic-ecological trade-offs at both local and global levels. The criticality of an operation should not be assessed solely in economic terms, but also in terms of:

- The value of resource development to the region and for livelihoods of local communities, and
- The intrinsic need for the commodity for wider human progress and new technology.

Recommendations

Link supply scenarios into demand assessments: Whilst initiatives at a global level examine future demand for key metals (for example, USGS and BGS), a conceptual understanding of supply implications, by region and in terms of criticality is needed. This could be achieved by incorporating geosciences and mining specialists into the work of the International Resource Panel (IRP) to develop conceptual supply responses to scenarios for future demand for key metals.

Develop international guidelines for planetary consumption: Articulate at global and regional levels a vision for future demand pathways (for example, UN Sustainable Development Goals: G7 Resource Efficiency; EU Raw Materials Directive, OECD Sustainable Materials Management) and further groups which could lead (Asia Pacific Economic Cooperation, African Union) based on sufficiency targets for metals consumption, consistent with sustainable development goals and planetary boundaries.

Raise awareness of the impacts of consumption from source to product: Investigate a system for tracking mineral use from source to product, such as a global chain-of-custody similar to the concept of food miles or sustainable forestry marking.

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Theme 2: The challenge of supply: Accessing new resources from the earth

The emerging vulnerabilities discussed above focus attention on several key issues that must be confronted in the extractive sector for the long term provision of an adequate mineral and metal supply to future generations.

Making the most of known resources

Mining companies choose to operate in regions where the balance of risk and opportunity is economically sound. This means that the exploration and exploitation effort is often concentrated in established resource regions and leads to depletion of the resource in these particular regions, resulting in increasing costs as lower grade ores are pursued and mines go deeper (Figures 6 & 7).

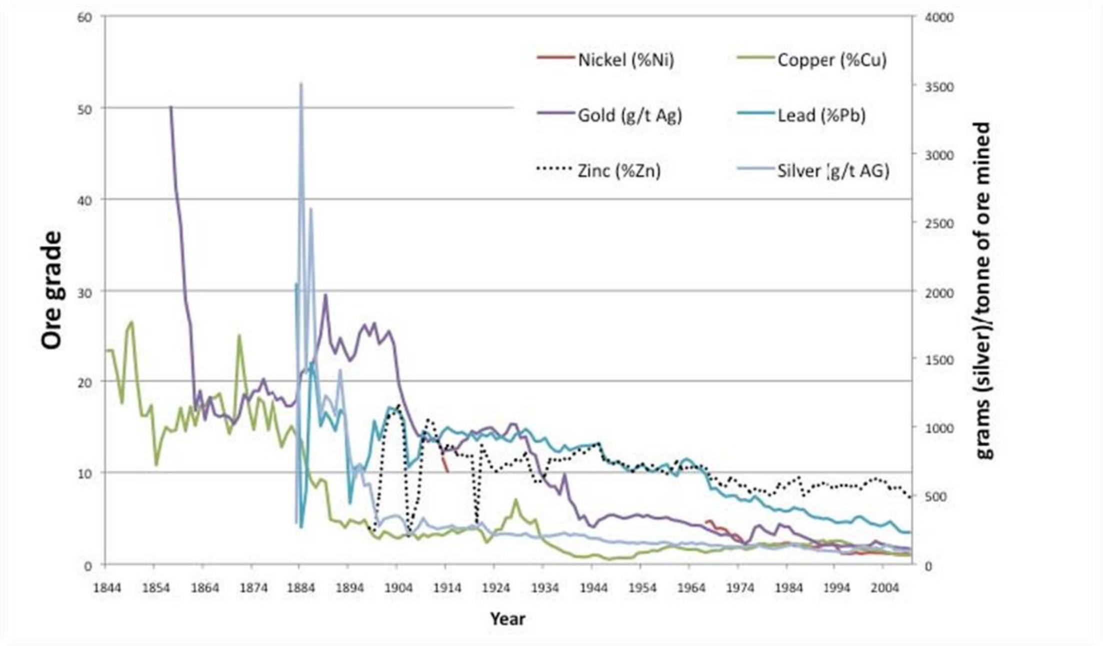


Figure 6: Ore grades are steadily declining for a variety of base and precious metals in Australia (Source: Prior et al., 2012, Fig 3).

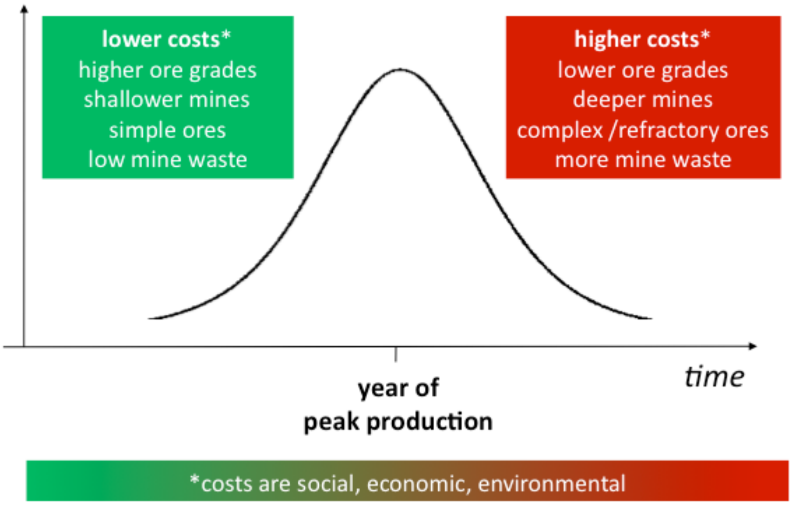


Figure 7: Conceptual model of peak minerals; illustrating higher costs post-peak (Source: Prior et al., 2012, Fig 2).

Several trends are emerging:

1. Lower grade and deeper mines increase emissions and waste production.
2. Energy and water consumption increases, driving operational costs up and increasing the environmental impact of the operation.
3. Increasingly, operations are delayed or prevented by problems in receiving permits and licences or social conflicts. In many jurisdictions, community and legal barriers cause more than 50% of delays producing many millions of tonnes per year loss in supply.

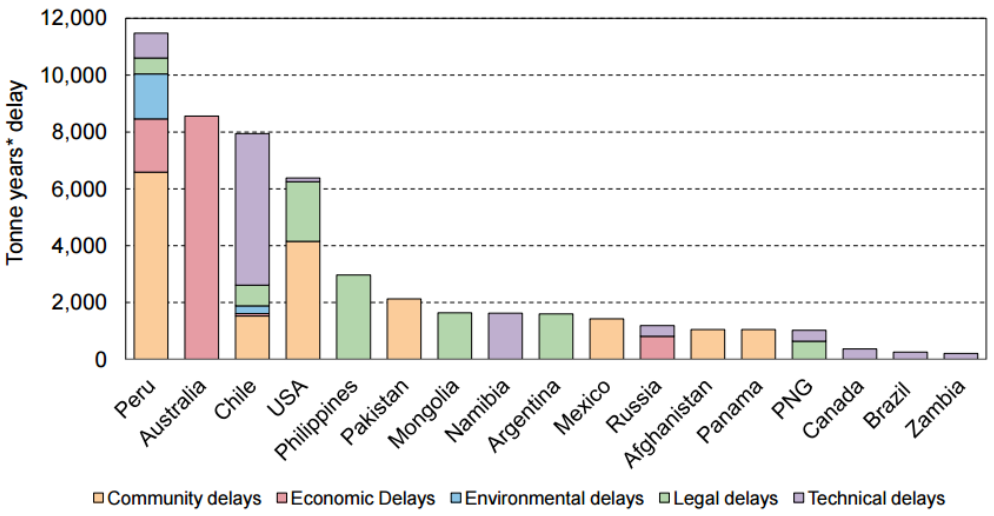


Figure 8: Comparison of initial and current commissioning dates for largest 50 copper projects (Robinson, P., 2013)

Industry led technology innovation is addressing these issues with rapid advancements in automation, processing efficiency and productivity and new extraction techniques, such as *in-situ* recovery (Appendix 2). However, as discussed previously, known resources will not meet the demand of future generations, and new resources will need to be found through systematic mineral exploration. However, the costs of exploration are rising and exploration in untested regions is declining, significantly reducing the chances of new discovery.

Finding new primary mineral resources: The role of untested regions in exploration and geosciences data

Exploration targets are becoming more inaccessible - deeper, under significant cover material and in as yet unexplored territories. Consequently, the costs of exploration are rising. There is a tendency to focus on exploration near existing operations and this has resulted in a decreased rate of discovery of large new ore bodies (Schodde, R., 2014)[1].

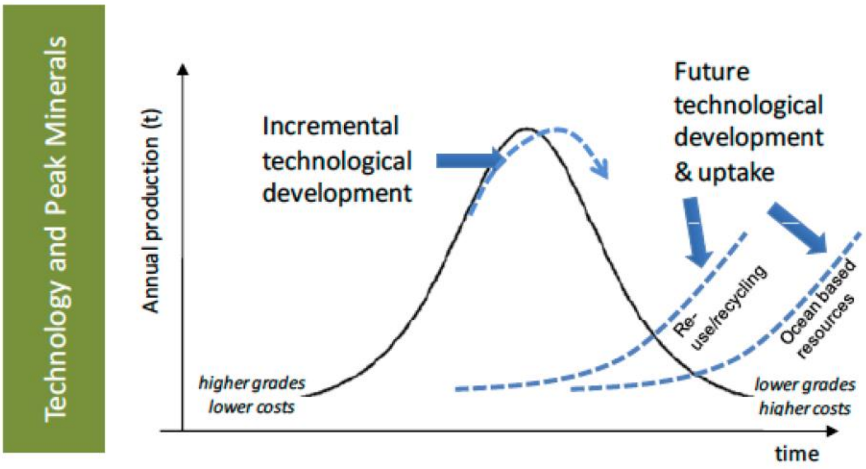
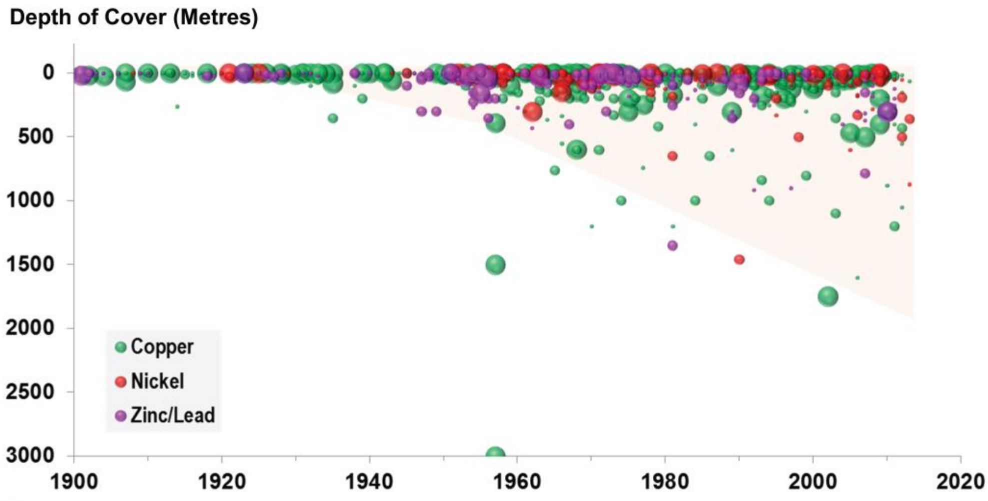


Figure 9: The traditional and future roles of technology in relation to the peak minerals paradigm (Source: Prior et al., 2012, Fig: 9; original from Giurco et al., 2010, Fig: 13, p.24)



N = 1034
Note: Size of bubble refers to "Moderate", "Major" and "Giant"-sized deposits.
Excludes Nickel Laterite deposits

Figure 10: Base metal deposits found in the World between 1900-2013 by progressively exploring under deeper cover. Source: Schodde (2014a).

There are still accessible resources near the surface, but the conditions for exploiting them are not always favourable for industry. There is an insufficient amount of data in some parts of the world, which inhibits exploration in those areas. Two key conditions could open up currently under-explored areas:

- The integration of mineral exploration data for an improved understanding of where new resources may be located (for example, the UNCOVER initiative. Mineral exploration data might include combining geological, structural, geochemical and geophysical data to produce a mineral prospectivity map (Harris et al., 2001[2]; Carranza, 2008[3]), and
- Stable operating conditions and governance to attract industry to explore in these areas.

Hence, the provision of accessible global baseline geological data to support resource and infrastructure development can be an extremely effective agent in developing countries. Appendix 3 outlines the example of Namibia where a young country has established efficient systems for the governance of geosciences data and building geosciences skills.

The fixed nature of geological assets: Implications for land use trade-offs

Mineral deposits are irregularly distributed around the world and their location controlled by unique geological factors (Figure 11). For some minerals, a few large deposits account for a great proportion of world resources and production. For example, 90% of the world's platinum occurs in South Africa, Zimbabwe and Russia.

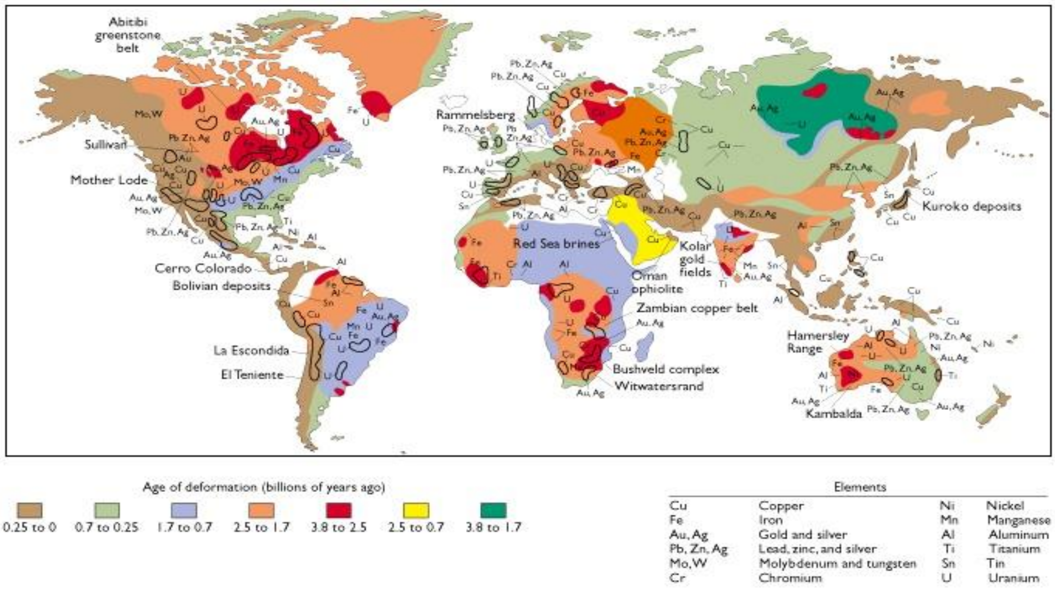


Figure 11: Distribution of mineral deposits on land (Source: Press & Siever, 2002, Fig: 22.28, p: 536).

Because of the unique location of ore deposits, their value must be compared to the alternative uses of the land, such as agriculture, forestry, water, habitats for fauna and flora, cultural and natural heritage, as well as land for settlements and infrastructure. Conservation and mining activities are not necessarily mutually exclusive, and there are examples of farming at the surface of the land that is being mined underground, such as on the potash mines of Canada, iron ore in Carajás Brazil (Figure 12) and mining and tourism co-exist in the Kiruna region of Sweden.

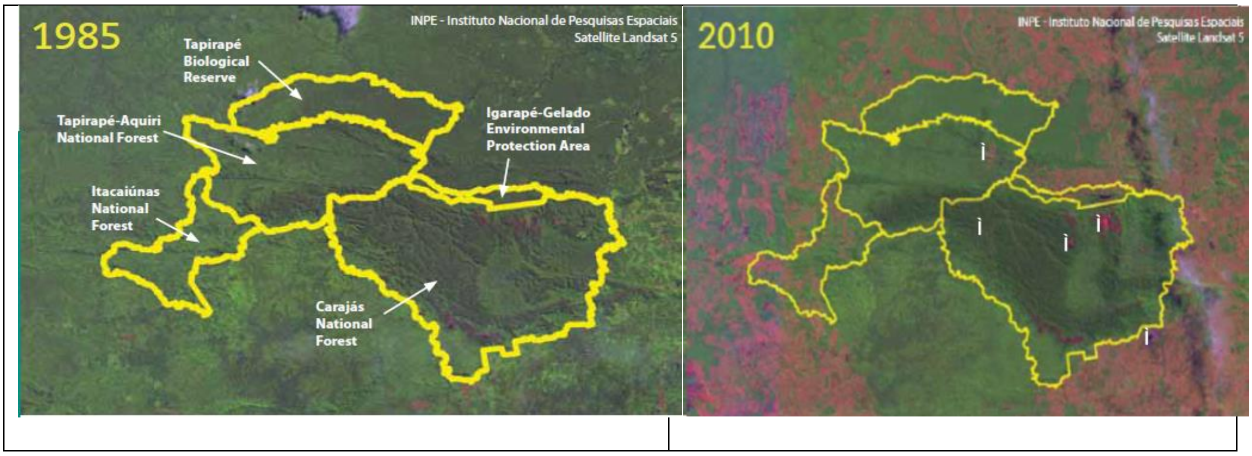


Figure 12: Coexistence of mining and other activities (Source: Satellite image from National Institute of Space Research (INPE), Vale) 2010 mines are N4 (Iron Ore), Igarapé Azul (Mn), Igarapé Bahia (Au), Sossego and Salobo (Cu and Au).

In the mid-1980's, the then state-owned Companhia Vale do Rio Doce, now Vale, to avoid a potential influx of “garimpeiros”(Independent mineral prospectors) in their productive area undertook efforts to establish borders surrounding a number of specially protected areas, amounting to an estimated 411,000 hectares. Three decades later, the result is a vast area of maintained forest that would have likely been devastated if the mining company was not there.

Like many industrial activities, there are examples of negative societal and environmental externalities caused by mining. Environmental degradation around nickel mines in Sudbury, Canada, extended many kilometres from the mines, and dam failure at Ok Tedi in Papua New Guinea resulted in deaths and river pollution downstream. Through the centuries, mining at Potosi in Bolivia has caused many deaths through bad and unsafe practices, acid mine drainage has often polluted groundwater, while waste dumps around gold mines in Johannesburg caused a hazard affecting communities and schools with mildly radioactive wind-blown dust. However, more recent remediation coupled with environmental legislation and best practice employed by mines has improved the situation considerably, although a negative perception of mining still remains in many minds.

At present, mining regulations, societal pressure and technological advances have improved the situation. Examples of best practices exist but are not universally applied. The Mittersill tungsten mine in Austria is not visible from a road that passes a few hundred metres from the shaft, because mining and crushing is entirely underground. Waste mine water from the Navan zinc mine in Ireland is pumped to sites that have become a haven for wildlife and birds, and dust is minimised by housing crushing activities under tepees.

It is also important to stress that mining is a temporary activity that can allow for future uses of the land. Whilst some large copper mines, such as Bingham in Utah, have been in existence for more than 100 years, other deposits are mined for just a few years. Planning for closure ensures that when the mine life is exhausted, the landscape is either returned to its former state, or is left in a way that can be used for different activities. Areas mined for bauxite in Australia and Greece have been so successfully remediated that after 20 years there is no vestige of the former mining activity. Local mining companies have preserved the Carajás forest of Brazil from illegal logging. Brown coal surface mines in Germany have been re-vegetated for agricultural use and 70% of the preserved *'Sites of Special Scientific Interest'* in the United Kingdom were formerly mined or quarried. One of the most visited botanical gardens in the world, Butchart Gardens in Victoria, British Columbia, Canada, was formerly an open pit mine (http://www.butchartgardens.com).

New mineral resources are required for future generations, whether for our computer-driven technological development, climate issues related to energy, or to support our lifestyle with building materials for homes, shops and offices, or for cars and mobile phones. Because of the irregular distribution of primary raw materials, measures must be taken to ensure access to these resources. However, whilst many countries have strict codes of conduct that underpin the social licence to mine, legislation is often lacking or not enforced.

Standardisation of best practice should become a norm, rather like the standards of reporting of ore resources (For example, JORC in Australia, SAMREC in South Africa, NI43-101 in Canada). International agreements and protocols may help ensure regulations are widely adopted; already major international companies are adhering to, and even exceeding expectations. However, in the future, regulations need to be enforced and more widely applied. New technology and practices are developing to ensure more effective mining, more efficient extraction of metals that will minimise waste, so that the environmental footprint can be reduced. Improved synergies with other land types of use need to be explored.

Table 1: Examples of the interaction between mining and the environment.

Statement	Examples	Need for action
Because of the unique location of ore deposits their value must be compared to alternative uses of the land	Copper mining versus golf courses	Inter-governmental agreement on these factors in policy making
Bad environmental and social practices in the past have led to environmental remediation requirements and social effects	Witwatersrand gold spoil tips Olympias polymetallic deposit waste dumps (Greece). Cerro Rico Potosi, Bolivia	
Sometimes mining leaves the land in a better state	Bauxite mining in Australia, Greece and Namibia Carajas national forest Minnesota iron mines	Mining companies invest in the rehabilitation of land
Recent improvements	The proposed Sirius Polyhalite mine in England in a national park	Mining companies are much more willing to meet best practices, but government

Statement	Examples	Need for action
		needs to ensure standards are met.
Other land uses can co-exist with mining	Brown coal in Germany where land is remediated. Potash mining in Canada with agriculture above. The Kiruna Mine in Sweden coexists with tourism.	
Mining is a temporary activity that can allow for future use of the land	70% of United Kingdom '*Sites of Special Scientific Interest*' were originally sites of mining activity	Requirement to leave the land so that it can have a future use
Mining and societal regulations have improved	Aboriginal rights Social consultation and engagement Strategic environmental impact assessments, Compensation	Regulations need to be enforced and more widely applied, and there is a need for international agreements on best practice protocols
Large ore deposits are irregularly distributed	Escondida copper Bushveld platinum, South Africa	International measures need to be taken to guarantee access to these resources
Across the world with increasing populations there are increasing competitions for land use	Increasing conflicts in mineral countries	Main message: Mining is required
Needs to better balance between costs and benefits, considering the unique value of mineral deposits	Value of rare deposits Good compensation for externalities [4]	Go and No-Go Zones

Finding resources through understanding the subsurface

The search for new mineral deposits ("greenfields"[5] exploration), extensions of existing deposits ("brownfields"[6] exploration), and the safe, efficient and environmentally responsible mining of the deposits is facilitated by the availability of integrated geological, structural, geochemical and geophysical data, and many advanced exploration, mining and metallurgical technologies (see Appendix 2).

Our ability to identify regions with high exploration potential; to "see" more deeply beneath the surface; to mine low-grade ore bodies profitably; and to mine deep ore bodies safely has improved considerably over the past decades. Continued progress depends on further investment in research and innovation, and the improvement of services provided by geological surveys. The capacity of universities to deliver high-level training and research must be improved, especially in developing countries that are likely to supply a significant proportion of minerals in the future.

Table 2: Critical questions for future exploration and extraction of mineral resources.

Questions	Challenge	Best Practice
Will current exploration methods provide the metals & minerals for future generations?	The need to counter declining exploration success. The need to explore beneath cover on 90% of all continents. The need to explore in "no go" regions, i.e., where exploration is dormant. Better/new ore genesis predictive models. More investment in people, technology development, research, exploration, etc. Standards for reporting reserves.	Active State-Industry-Academia collaboration. Knowledge transfer between academia and industry, and from developed to developing countries. Development of new ore types (for example zinc oxides). Recovery of critical metals that occur as minor constituents in ores. Improve current exploration technologies (geophysics, geochemistry, drilling, etc.) Transfer/adapt of technologies from other fields (for example, astrophysics - muon geotomography). Develop new exploration technologies (for example, airborne seismics ,see https://www.google.com/patents/US3509960, and a trial survey conducted http://data.gov.au/dataset/l117-northern-new-guinea-basin-airborne-seismic-survey-1970
What background data for exploration are available? **Historical exploration data** **Geological mapping** **Geophysics** **Geochemistry** **Remote sensing**	Uniformity and correlation, including across national boundaries. Accessibility Coverage Scale Interoperability Quality (age, sensitivity, reliability)	Australia Canada Namibia Finland USA Make reporting of exploration results to state authorities mandatory
Existence of modern legal mining framework	Weak, old or non-existent	Code that supports investment and development of country.
What ground is open for exploration? **Status of licences (licence holder, location, size, duration, conditions)**	Ability of state regulator to evaluate and archive data. Confidentiality of data. Efficient issuing of new licences.	Open cadastre Security of tenure Issuing of licence under clear and transparent rules Clear obligations of State and licence holder. Sufficient time to explore and develop Assurance that licence may be traded and used as warranty for loans.
How to ensure environmentally and socially acceptable exploration and	Impact on communities, agriculture, fisheries, nature reserves. Comparison of costs/benefits of other	Less intrusive exploration techniques Develop social skills of exploration team (geologist, drillers, etc.) to deal with communities Broad social compact encapsulated in an

Questions	Challenge	Best Practice
mining practices?	land uses.	agreement so that the community benefits.
How to escape the energy loop?	Low grade ore requires more energy; Future energy is renewable (low carbon); Renewable energy requires more metals. Greater recovery of metals from high tech goods (TVs, mobile phones, computers, etc.)	Improve metal discovery and recovery techniques. Increase rates of recycling and substitution and reduce waste (for example, "urban mining"). Products manufactured to aid recovery of metals.
How can best practice be globally applied?	Achievement of global acceptance	Adoption

Responsible Resource Development: the importance of best practice

The discovery and extraction of resources presents social and environmental impacts at every stage of the operation including exploration, extraction and closure. If governed effectively, these interactions can stimulate significant economic development and poverty alleviation (see Appendix 4 and as discussed in the next section). Handled poorly, they can lead to inequality, corruption and environmental degradation

There are many guidelines already in existence to promote positive impacts and the quality of interaction at each of these stages will determine the future success and viability of the operation. Different impacts occur at different scales and require many levels of engagement: Local; Regional; National; Global. Examples of existing guidelines and best practice are outlined below.

Table 3: Examples of the challenges and potential solutions faced in resource development

Theme	Challenge	Best practice
Environmental impacts	Ensuring environmental and social engagement procedures for exploration and mining activities are of high standard in the industry	Guidelines available from regional mining associations, for example, Minerals Council of Australia (MCA), 2005. Enduring Value: The Australian Minerals Industry Framework for Sustainable Development. Enduring Value Secretariat, MCA[7] Equator principles (social & environmental risk in project financing)[8] International Finance Corporation's environmental and social sustainability policy (IFC, 2012)[9]
Transparency	Informing communities and the public about geoscientific,	Global Reporting Initiative (2013) G4 Sector Disclosure: Mining and

Theme	Challenge	Best practice
	exploration and mining activities. Explanation of exploration activities and managing expectations of impacts and effects relating to the stage of exploration	Metals.[10] Companies in collaboration with local authorities and directly with the public[11]
Communication (about managing expectations)	Understanding and discussing the expectations with the public. Establishing trust from the beginning (for example, exploration). Building a relationship with communities.	Dialogue[12] between local people, government and the companies concerning exploration and extraction of minerals – early engagement[12] International Council on Mining & Metals' Community Development toolkit (ICMM, 2012)[13]
Cultural heritage	Recognition of cultural heritage that is important for local, regional and national communities in the areas	Lihir Island, PNG – A gold mine on a remote island operated by Newcrest.[14] International Union for Conservation of Nature and Natural Resources
FPIC (United Nations 'Free prior and informed consent')	Seeking and gaining communities consent – licence to operate – for specific extraction projects. Applying the principles of FPIC	Clear national legislation concerning environmental and social impacts in mining[15] Industry best practice examples from: Exploration - Rio Tinto – La Granja – Peru, BHP Billiton, Anglo American, Vale – things that have worked[16]
Indigenous peoples rights	Recognising indigenous people rights and their rights for land use and natural resource use	International Council on Mining & Metal's statement of indigenous peoples and mining (ICMM, 2013)[17] Best practice for indigenous people engagement comes from state where land ownership and natural resource rights are recognised – for example, USA and Canada Enterprise development with indigenous communities[18] – Indigenous Corporations – where they engage in mineral resource development.
Land use and access	Ownership and rites of passage and usage of lease land	Red Dog Mine in Alaska – with joint indigenous ownership and access for resource usage[19]
Revenue distribution	Considering revenue distribution with local, regional and national authorities in jurisdictions	The recent review of benefit-sharing arrangements in developing countries demonstrates a wide range of solutions available [20] for benefiting regional development from mining

Theme	Challenge	Best practice
		operations.
Community development – Education and health	Building capacity for community development – contribution to social development in the areas, especially in health, education and community infrastructures	Corporate foundations – Rossing Foundation (uranium), Namibia – undertaking a broad range of activities across a wide spectrum of community development [21] areas. How well they are managed and deliver initiatives [22] Community development fund that continues social license with the community. Tri-sector partnership funds – involving local authorities, communities and companies. These are grant making foundations. [23]
Economic development	Contribute to economic development	Numerous examples throughout the world, including Australian [24] iron mines, Namibia diamond mines, Aitik Mine in Sweden, and other examples in Botswana, Chile, Greece, etc. [25]
Local procurement	Possibilities for supporting local enterprises and suppliers to procure for the exploration and mineral development activities	Examples from Australian SME local procurement efforts [26] Local procurement ideas have been tested in developing countries as well, though challenging, there are solutions [27] to improve local procurement in mining enterprises.
Employment	Possibilities for providing local employment and assisting in skill acquisition	Supplier's development programme implanted in the Espirito Santo and Para State in Brazil. Local employment opportunities in Australia [28]
Training and skill development for local communities	Assisting communities to acquire skills and provide training, for example, driving, machinery operators, geologists, etc.	An example of such a scheme is the Aboriginal Minerals Training and Employment Programme (AMTEP) [29] CSR implemented by benchmark companies
Poverty	Contribute in the reduction of poverty	Direct employment [30] at the mine, and indirectly supporting the local market
Small-scale mining	Solutions for environmental impacts arising from Artisanal	Exploration geologists where they venture in areas with the history of

Theme	Challenge	Best practice
	and Small-scale Mining (ASM) Consideration for formalisation of small-scale mining sector. Consideration of co-existing strategies between ASM and large-scale mining activities.	small-scale and artisanal mining [31] should do a baseline study of pre-existing impacts. There needs to be a recognition granted to the knowledge of the reserve by the artisanal and small-scale mining and how the benefits can be shared for future development. Government recognition of small-scale mining and formalisation. Cooperatives of small-scale mining – access to markets [32]– Rwanda tin mining. Some best practice of sharing land for mining for deep mining by mining companies and surface mining by small-scale mining. Goldfields. [33]
Health and safety and public health	It is important to consider the health and safety impacts on local community and wider society.	Mining safety and health improvements over the past decades are remarkable by many metrics. The longer-term improvements are also visible in the lost-time injuries. Further, the industry is oriented at 'zero harm' approach in the workplace, [34] i.e. eliminating fatalities and occupational illnesses and reducing injuries.
Local enterprise development	Local enterprise development during operation level – capacity building for business development in areas of mining	Enterprise Facilitation in the Democratic Republic of Congo. There is a growing interest in identifying robust indicators which demonstrate the links between mining and regional development [35]
Coexistence with other land use activities – tourism, agriculture	Considering co-existing strategies with other land use activities such as tourism and agriculture.	Eldorado's Efemçukuru mine in Turkey where vineyards coexist with mine site Methodologies [36] are required to analyse the trade-offs and sensitivities of mining operations and other land uses
Technology transfers	Consider possibilities for technology transfer for locations from exploration and mining activities	Australia's Cooperative Research Centre program bringing together industry, government and research, for example CRC Ore and also includes a partnership with Austmine, the peak body for the Mining,

Theme	Challenge	Best practice
		Equipment and Technology Sector.

Recommendations

Build a global baseline of geological data to stimulate exploration in new regions: Accessible global baseline geoscientific data (for example, geological, structural, geochemical, geophysical, remote sensing) to support resource and infrastructure development, we recommend global support for geological surveys in developing countries to encourage exploration in as yet unexplored regions. It is noted that the amount of good quality national geoscientific data to support mineral exploration is limited. Presently, continental-scale geochemical data are freely available for Australia (Caritat and Cooper, 2011a, b)[37], Europe (Salminen et al., 2005[38]; De Vos, Tarvainen et al., 2006 [39]; Reimann et al., 2014a, b[40]), and the United States (Smith et al., 2014?)[41].

Support industry investment into new mineral exploration technology: Industry is enabling the evolution of technology to maximise efficiency, minimise waste and reduce the consumption of water and energy. This should be encouraged as it fosters economic growth not only of the resources sector, but also of the service providers and manufacturing sectors supplying the industry. Further, technology offers the potential for opening up resources hitherto inaccessible

Development of global best practice for responsible resource development: Technological evolution needs to be reinforced by the development of global practices for responsible resource development, which balance the long-term value of any mineral assets against alternative land uses, such as biodiversity protection, agriculture and urbanisation. Examples of good environmental practice and co-existence for land use exist on which to model such global guidelines and need to be balanced by asking society to step up to the plate in terms of understanding consequences of their/our consumption.

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(4) ***Externality*** – A consequence of an economic activity that is experienced by unrelated third parties. An externality can be either positive or negative.

(5) ***Greenfields Exploration*** - Mineral exploration undertaken in an area in which a Company holds no mining operations for the minerals being explored. The exploration of new deposits will not leverage from existing geological knowledge and historical exploration data of known deposits. New mining developments will not leverage from existing infrastructure such as transportation infrastructure, mining facilities and equipment, tailing dams, and trained workforce, among other factors.

(6) ***Brownfields Exploration*** - Mineral exploration undertaken in the proximity to existing mineral deposits and mining facilities. Such exploration leverages from the geological knowledge, expertise and data acquired over the years, which facilitate new discoveries. It also benefits from the fact that deposits tend to cluster in "districts" that are highly endowed in metal content. Brownfields developments usually leverage from existing mining and transportation infrastructure and operational knowledge and therefore tend to be less risky and more economical in their development. Brownfield exploration assures the continuity of mining operation past the initial mine life for which projects were designed.

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(12) Satellite image from National Institute of Space Research (INPE), Vale

Theme 3: Building additional capacity to facilitate responsible development in less developed nations.

Extraction of oil, gas and minerals present an array of unique economic, social and environmental challenges that are commonly poorly understood by governments and are difficult to regulate (Ali, 2010[1]; IIED and WBCSD, 2002[2]; Sagebien and Lindsay, 2011[3]). The development challenges associated with resource extraction have often been framed using concepts such as the 'resource curse'[4], 'Dutch disease'[5], the 'rentier effect'[6], and the 'two speed economy'[7] amongst others (Auty, 1993[8]; Sachs and Warner, 1995[9]; Ross, 1999[10]). In 2011, there were eighty-one countries where the oil, gas and mineral sectors accounted for more than 20% of exports; more than 20% of fiscal revenue; and where resource rents represented more than 10% of economic output (Dobbs et al., 2013)[11]. These countries represented 69% of the global population living in extreme poverty. Despite these challenges, when managed effectively resource extraction can present transformative development opportunities, particularly in Asia, Africa and Latin America (UNECA and African Union, 2011[12]; Franks, 2015[13]). For example, by 2030 $17 trillion are forecast to be needed to keep pace with demand, and a further 540 million people could be lifted out of poverty if oil, gas and mineral reserves were developed to the standard of the best performing resource-endowed developing countries (Dobbs et al., 2013)[14].

Developed economies are not immune to the development challenges of resource extraction. In Australia the commodity boom of 2003 to 2010 induced significant changes in macro-economic, fiscal, employment, human capital and infrastructure conditions (Measham et al., 2013)[15]. Upward pressure on inflation and currency exchange rates generated negative flow-on effects for the farming, manufacturing and resource processing sectors (Downes et al., 2014)[16]. Dramatic increases in taxation revenue increased the resources available to governments to invest in policy priorities, but left governments ill prepared to adjust when prices and economic conditions changed (Garnaut, 2013)[17]. In regional communities, where mining and drilling is undertaken, local distortions in wages, the price of housing and accommodation, and pressure on social infrastructure and services were disproportionately experienced by the people working outside of the extractive industries, even while substantial employment and business development opportunities were realised (Haslam-McKenzie et al., 2009[18]; Rolfe, 2013[19]; Chapman et al., 2014[20]). Changes to environments in the vicinity of sites of resource extraction have impacted on the livelihoods of the people dependent on these environments and triggered environmental and social conflicts (Franks et al., 2014)[21].

Conceptual framework: For governments wishing to leverage extractive industries for development for wider economic development there are four key areas of focus. The first focus is the fiscal and consumption linkages, where taxation and royalties can be invested in priority areas of the economy, and where economic demand, wages and the profits of domestic business can stimulate domestic consumption. The second focus is the production, or backward linkages, where domestic companies and employees provide goods, services and infrastructure for the operation. The third focus is resource processing and value addition, or forward linkages, where minerals, oil and gas are refined and transformed into other products. The fourth focus comprises the horizontal linkages that promote industrial and societal transformation, where the skills and capabilities developed within the sector can be applied in other economic sectors. Each of these economic linkages in turn interacts with human, social and sustainable development processes. Economic development does not necessary translate into human development in all circumstances and resource operations can negatively impact the livelihoods of communities in the vicinity of sites of extraction. Furthermore, the regulation of resource extraction activities can play an important role in determining whether sustainable development outcomes are reached. The research programme that emerges from this Theme has been carefully designed to respond to each of these domains (Figure 13).

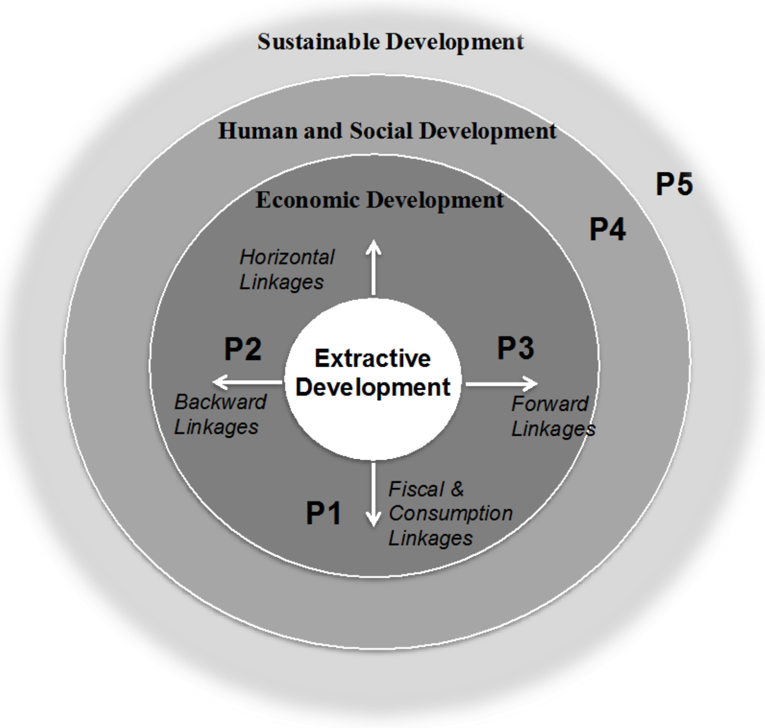

Figure 13: Figure and characterization of thematic areas developed by Daniel Franks and Saleem Ali as part of a proposal to the Australian Research Council, 2015

*Programme one (P1) could investigate the management of resource revenues through three phases –*Topics that will be included in this regard are**:** revenue collection, budgeting and expenditure. Resource revenues may be harnessed through many different legal and governance modes from private resource agreement payments, to licence fees and tenders, permit sales or leases, royalties and taxation on production, and general company and profits taxes on resource companies. Using a case study approach the research should map these different modes for established, prospective, and emerging resource extraction economies with the objectives of investigating failure (and some successes) to effectively harness resource revenues. The programme should investigate the relative merits of each mode in the particular contexts of different local, national and regional resource economies; and by connecting the resource extraction methods to the specific features of their local circular resource economy new approaches with a greater chance of success. Relevant comparisons include the use of property law versus taxation mechanisms; the economic, political and legal aspects of royalty/production style versus profit based revenue tools (for example, royalties versus super profit taxes); and the effects of revenue rising at different levels of community or government.

The effective management of resource revenues requires application of prudential budgeting principles, including fiscal transparency, accounting and investment in respect of both the resource company and the government or community in receipt of revenues. Governments should examine the management of resource revenues at local, provincial and national levels, including the diverse ways in which resource revenues are managed, for example, through private trusts for community benefit; sovereign wealth funds or off-budget resource funds; or consolidated revenue of governments through taxation. In spite of numerous attempts to improve budgeting and transparency of resource revenues, through major efforts at the international level, these frequently remain closed to community members and observers, and there are many examples of poor investment and management of resource revenues.

Turning to expenditure of resource revenues, the project should examine the expenditure frameworks and goals for resource revenues including short and long term time horizons; earmarking of resource revenues and agreements under which the return from resource extraction is to be returned to local communities through particular goods and services; expenditure formulas and protocols for sovereign and government resource funds; and public expenditure frameworks that operate on resource revenues. Key factors include the weight given to local, provincial, national and supranational expenditure goals in expenditure decisions; political and democratic accountability and transparency of expenditure decisions; and effectiveness and efficiency of expenditures.

Programme two (P2) should investigate the connections between resource extraction and regional development. One of the longstanding critiques of extractive industries is that they are often associated with ‘truncated’ forms of economic development, characterised by modest levels of integration into local and regional economies, a high level of economic dependence, and a considerable volatility. While a considerable body of work has examined these issues, there is a tendency to place an excessive focus on ‘spatial proximity’ when considering how extractive industries contribute to regional development. For example, a common focus on mining, oil and gas is how the industry contributes to employment in the host or immediately surrounding communities. In reality, though, the mining supply chain, and its impacts are spatially disaggregated and complex. Extractive activity in one location is likely to have impacts in what are often far distant localities and regions given the ‘stretched out’ nature of its supply chain. This means simple analyses that emphasise local impacts and spillovers are of limited value. New methods are needed that can generate a sophisticated understanding of the ways in which extractive industries interact with local and regional economies that are both proximate to the activity and ‘at a distance’.

This research theme should pioneer a new set of methodological and conceptual approaches for interpreting the impact of extractive industries on development. Drawing on recent work on global production networks, it should carefully map the network for extractive industries, building a new spatial economic model for interpreting the nature and magnitude of impacts in different localities – some of which should be at the site or near the industry, and others that should be quite removed in spatial terms. The research should enable insights to emerge into how resource extraction affects economic development, and how local and regional economies fit together in a complex set of spatial interdependencies. This should provide the basis for understanding the performance and resilience of these local and regional economies in the face of economic and other shocks.

Programme three (P3) should investigate mineral and energy supply chains and their potential to be incorporated into a circular economy. A circular economy emphasises the linkages and interactions between activities and the reuse and recycling of materials. New opportunities for harnessing development potential should be realised that have not previously been captured in the linear model of resource rents from resource investments. An important component of this theme should be to assess the service value that energy and minerals provide for societal development and integrate these values into the proposed transformation to circular supply chains.

The research should produce an up-to-date flow analysis (for example, Sankey diagram[23]) with supporting analysis) of energy and mineral with reference to similar international analyses. The flow analysis should be used to assess the service value that energy and minerals provides to, for example, the Australian economy and to determine the opportunity to enhance the overall service value and reduce impact through alternative supply chain strategies. A desired future flow analysis should be developed to achieve target levels of circularity of energy and minerals/metals in the Australian economy (based on national and international goals for energy reduction and metals recycling), and to incorporate the identified alternative supply chain strategies to enhance overall serviceability of energy and minerals.

A back casting approach in conjunction with industrial ecology principles should be used to develop feasible pathways to attain the desired future flows as specified by the outcomes of the above steps; this task would also rely on the progressive outcomes from Programme 2 '*Connecting Resources to Regions*' to incorporate contextual and geographical elements into the proposed pathways. By applying a techno-ecological economic analysis, the top ranking feasible pathways would be determined, and an analysis would be conducted to identify any potential environmental, social and regulatory impacts (both positive and negative) associated with these pathways.

Programme four (P4) should investigate the linkages between resource extraction, livelihoods and gender equity. The research should take a bottom-up approach to shift the centre of attention from analysis of the extractive development to the livelihoods of people who live around mining, oil and gas reserves and operations. A livelihoods approach will allow the research to consider the ways by which economic development through resource extraction is linked to the human and social development in resource-endowed societies. Through case studies, and using ethnographic research methods, the research should explore the implications of the entire spectrum of extraction practices from highly corporatised and capitalised enterprises to artisanal, small scale and informal extraction.

Case studies could emphasise issues, such as resource ownership, land and property rights; extraction induced social change, such as urbanisation, de-agrarianisation and changing gender dynamics within host communities; the dynamics of social power associated with displacement, resettlement and relocation of indigenous and vulnerable communities to make way for resource extraction; livelihood transitions, for example, from agrarian (or forest and/or pasture-based) livelihoods to extractive livelihoods; the relationships between poverty and extractivism; and the gender roles and relations within the mining, oil and gas industries.

The approach has the capacity to lead to a significant advancement of knowledge and expertise on extractives and sustainability. Theoretically, it opens up the space to allow a range of practical investigations and initiatives, in order to transform a non-renewable and destructive activity into renewable economic practices that support livelihoods and replenish ecologies. At a more practical level, this is done through an integration of gender considerations as, in both large-scale and informal resource extraction sectors, women have long-standing interests and contributory roles as workers, as part of mining, oil and gas families and households, and as part of those movements who have struggled with men to protect the environment.

Programme five (P5) could investigate the effectiveness of the regulation of the extractive industries in achieving sustainable development. Policy-makers often face a significant dilemma. Should they wish to harness international capital to develop their resources, they are encouraged to maintain an attractive investment climate, which is often argued to require the reduction of so-called ‘green tape.’ The assumption that environmental and social obligations are a barrier to investment has guided extractive industry reform in many jurisdictions especially where the legislative framework is lacking or perceived to be fragile and where security of tenure is challenged by possible expropriation in the absence of a stable taxation regime or equitable revenue sharing mechanism. Literature on the factors that influence investment decision-making, however, suggest a number of unique features that differentiate the extractives sector from other forms of foreign direct investment, including high capital intensity, long lead times, finite life, and the fixed geographical locality of reserves and ores. The absence of effective environmental regulation can in fact increase business risks and jeopardise the prospects for long-term success of developments.

The research would look at the influence of environmental and social policy on investment attractiveness. A review of international policy, legislation and governance models, used to address the environmental and social consequences of mining, oil and gas development, will be undertaken to identify appropriate policy interventions, balance the impositions of regulatory compliance with the protections afforded by the effective management of environmental and social issues in different governance contexts.

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(5) ***Dutch Disease***: It is the negative impact an economy experiences when a sudden sharp increase in the inflow of foreign currency occurs. The increase leads to currency appreciation making most of the countries goods more expensive leading to a reduction in competitiveness on the export market. It is mostly associated with an increase in foreign direct investment, foreign aid or discovery/price increases of/in natural resources.

(6) ***The Rentier Effect***: refers to the occurrence of a state/nation deriving a significant portion of its national revenues from the rent of indigenous resources to external clients.

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(22) ***Sankey Diagram***: a specific type of flow diagram where the width of the arrows are shown proportionally to the quantity of the flow. It is used as a visualization to depict flows from one set of values to another set.

FIGURE REFERENCE THEME 3

(13) Figure and characterization of thematic areas developed by Daniel Franks and Saleem Ali as part of a proposal to the Australian Research Council, 2015

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Appendices

Appendix 1: The energy-minerals nexus. Raw materials for a low carbon future

Appendix 2: Technology and Innovation: How resources are discovered and extracted

Appendix 3: The importance of geoscience data in attracting mining investment into Africa.

Appendix 4: Brazil: A case study in the responsible governance of resource revenues for economic and social development

Appendix 1: The energy-minerals nexus: Primary raw materials for a low carbon future

Introduction

In a time when global attention has focused on the struggling finance sector and the booming service sector (internet and communication, tourism) it is easy to forget that the physical basis of our economic activities is primary raw materials Kleijn (2011)[1]. This may be partly due to the fact that the price of materials has continuously declined over the 20th century, while our production and consumption systems were physically and socially engineered (UNEP, 2010)[2]. Despite the recent resource price fluctuations (UNEP, 2010)[3], the monetary value of the raw materials we are using is very small compared to GDP (references cited in Kleijn, 2011)[4].

However, primary raw materials provide 97% of our current energy through fossil fuels, uranium and biomass (IEA, 2010)[5]. These energy carrier materials need to be complemented by the use of minerals and metals, in particular (1) steel for ships, pipelines, mining equipment, power plants, refineries and exploration activities, (2) copper for the electrical power grid, generators, electric motors, (3) aluminium, primarily for the electrical grid, and a host of other metals and minerals.

The remainder of the energy is produced through hydropower, wind and sunlight – in order to produce this 3% we need significant amounts of concrete, steel and specialty metals. It is this low carbon 3% of the energy mix that global leaders will seek to expand in order to transition to a low carbon society within the coming decades in order to mitigate climate change. There are fundamental differences in a renewable energy based energy system to a fossil fuel energy system: (1) lower exergy means more infrastructure, although decentralisation might mitigate this in part; (2) intermittent supply requires buffering and storage, and (3) it is cleaner during the use phase, but impacts on resource use during impacts in the production phase.

Metal Requirements for energy collection

In terms of the metal requirements for energy technologies, Graedel (2011)[6] has noted the following: wind turbines would require rare earth elements, such as neodymium and dysprosium for magnets, copper for the generators, whilst photovoltaic solar cells require cadmium, tellurium, indium, gallium and others. In addition, steel is required for applications ranging from wind turbine construction to machinery for energy crops.

In terms of the metal requirements for the transmission and buffering of renewable energy, copper and steel are required for the electricity power lines and pipelines, and platinum and other specialty metals are needed for catalysts and storage. In terms of the metal requirements for low carbon end use, there are many different technologies to consider, but one that stands out is electric vehicles, which require rare earth elements in magnets, copper for motors, lithium, cobalt, nickel, lanthanum for batteries and platinum for fuel cells.

Even without a switch to renewable energy, a transition to a lower carbon fossil fuel based energy system would still require new materials, namely Carbon Capture and Sequestration (CCS) would require 30-60% extra steel and would decrease the overall efficiency of energy systems, therefore, require more capacity to compensate Klein, (2011)[7]. Highly efficient turbines in jet engines and power plants require rhenium for special temperature resistant alloys, and rare earth elements are needed for the turbines, as well as efficient car engines, and LED and fluorescent lighting (Klein, 2011)[8].

The future of supply

It would be impossible to accurately predict the quantities of metals needed by 2050 for scale up of a low carbon energy future. (Klein, 2011)[8] provides some estimates for the amount of metals needed per kilowatt hour compared to the current mix, and then compares four different energy scenarios: the IEA blue map scenario, which is a low carbon energy system based on renewable energy, the current energy mix, a CCS based scenario and a fossil fuel based scenario. The results are shown in figure 14.

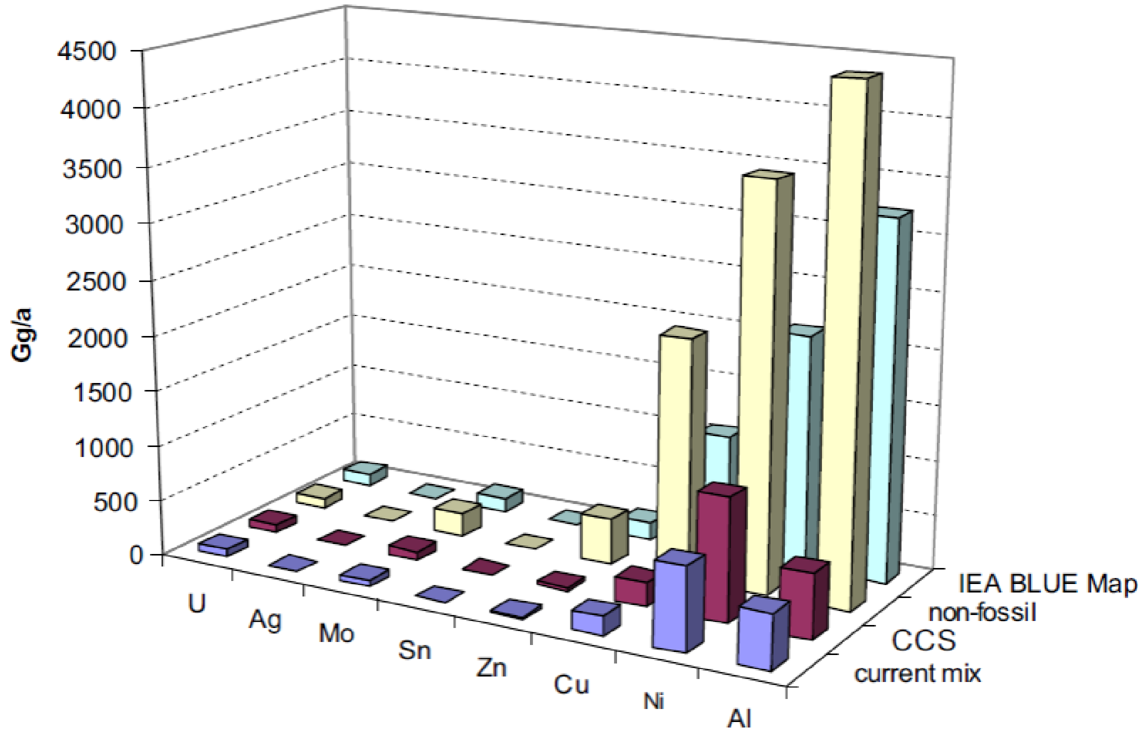

Figure 14: Material requirements related to current world mining (Kleijn, 2011).

This study concluded that the transition to a low-carbon energy system required to tackle climate change, implies a steep increase of the metals intensity of the energy system, which in turn implies a substantial increase in the demand for metals. Specifically, "*The introduction of Carbon Capture and Sequestration in fossil-based power production would increase the metals intensity of power generation by 30% for iron and 75% for nickel at coal-fired plants, and by 40% for iron and 150% for nickel at gas-fired plants. There are two main causes: (i) the efficiency of power production is reduced, because energy is needed to capture and transport* CO_2*, and (ii) additional infrastructure is needed in the form of capture installations, pipelines, pumps and injection wells. A full transition of the current generation system to a non-fossil electricity mix would require a substantial scale-up of the mining and refining of many metals including nickel, molybdenum, uranium, silver and, to a lesser extent, aluminium and copper. When a business-as-usual economic growth scenario (Special Report on Emissions Scenarios A1) is combined with a complete transition to renewable energy AD (65% PV solar from the deserts, 15% PV solar from rooftops, 15% wind and 5% others) by 2050, the metals requirements for this transition would be very high.”*

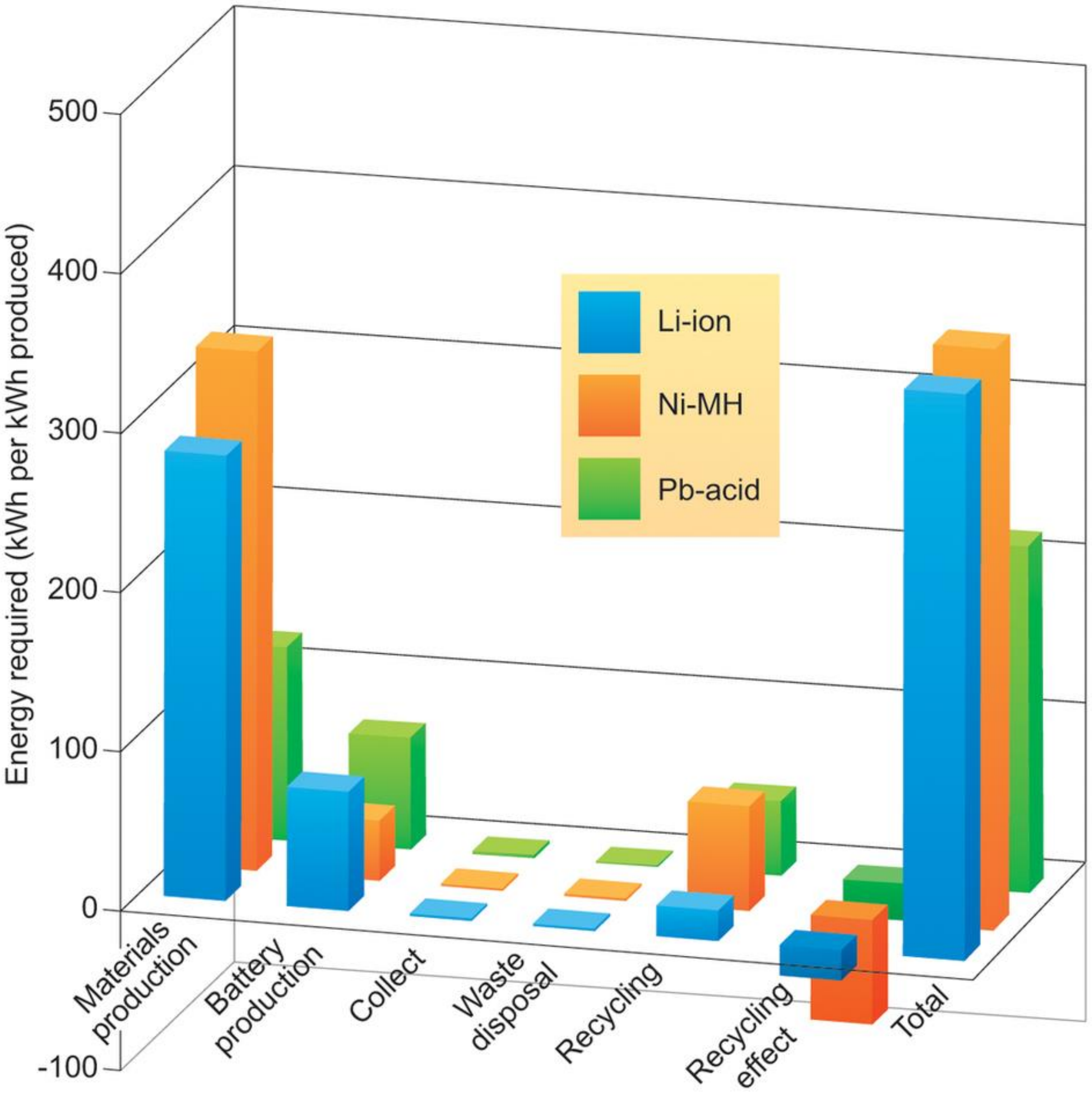

Figure 15: Energy required for the production of a 1 kWh electrochemical storage system (Source: Larcher and Tarascon, 2015, Figure 2)

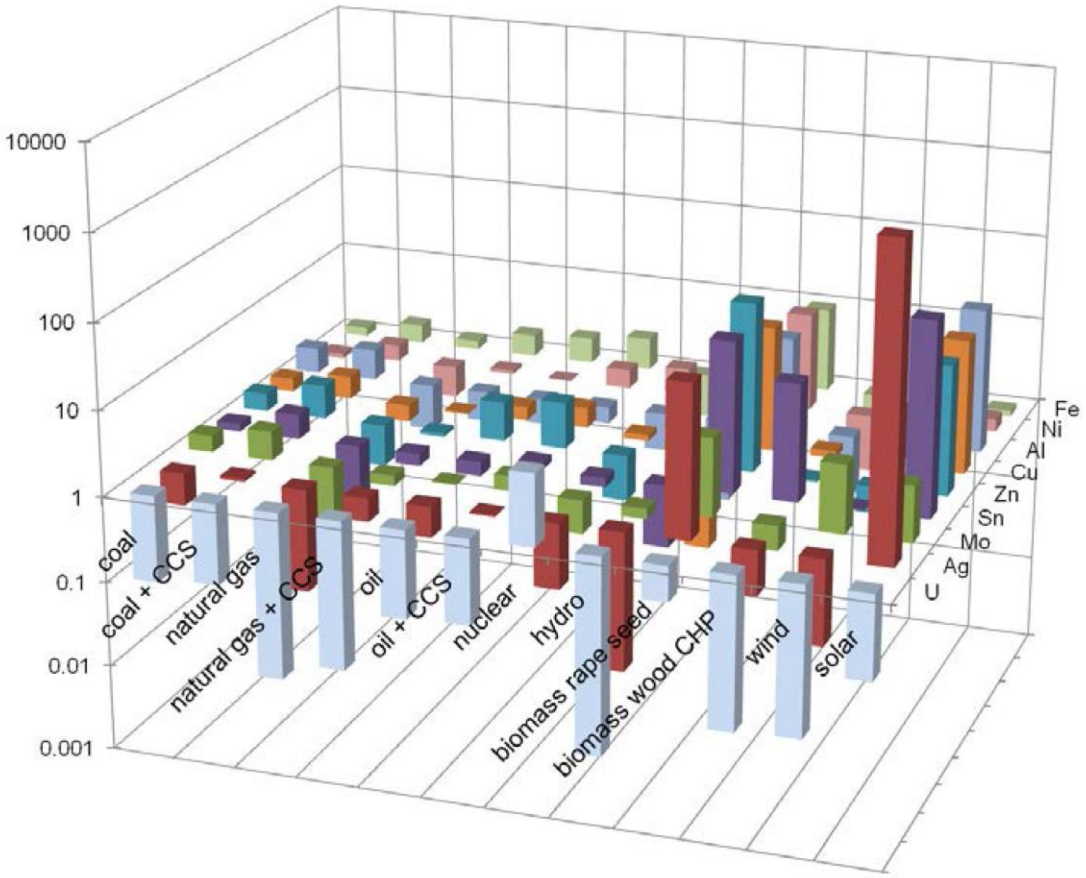

Figure 16: Requirements of selected metals in different power generation technologies relative to the metal demand of the current mix. (Source: Kleijn et al 2011, Figure 4).

“The equivalent to several hundred times current annual world production would be needed to build the required electrical power grid, wind turbines and hydrogen pipelines. For certain technologies, it is highly likely that materials requirements will hinder their scale up to significant levels (hundreds of Giga Watts, GW, worldwide) in the time frame available to address climate change (three to five decades). This is certainly true for thin-film cadmium-tellurium (CdTe) and copper-indium-gallium-selenide (CIGS) solar cells (ten to a hundred times current annual production); new efficient and low maintenance direct-drive wind turbines and electro motors that contain permanent magnets with neodymium and dysprosium (tenths of times current annual production for 100 GW installed capacity and 10% of produced cars); Proton Exchange Membrane (PEM) fuel cells that use platinum (Pt) as a catalyst (more than current annual production of Pt for 10% of annual car production); cobalt-containing lithium-ion batteries for electric cars (all current annual cobalt production for 10% of produced cars). The conclusions above are based on the up-scaling of current technologies. In many cases, alternative technologies are either available or being developed that are less likely to run into material constraints when scaled up to substantial levels. However, in many cases this might come at the cost of functionality or efficiency. Examples are neodymium-containing wind turbines and electro motors, indium and tellurium-containing thin-film photo-voltaic (PV) cells and copper-containing high voltage direct current (HVDC) power lines."

Two further studies conducted for the European Commission also looked into which metals would be most critical for a transition to low carbon technologies. The first study (Moss, 2011)[9] looked into the metal requirements for wind, solar (both PV and concentrated solar power, CSP), Carbon Capture and Storage, nuclear fission, bio-energy and the electricity grid, and identified 14 metals to be a cause for concern, and 5 as 'critical', after considering market and geopolitical concerns: tellurium, indium, gallium, neodymium and dysprosium. These materials are most linked to supply chains for wind and PV energy technologies.

A follow up study[10] included a larger range of low carbon technologies including fuel cells, electricity storage, electric vehicles and lighting. It investigated sixty metals, but excluded iron, aluminium and radioactive elements. "*Graphite was also included, reflecting its status as one of the critical raw materials identified by the EU Raw Materials Initiative*" (EC, 2011)[11]." Information technology found that eight metals are 'critical': "*These are the six rare earth elements (dysprosium, europium, terbium, yttrium, praseodymium and neodymium), and the two metals gallium and tellurium. Four metals (graphite, rhenium, indium and platinum) are found to have a medium-to-high rating and are classified as 'near critical', suggesting that the market conditions for these metals should be monitored in case the markets for these metals deteriorate thereby increasing the risk of supply chain bottlenecks.*" These materials are needed for electric vehicles, wind and solar energy, and lighting.

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FIGURES APPENDIX 1

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Appendix 2: Technology and Innovation: How resources are discovered and extracted

Introduction

The primary requirements for finding new mineral resources are: (i) a favourable geological environment likely to contain ore deposits (i.e., mineral occurrences are known to exist, or the terrain resembles other areas in the world known to host mineral deposits), and (ii) government policies and practices that make it attractive for companies to explore and mine. Once these conditions are met, it is up to the explorationist to discover the ore bodies.

In well-explored parts of the world, most easy-to-find near-surface deposits have already been discovered, and the average depth beneath the surface of new discoveries in well-explored regions has increased (Figure 18), particularly since the middle of the 20th century when geological, geochemical and geophysical methods that can "see" hundreds of metres or even kilometres beneath the surface were developed and applied (Figure. 18; Schodde, 2014)[1].

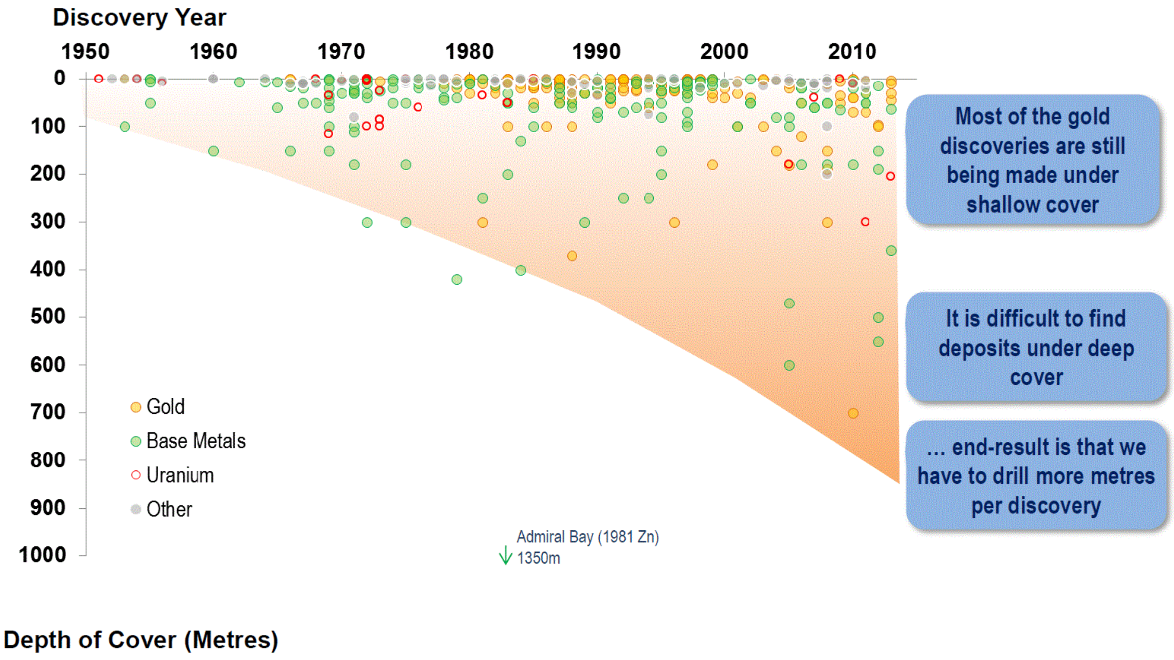
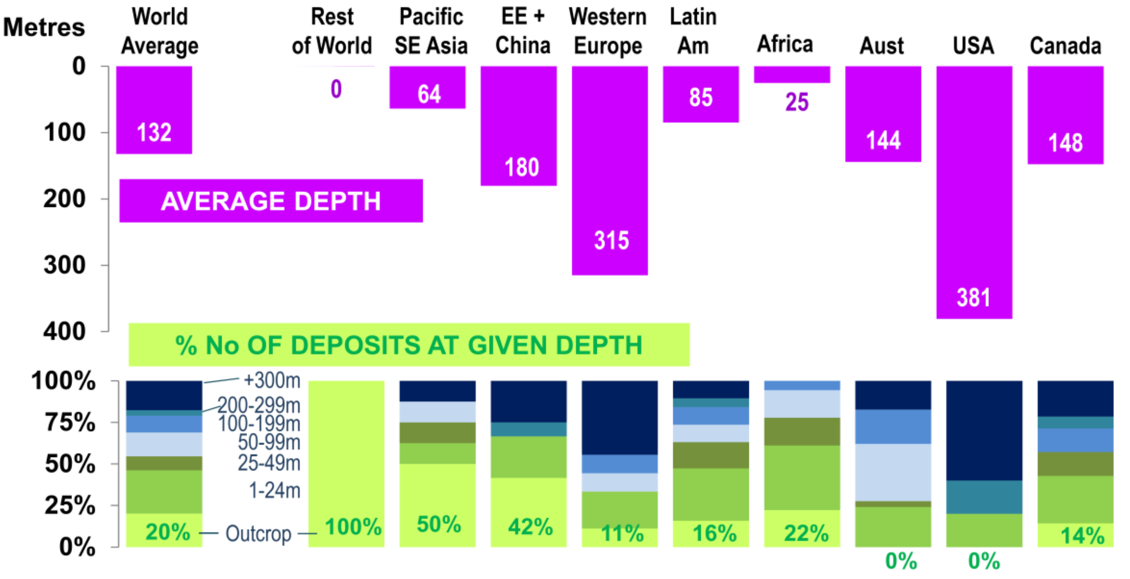


Figure 18: Change in the depth of discovery of gold, base metals, uranium and other deposits from 1950 to 2013 in Australia; it excludes satellite deposits within existing mineral deposit camps, and also bulk mineral discoveries; the analysis is based on moderate-, major and giant-size deposits (Schodde, 2014b).

In well-explored regions, such as Western Europe and North America, new mineral deposits are most likely to be found at greater depths or in regions with complex geological histories (Figure 20). Here advanced technology and expertise is needed. However, there are large regions with geological potential that are underexplored (notably in Africa and Asia) owing to security concerns, economic policies, unfavourable legal frameworks, or the lack of modern Mining Codes. Many regions with long mining histories, including large parts of Europe, have not been explored using modern methods. In these regions, current exploration technology could produce new discoveries, and advanced technologies could reduce costs and improve the success rate. New mineral treatment methods will allow metals to be extracted from rocks not previously considered as ore.



Note: Relative proportions were calculated on the number of deposits (not contained metal)

Source: MinEx Consulting © September 2014

Figure 20: Depth of cover for base metal discoveries in the World from 2005 to 2013 (Source: Schodde, 2014a).

Exploration

In order to establish whether a province or district has geological potential, explorationists require modern geological and structural maps, geochemical and geophysical data (for example, aeromagnetics and radiometrics) on a regional scale, as well as reports on past exploration and mining activity. These are normally provided by a government agency such as a Geological Survey. These products should be digitally available at a reasonable cost. The data should be in a format that allows the explorationist to re-process and interpret the data using modern tools and concepts.

Mining companies generally conduct exploration on project or prospect scale (typically areas 100's of kilometres to kilometres in size). The techniques used to locate drilling targets depend on the mineral that is sought, the cover rocks, and the scale of the survey. Airborne geophysical surveys, geological and structural mapping and regional geochemical surveys (Figure 21) are usually conducted first; followed by detailed geological, geochemical and geophysical surveys, drilling, and logging and assaying of core.

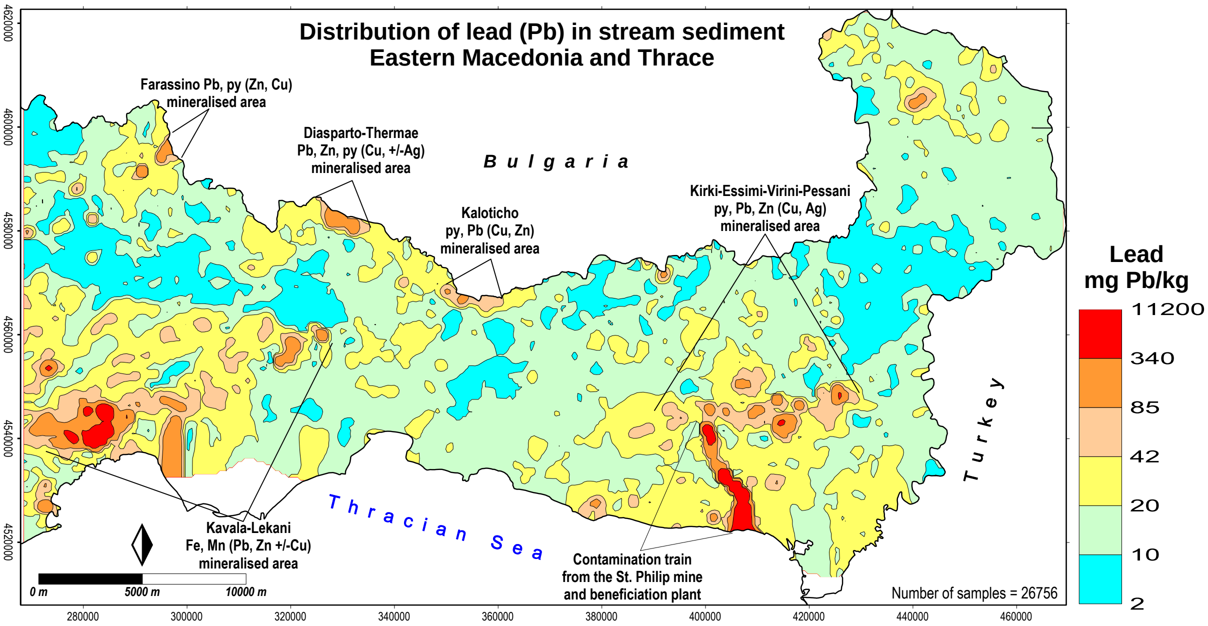


Figure 21: Map showing the distribution of lead (Pb) in the <0.180-mm fraction of stream sediment, Eastern Macedonia, and Thrace, N.E. Greece, and the delineation of potential base metal mineralised areas; sampling density about 2 samples per km^2 (Source: Demetriades, A., 2014, Fig 2, p4)

Currently most exploration is done by “junior companies” with little capital or long-term vision, rather than by the major mining companies. Many of the research centres that existed in major mining companies and universities during the 1970s-1990s have been closed. Consequently, the development of new ore genesis models, exploration concepts and techniques has slowed down.

In recent decades a wide range of exploration technologies have been developed that are able to map the surface and subsurface in greater detail and depth and at lower cost: for example, space-based navigation systems, such the Global Positioning System, airborne gravimetry, and 3D reflection seismology. These advances are well documented in the proceedings of the *International Conference on Mineral Exploration,* held in Canada every decade, first in 1967 and most recently in 2007. The proceedings of the 1997 and 2007 conferences can be downloaded at http://www.dmec.ca/. The next Decennial Mineral Exploration Conference (DMEC) is scheduled to take place in Toronto from 21-25 October 2017.

It is anticipated that advances in earth observation and exploration technology will continue. They are often driven by the oil and gas sector, space technology and the military, and subsequently adapted for use in mineral exploration. Increased support of mineral exploration research in mining companies, universities, geological surveys, consultancies and equipment manufacturers would likely accelerate progress.

Mining

Once an ore deposit is found, the viability of mining it is investigated. This depends on many non-geological factors that are outside of the control of the mining company, such as the existence of infrastructure (for example, railways, ports and electricity supply) and commodity prices. However, there have been major advances in mining and metallurgical technology over recent decades that have made it possible to mine more deeply and more cost-effectively; to treat ores with lower grades, and extract metals and minerals from materials that were not previously conducive to processing. However, viability also depends on many non-geological factors that are outside of the control of the mining company, such as the existence of infrastructure (for example, railways, ports and electricity supply) and commodity prices.

Deep mines have to deal with high rock stresses and temperatures. Technologies have been developed to mitigate the risk posed by rock bursting, to cool and ventilate mine workings, and to operate machinery remotely[2]. Equipment used in open pit mines has increased in size, bringing economies of scale. Doppler radar systems have been developed to continually monitor the stability of the pit wall.

Mining inevitably has an impact on the environment, which may sometimes be negative (for example, noise, dust and vibrations that may disturb wildlife and communities; pollution of ground water by acid mine drainage, reduction of agricultural potential). Deeper mines and low grade ore will require more energy to mine and increase competition for scarce water resources. Technology and adherence to guidelines has mitigated these impacts, and there is considerable scope to do even better. Increasing automation of mining techniques reduces costs and increases worker safety (but at the same time reduces employment). "Green mining" ideas are gaining traction, i.e., the notion that new mines will by necessity have less environmental impact.

Figure 22: Modern open-pit mining of iron-nickel laterite employing sophisticated blasting technology, large haulage trucks and Doppler radar systems to monitor slope stability, Agios Ioannis mines at Neo Kokkino, Larymna, Greece. Photo: A. Demetriades

Skilled Human Resources

Advanced technology is developed, operated and repaired by skilled people, and mineral-producing countries have expectations that their citizens should benefit from employment opportunities, thereby raising the standard of living and education, stimulating the economy and contributing to the tax base. There is an expectation that mining companies should play an active role in the development of skills by supporting colleges and universities, and through on-the-job training. A precondition to this, however, depends on the educational standards already present in a less developed country. Basic levels of education and training standards need to be in place before a company can provide the necessary step up to meaningful employment within the sector.

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FIGURES APPENDIX 2

(17) Change in the depth of discovery of gold, base metals, uranium and other deposits from 1950 to 2013 in Australia; it excludes satellite deposits within existing mineral deposit camps, and also bulk mineral discoveries; the analysis is based on moderate-, major and giant-size deposits (**Schodde, R.,** 2014b). Uncovering exploration trends and the future where's exploration going. Presentation to International Mining and Resources, 22nd September 2014, Melbourne. MinEx Consulting, Strategic advice on mineral economics & exploration

(18) Primary search method used at the project-scale in base metal discoveries of copper (>0.1 million tonne copper equivalent) in the world from 1900 to 2013 (Source: **Schodde, R.,** 2014a). The global shift to undercover exploration: How fast? How effective? Presentation, Society of Economic Geologists 2014 Conference, 30 September 2014, Keystone, Colorado. MinEx Consulting, Strategic advice on mineral economics & exploration. https://www.science.org.au/sites/default/files/user-content/3_shodde.pdf

(19) Depth of cover for base metal discoveries in the World from 2005 to 2013 (Source: **Schodde**, **R.,** 2014a). The global shift to undercover exploration: How fast? How effective? Presentation, Society of Economic Geologists 2014 Conference, 30 September 2014, Keystone, Colorado. MinEx Consulting, Strategic advice on mineral economics & exploration. http://www.minexconsulting.com/publications/Schodde%20presentation%20to%20SEG%20Sept%202014%20FINAL.pdf

(20) Map showing the distribution of lead (Pb) in the <0.180-mm fraction of stream sediment, Eastern Macedonia, and Thrace, N.E. Greece, and the delineation of potential base metal mineralised areas; sampling density about 2 samples per km^2 (Source: Demetriades, 2014, Fig. 2, p.4)

(21) **Demetriades, A.,** 2014, Fig. 2, p.4

(22) Modern open-pit mining of iron-nickel laterite employing sophisticated blasting technology, large haulage trucks and Doppler radar systems to monitor slope stability, Agios Ioannis mines at Neo Kokkino, Larymna, Greece. Photo: **Demetriades, A.,**

Appendix 3: The importance of geoscience data in attracting mining investment into Africa - Lessons from Namibia

Introduction

Mining has been the backbone of the Namibian economy for more than 100 years. In 2015, the country was named the number 1 mining investment destination in Africa according to the global survey by the Fraser Institute of Canada. It stands at number 25 globally. The mining industry in Namibia is attractive to mining investors, because of its extensive mineral deposits including diamonds, uranium, gold, copper, lead, and zinc, with good potential for the discovery of more. Mining contributes to about 58% of Namibia's exports and it is at 13%, the largest contributor to the national GDP. Namibia has a government that encourages foreign investment to stimulate the economy. The Namibian government is a stable multi-party democracy.

The Namibian government promotes mineral exploration and mining through sound legislation, a stable and competitive taxation framework, environmental and social demands that are balanced, progressive and clear with acceptance of international practices for capital markets and foreign trade. The State allows time to explore and develop, permits mineral rights to be used as collateral, with freedom to trade the minerals produced. The country provides good roads and communications and is currently upgrading its harbours. It offers a good standard of living for employees in the exploration and mining industry and is a popular tourist destination.

Mineral investment promotion in Africa

Africa as a whole has vast resources of mineral wealth. However, much of Africa remains under-explored and Africa received only 15% of global exploration expenditure in 2014. But mineral extraction is vital for economic development. In today's hi-tech world, mineral investors need access to good and digital geo-scientific data. These must be logically presented, well structured, comprehensive and easy to use. The Geological Survey of Namibia ensured that this African country gets a fair share of global exploration expenditure through excellent service provision to the exploration industry; it can therefore provide a role model for other countries. It has provided guidance and information to surveys throughout Africa and beyond.

Activities of the Geological Survey of Namibia

The Geological Survey of Namibia, the National Institute for Earth Science and Mineral Resources, is entrusted with management and research of one of our most important assets –

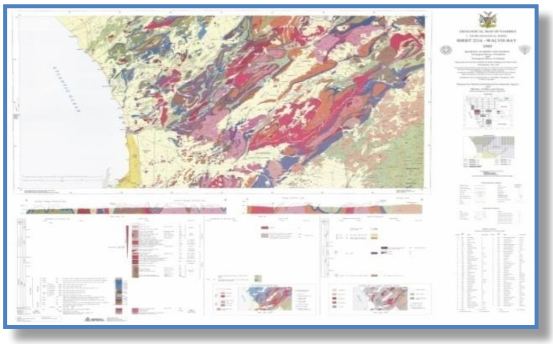
the Earth in which our life support system is rooted. Its mission is to enhance knowledge and awareness of Namibia’s geological resources. Through scientific investigation, as well as application and dissemination of quality research data, the Geological Survey of Namibia facilitates the search for, and the assessment of mineral resources, geological engineering and land use planning and sustainable development with due regard to the environment.

Investment in the minerals sector is promoted by:

- Obtaining and archiving historical data
- Building capacity and generating new data
- Providing a compilation of saleable products
- Marketing these products internationally
- Assisting other African countries to bring their Geological Surveys to an equal level

Maps

The Geological Survey of Namibia compiles digital geological maps from historical and recent data. Maps are available at different scales, which are important for the success of the Survey. Data are easily accessible at the Geological Survey and on their website.



Geochemical data

The Geological Survey of Namibia has well equipped laboratories that service all departments. In addition, Namibians in need, for example, small scale miners are assisted with analytical services.

Geochemical mapping is ongoing, using both historical archived data and new analyses. Every year one map sheet at 1:250 000 is sampled and XRF and ICP-MS data are acquired to be collated digitally.

Geophysical data

High resolution geophysical surveys now cover 98% of the country. This has promoted company expenditure on exploration, identified countless exploration targets, and led to the discovery of the world-class Husab uranium deposit with 267 Mlbs @

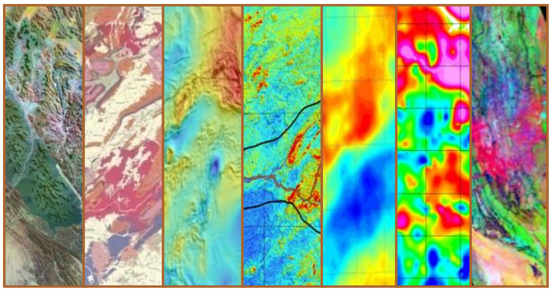
488 ppm U_3O_8. It will be the second largest uranium mine when in production, and will promote Namibia from 4th biggest world producer to 2nd.

Licences

The Ministry of Mines and Energy promotes exploration and mining through the services of a vibrant Geological Survey and the Directorate of Mining's efficient administration of modern mining legislation. They demonstrate best practice, by requiring companies to deposit data and core with the Geological Survey of Namibia. Information is moved into the public domain as soon as a licence has lapsed. Information of licence availability can be accessed via the website (Flexicadastre).

Data availability

The Survey, which is centrally located in Windhoek, provides a 'one-stop shop' where new and historical data can be studied, archived core examined and licences applied for at the Directorate of Mines in the same building. Digital data are available at low cost.



Budget and staffing

The Geological Survey of Namibia currently has 60 members of staff, more than half of which are professionals and the remainder support staff. Only one staff member is an expatriate. Professional staff members have obtained their first degree in either Namibia or abroad and higher degrees from outside the country. The operating budget is currently 30 million Namibian dollars from government per year (approx. US$ 3 million).

Appendix 4: Brazil - A case study in the responsible governance of resource revenues for economic and social development

According to the capital substitute rule, the rent (revenues) arising from the minerals industry, which is operating in the area of natural capital depletion, can be successfully used to increase other forms of capital - human, financial and man-made - thus investing into capabilities of current and future generations to meet their needs. Indeed, extraction of mineral resources leads to depletion of non-renewable resources and thus the minerals industry is often viewed as a sector that cannot contribute to sustainable development. Current human development cannot avoid primary extraction of mineral resources for the foreseeable future and many industrial sectors, infrastructures, energy generation, as well as electronics and green technologies firmly relate to further extraction of minerals resources. Thus, extraction of mineral resource can and should contribute to the sustainable development with a substantial shift in the global economic system that requires significant efficiency improvements, new technological development and changes in governance system over revenues for economic and social development.

Contributions from the minerals industry to regional economic development is often discussed in the context of direct economic impacts, such as foreign direct investment, taxation, royalties, foreign currency income, export earnings and employment, and secondary impacts, such as infrastructure development, local procurement, business development, technology transfer and skills upgrade. There are criticisms about the capacity of the minerals industry to rapidly shift economic growth in developing countries, such as the '*resource curse*'. 'The *'resource curse'* refers to the paradox that nations abundant with mineral resources tend to have less economic growth than countries with fewer mineral resources. Various economic reasons are attributed to the cause of this problem, such as corruption, misuse of revenues, Dutch disease, an ineffective taxation system, price volatility and excessive borrowing.

Major questions concerning fair distribution of revenues arising from the minerals industry for regional economic and social development revolve around several key points, such as transparency of payments and revenue movements between the minerals industry and government spending; catchment of mineral rents and planned distribution for economic and social needs in the regions, and consistent policies for current and future generations spending relying on mineral sector revenues. Several mechanisms exist for reinvestment of mineral revenues into regional economies. One of the most promising initiatives for minerals producing nations to invest the surplus of revenues from mineral production for future generations is a development of sovereign wealth funds, following the examples of oil producing nations in the Gulf and Norway.

Further, the governance of mineral revenues should consider fair distribution of resources to causes, such as poverty alleviation, health and education initiatives in regions that are most affected by psychical impacts from mining. The mining industry needs to strengthen its commitment to sustainable development. Alternative strategies need to be developed in areas of stakeholder engagement, risk management, closure arrangement, sustainable livelihoods and cooperation among the State, public and private sectors for development.

RENT DISTRIBUTION FROM MINERALS INDUSTRY – The Brazilian and Namibian Case

A new Brazilian mineral bill has been under discussion at the National Congress since 2013, and is receiving many amendments due its sensitive nature and is a delicate conjunctural moment for both the mineral commodities market and as national policy. However, there is no question about the fundamentals of mineral royalties, particularly their distribution that benefit mainly the mining city. This policy was established by Federal Constitution in 1988 and stipulates that although the mineral goods belong to the Federal Government, States and Municipalities have the right to share the benefits related to Financial Compensation for Mineral Exploration Assets (CFEM), i.e., the mineral royalty.

The CFEM is a portion of mineral rent, and its rate varies from 1 to 3% of the net revenue (gross sales less transportation insurance and taxes expenses) of each mining sales. The amount collected is distributed among the three government levels: Federal (12%), State (23%) and Municipal (65%). There are many suggestions in the bill for changes in the calculation base (to gross sales instead of net revenue), rates (to increase to 4%), and criteria of distribution in order to include impacted non-mining cities at the border of the city with mineral activity, but there are no questions about legitimacy of the mining city receiving the lion's share of the royalty.

For some mining cities, this benefit reaches almost 40% of municipal finances. Such distribution represents a unique opportunity for dependent mining cities to receive funds for strengthening and diversifying their economies. Nevertheless, Enríquez (2007) has found that most municipalities misuse these resources and one of main causes is the lack of enforcement mechanisms that can induce a good use of this revenue. She concluded that social pressure and the force of law has been the principal difference between the good and the bad use of these royalties.

A fair share of mineral rent must be considered as an important mechanism to induce a social acceptance, mainly, in remote cities with high level of poverty. In this vein, some Brazilian States only grant the environmental licence for a mineral project if it assumes the compromise to implement a Local Development Fund (around 1% of all investment), independent of other licence conditions, in order to strengthen the local economy and, consequently, reduce societal pressure over the mineral project, in turn reducing the mining cities dependency on mineral revenues.

The distribution of mineral diamond rent in Namibia is quite impressive - 50% of the project belongs to the government and 50% to private company in a public-private model, royalties are 10% on gross sales, in addition to payment income tax around 30%. The level of state participation, for example, shareholding, royalty shares and any other types of additional income tax payments are dependent on the value of the commodity, and may work for only highly profitable minerals, such as diamonds and may otherwise act as an impediment to project development.

In Brazil, as in Namibia, the first level of mining towns and the second at the country, the big question that arises is: how well mining income is used to bridge the gap between an impermanent and volatile income stream and an economic activity that can be perpetuated through time, in a sustainable way?

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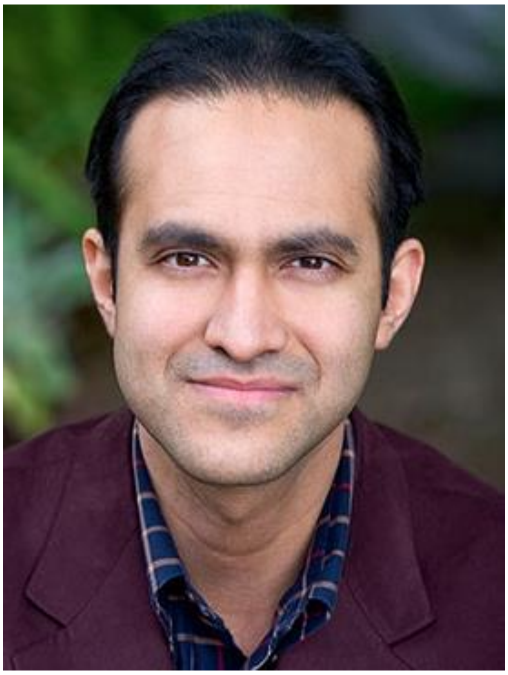
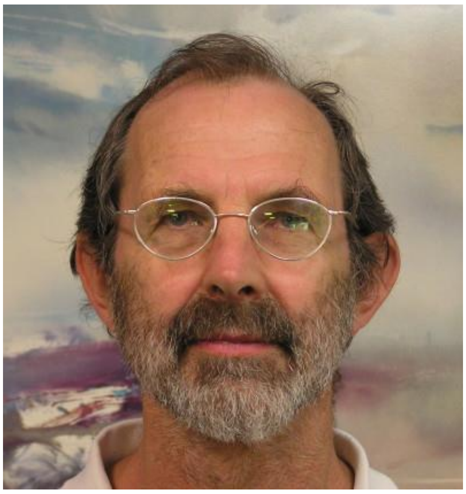


Saleem is the Director of the Centre for Social Responsibility in Mining (CSRM) at the University of Queensland, Australia. He leads the University of Queensland's Rare Earths Minerals Consortium and is also working with the Australian Department of Resources, Energy and Tourism on the evaluation of the Extractive Industries Transparency Initiative. His current industrial engagement includes serving as a lead advisor on social investment for Vale Malaysia in partnership with JK-Tech. Previous positions include Professor of Environmental Studies and Director of the Institute for Environmental Diplomacy at the University of Vermont. His most recent book is *Treasures of the Earth: Need, Greed and a Sustainable Future* (Yale University Press, 2010).

Nick ARNDT



Nick is Professor at Institut des Sciences de la Terre, University Joseph Fourier, Grenoble France, and has previously held positions at the University of Rennes, the Max-Planck-Institut and the University of Saskatchewan. His research interests include the petrology and geochemistry of volcanic rocks and magmatic ore deposits. He is a Fellow of the Geochemical Society and a senior member of the Insitut Universitaire, France.

Graham BROWN

Graham is a consulting Geologist formerly of Anglo American where he was Group Head of Geosciences and Exploration, responsible for geosciences governance and exploration activities across the Anglo American Group.

Graham holds a B.Sc. from the University of Strathclyde and an MSc from James Cook University. He has been a Fellow of the Society of Economic Geologists since 1999, participated in the Colombia Senior Executives Program in 2004 and the Duke Business Leaders Program in 2007. In 2011 he was the recipient of the PDAC Thayer Lindsley Award.

Recent exploration discoveries made by his team include; Boyongan and Bayugo (Cu-Au) in Philippines, Morro sem Bone and Jacaré (Ni) in Brazil, Gamsberg East (Zn) in South Africa, Gergarub (Zn) in Namibia, West Wall, San Enrique Monolito and Los Sulfatos (Cu-Mo) in Chile, and Sakatti (Cu-Ni) in Finland

Alecos DEMETRIADES

Alecos holds a B.Sc. (Hons) degree in Geology from the University of London, and a M.Sc. in Mining Geology and Mineral Exploration with emphasis in Applied Geochemistry from the University of Leicester. He has worked at Rio Tinto Finance and Exploration Limited as a researcher for the compilation of a global mineral deposits inventory, and as a consultant and trainer in applied geochemistry for mineral exploration purposes. Since, 1976 he has worked at the Institute of Geology and Mineral Exploration (I.G.M.E.) as a geologist/applied geochemist and has managed many exploration geochemical and environmental geochemistry projects. From 2009 until his retirement in November 2011 he held the post of Director of the I.G.M.E. Division of Geochemistry and Environment. Since 1986 he has represented I.G.M.E. in different groups of the former Western European Geological Surveys (WEGS) and Forum of European Geological Surveys (FOREGS) and currently the Association of the Geological Surveys of Europe (EuroGeoSurveys). He is still an active member of the EuroGeoSurveys Geochemistry Expert Group. He holds the post of treasurer to the IUGS/IAGC Task Group on Global Geochemical Baselines, and the chair of the Sampling Committee. He is author to more than ninety publications, an Associate Editor of the Journal of Geochemical Exploration, and a reviewer to many other geoscientific journals.

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Ray is South African Research Chair in Exploration, Earthquake & Mining Seismology and holds a with joint appointments in the School of Geoscience, University of the Witwatersrand and the Natural Resources and the Environment Unit, Council for Scientific & Industrial Research (CSIR). He is a member of the IUGS New Activities Strategic Implementation Committee charged to develop the Resourcing Future Generations Initiative, the South African National Committee for the IUGG, the ICSU Regional Office for Africa Science Plans Steering Committee, and the International Geological Congress 2016 Scientific Programme Committee. He is Co-director of the AfricArray research and capacity-building program and Principal Investigator of the Japan-SA collaborative project "Observational studies in South African mine to mitigate seismic risks".

Maria Amélia ENRÍQUEZ

Maria Amelia Enriquez is an economist who holds a PhD in Sustainable Development from the University of Brasília. She is a professor and a researcher in the faculty of economics at the Federal University of Pará State. Since 2009, Amelia has been an International Resource Panel Member of the UNEP participating in the Working Group on Metals, Trade and Decoupling

She is the national director of the Brazilian Society for Ecological Economy (ECOECO). She was also an economic advisor at the Ministry of Mines and Energy (MME) during the period 2008-2011. She was the president of the Brazilian Society for Ecological Economics (ECOECO) from 2008 to 2011.

Currently, Amelia serves as the Deputy Secretary of Commerce for the Bureau of Industry and Mining in the State of Pará (Brazil).

Amelia is also a council member of the Brazilian Mineral Magazine and author of the book: Gift or Curse: The Dilemmas of the Developing Regions of Base Minerals (São Paulo: Editora Signus). In 2012 she received the title of Economist of the Year by the Economist Syndicate of Para.

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Damien is Associate Professor and Research Director for Resource Futures at the Institute for Sustainable Futures, University of Technology Sydney. He holds Bachelor degrees in Science and Chemical Engineering from the University of Melbourne and a PhD on the life cycle impacts of copper production from the University of Sydney, Australia.

His research team has been active in modelling future mineral supply and working with stakeholders to develop Vision 2040: Innovation in mining and minerals. He is currently leading the Wealth from Waste Cluster, a research collaboration focussed on opportunities to recover value from urban stocks of metals in the circular economy.

Damien was Chair of the Sustainability Committee of the Australasian Institute for Mining and Metallurgy and in 2015 co-chaired the World Resources Forum Asia-Pacific.

Judith KINNAIRD

Judith is an Associate Professor of Economic Geology in the School of Geosciences and Director of the Economic Geology Research Institute, University of Witwatersrand. She was awarded an Honours BSc degree from the University of London, an MSc and PhD from the University of St. Andrews in Scotland, for research on tin-tungsten and columbite-bearing granites in ring complexes in Nigeria. She has taught for the Open University in UK and University College Cork in Ireland where research studies focussed on zinc-lead and copper deposits in Ireland.

In 1999 she was appointed a research fellow in the School of Geosciences at the University of the Witwatersrand and after two years she joined the Economic Geology Research Institute (EGRI) to focus on ore deposits in Namibia, Botswana, Zambia, DRC and South Africa. As Director of EGRI she leads several research teams.

She has been an Honorary Visiting Professor at Birmingham University in UK and University College Dublin in Ireland. She is a member of the UK Institution of Mining and Metallurgy since the 1970's, is a Chartered Engineer, a Fellow of the Geological Society of South Africa and recipient of the Des Pretorius award, a Fellow of the Society of Economic Geologists (SEG), was a Regional Vice President and Councillor and is current President of the SEG

Anna LITTLEBOY

Anna is a Research Director at the Commonwealth Science and Industry Research Organisation (CSIRO) – Australia in where she leads research exploring the future of the Australian minerals sector given the trends shaping the world today. She sits on the Executive of CSIRO's $100 million/year Mineral Resources National Research Flagship. With a background in geochemistry, Anna has more than 20 years research management experience studying risk for the water, energy and resources sectors. Her current focus is on assessing the social and environmental impacts of innovation to inform long term investment decisions. She has established influential initiatives at the interface where science informs policy and is currently working with the Queensland Government on Resources - a 30 year strategic vision for Queensland's resources.

Fabio MASOTTI

Fabio holds a degree in Geology from the Federal University of Minas Gerais, Brazil, and a postgraduate degree in Business Management with Fundação Don Cabral. Fabio has over 22 years of professional experience, mostly with Vale, initially in mineral exploration and mining project development and subsequently in strategic planning, business development and management roles. Fabio has worked in a variety of minerals and in several countries around the world. In 2004, Fabio established Tethys Mining LLC, a wholly owned subsidiary of Vale in Mongolia, acting as the company's Managing Director. In late 2005, he was appointed Regional Exploration Manager for Vale, Australasia Region, based in Brisbane, Australia, from where he became responsible for the establishment of a mineral exploration program for Vale in Australia and East Asia. Subsequently he was appointed as Exploration Director for Africa, Europe, Asia and Oceania, based in Brisbane (2008 to 2011) and Exploration Director Americas, based in Brazil. In his current role of Executive Manager Exploration, Fabio oversees Vale's multi-commodity greenfield exploration program outside Brazil.

Larry MEINERT

Larry is head of the Mineral Resources Program at the United States Geological Survey where he is responsible for leading the research, assessment, and information-gathering functions of more than 300 scientists. Previously he had a successful academic career spanning three different universities where he managed research laboratories and advised dozens of postdoctoral scientists and PhD, MS, and BS students engaged in mineral resource research, funded by NSF and private industry. He has more than 170 peer-reviewed publications and is chief editor of the leading international scientific journal in this field, Economic Geology. He earned a PhD degree in geology from Stanford University and B.A. from Carleton College. He has worked as a consultant for major mining companies in more than 50 countries.

Edmund NICKLESS

Edmund is the chair of the IUGS, New Activities Strategic Implementation Committee, charged with developing the Resourcing Future Generations Initiative. He is currently the Executive Secretary of the Geological Society of London. Previously he held senior posts within the British Geological Survey, the Natural Environment Research Council and the Cabinet Office, Science and Technology Secretariat.

Daniel NYANGANYURA

Programme specialist at ICSU Regional Office for Africa.

Daniel currently holds the position as a Programme Specialist for Physics, Mathematics and Engineering Sciences for the International Council for Science (ICSU) Regional Office for Africa (ROA); he holds a PhD in Atmospheric Physics, MSc in Agricultural Meteorology, BSc 4th Year Honour in Physics, and Licentiate Degree in Education in the Specialty of Physics and Astronomy

He has worked as a post-doc research fellow at Max Planck Institute for Chemistry in Mainz, Germany (Aug 2007-Jul 2008), served as a Physics Lecturer (2001-07) and teaching assistant in the Department of Physics (2000) at the University of Zimbabwe, Biophysics Lecturer at the Zimbabwe Open University, Zimbabwe (2000-03), and as an Environmental Science Lecturer (Bindura University of Science Education, Zimbabwe (2004), Advanced Level Physics and Computer Science Teacher at Gokomere High School, Zimbabwe (1991-98).

Roland OBERHÄNSLI

Roland is Professor of Mineralogy at the University of Potsdam, Germany, and the President of the International Union of Geological Sciences. Previous positions include professor of geochemistry at the Johannes Gutenberg University in Mainz, Germany, chair of Mineralogy at Potsdam University, and teaching positions at University of Neuchatel in Switzerland, University of Ouro Preto in Brazil and La Sapienza in Rome He was Dean of the faculty of science at Potsdam university, elected reviewer of the German Science Foundation (DFG), Chief Editor of the European Journal of Mineralogy and member of the Science Advisory Group of the International Continental Drilling Program (ICDP). His research interests encompass high-pressure metamorphism and geodynamics with related focus on the influence of bulk composition on mineral associations, high-pressure metamorphism in granitoid systems and low-grade high-pressure metamorphism of metapelites. He was awarded the Gay-Lussac – Humboldt prize in 2005.

Janet SALEM

Janet joined the ROAP in August as Programme Officer for the SWITCH Policy Support Component, where she coordinates policy support, capacity building and outreach on Resource Efficiency and Sustainable Consumption and Production. Before joining ROAP, she worked with UNEP DTIE in Paris in the Secretariat for the International Resource Panel, a science policy interface on resource issues. There she was the focal point for two technical working groups covering decoupling resource use from economic growth, and environmental impacts of products and materials. Before joining UNEP, Janet working with the United Nations Industrial Development Organisation, where she supported the Energy and Environment Branch in both technical project development and implementation in renewable energy and energy efficiency in the industrial sector and global forum activities, including coordination of the UNIDO contribution to the Global Energy Assessment on industrial energy efficiency, and UNIDO’s chairpersonship of UN-Energy, an initiative aiming to coordinate the UN’s energy activities. Prior to working with the United Nations, Janet worked with University Institutes and private sector consulting in the area of environmental assessment tools, in particular Life Cycle Assessment and Materials Flow Accounting. Janet holds a Bachelor's degree in Environmental Engineering and a Master's degree in Engineering Science from the University of the New South Wales (Australia).

Gabi SCHNEIDER

Gabi holds an MSc in Economic Geology from the University of Frankfurt, where she also obtained her PhD in the Faculty of Earth Sciences in 1984. She was appointed Director of the Geological Survey of Namibia in 1996. Her professional experience covers economic and exploration geology, mineralogy and geochemistry as well as management and administration.

Dr Schneider is the President of the Organisation of African Geological Surveys, the Vice Chairperson of the Environmental Investment Fund of Namibia; a Director of the Minerals Development Fund of Namibia; the Vice Chairperson of the Board of Trustees of the Namibian Institute for Mining and Technology (NIMT); a member of the Sustainable Development Council of Namibia; a member of the Benguela Current Commission; a member of the Commission for the Implementation of the World Heritage Convention in Namibia, chairing its Technical Subcommittee; and a member of the Scientific Committee of the National Heritage Council. She serves as a non-executive director of Anglo Gold Ashanti Namibia and is a founding member of the Small Miners Association of Namibia. In the past, she also served as a Director of the National Petroleum Corporation of Namibia (NAMCOR); as a Director of the Small Miner's Assistance Centre; as a presidential appointee on the Council of the University of Namibia and its Executive Committee; and as a member of the National Heritage Council of Namibia, where she also held the post of Chairperson of the Scientific Committee.

Natalia YAKOVLEVA

Natalia is a Senior Lecturer in International Business Strategy in Newcastle University London. She has a Degree in Economics and PhD in Environmental Studies. She worked as a Researcher in Business Relationships Accountability, Sustainability and Society Research Centre at Cardiff University. Then moved to the University of Winchester as a Senior Lecturer in Sustainable Development, and was later promoted to Reader. She worked as a Senior Lecturer in International Business in the University of Surrey. In 2013, she served as a Secretary of the UK and Ireland Chapter of United Nations Principles of Responsible Management Education (UN PRME).

Natalia specialises in research on sustainable responsible business practices, especially exploring corporate social responsibility and corporate-community relations. She has an extensive research experience in the field of social and environmental implications of extractive industry operations, examining issues of conflict, participation, indigenous peoples' rights and community development. She is an author of Corporate Social Responsibility in the Mining Industries, Ashgate, 2005. Currently, Natalia is a member of the editorial board of The Extractive Industries and Society (Elsevier).

DAY VISITORS

Daniel Kali

Daniel serves as the Independent Non-Executive Chairperson and Director of Namdeb Diamond Corporation (Pty) Ltd., De Beers Marine Namibia, Namibia Diamond Trading Company (NDTC), Namdeb Properties (Pty) Ltd. and Namibia Institute of Mining and Technology. Mr. Kali holds a Bachelor’s Degree in International Relations.

Veston Malango

Veston is the Chief Executive Officer of the Chamber of Mines of Namibia. He is a Mining Engineer with a M.Sc. Degree from the Technical University Bergakademie Freiberg, Germany and is also a qualified Gemmologist with Diplomas in Diamond Grading and in Coloured Gemstones from the German Gemmological Training Centre in Idar-Oberstein, Germany. He holds an MBA from the Maastricht School of Management, The Netherlands. He is a member of the Engineering Council of Namibia since 1996.

Mr. Malango has vast experience in the mining industry in Namibia and the SADC region. He worked as Deputy Director of Mines at the Ministry of Mines and Energy for 8 years and then joined Ongopolo Mining & Processing Ltd, now Weatherly Mining Namibia for 18 months as the Director responsible for strategic projects. He was appointed General Manager of the Chamber of Mines in October 2005 and in 2012 the position was changed to Chief Executive Officer.

Obeth Kandjoze

He became the Minister of Mines and Energy in March 2015. Obeth is the Managing Director of the National Petroleum Corporation of Namibia, NAMCOR.

He studied at the University of Cape Town in South Africa as well as at the University of Helsinki (Finland) in the field of geosciences and graduated with a Bachelor of Science at UCT and a Master of Sciences (geology and chemistry) in Finland.

He has previously worked for the Geological Survey of Namibia as a field geologist and from 1995 to 1997 he worked at the Australian Gold Exploration company TransContinental Resources serving as Country Exploration Manager.

Obeth is a member of the American Association of Petroleum Geologists. He is also a member of the Society of Exploration Geologists, the Geological Society of Namibia, a member of the Government Negotiation Technical Team (GNT) and a board member of the National Energy Council (NEC).

L-R: Gabi Schneider, Edmund Nickless, Obeth Kandjoze, Roland Oberhänsli, Veston Malango

RFG Workshop, GocheGanas, Namibia, July 2015.