RESOURCING FUTURE GENERATIONS

Draft White Paper

IUGS' New Activities Strategic Implementation Committee

INTRODUCTION

The International Union of Geological Sciences (IUGS; www.iugs.org) believes that it is important to develop, with other interested parties, a major new initiative with the challenging long-term goal of ensuring a supply of mineral, energy and water resources for the global society for the next century.

This initiative – called *Resourcing Future Generations* (RFG; Lambert et al., 2013) – is a response to the recommendations of the IUGS 2012 Strategic Report and the final report of the Global Geoscience Initiative, both of which recognised that population growth and the aspirations of less developed nations mean a priority is to secure new mineral, energy and water resources for future generations, while meeting the environmental and social imperatives for sustainable development. It is intended to involve researchers, academics, government agencies and industry globally.

IUGS believes it is the logical organisation to develop such an ambitious initiative because it:

- offers global geographic coverage and influence through its many country members (approximately 120);
- represents the international geoscience community;
- provides coordination and seed funding for international geoscience research and training programs, (including through the IUGS-UNESCO International Geoscience Program (IGCP) and Geological Applications of Remote Sensing (GARS) programs;
- develops international geostandards;
- has links to expertise in a range of disciplines (geophysics and geodesy, social sciences, material sciences, remote sensing, geoengineering, health, etc.) through membership of the international Council for Science (ICSU; www.icsu.org).

The Union does not have in-house research staff to conduct RFG activities. Rather, it will call on IUGS' international membership and affiliated groups to facilitate collaborative programs. IUGS has envisaged appointing a small leadership panel to drive different elements of RFG; involving other disciplines including social and material scientists; providing coordination where appropriate; helping identify gaps in knowledge and capacity and ways to fill these; and representing the geosciences at forums discussing future global remote sensing platforms.

While it is intended RFG will eventually cover energy and water, this White Paper focuses on the mineral resource activities. There are critical and challenging issues associated with water and energy and it is planned that these should be considered in detail once the minerals component of RFG is initiated.

IUGS' concept

It is intended that RFG will identify and address the key challenges involved in securing the natural resources to meet global needs post-2030. The scale will be regional (pre-competitive), the duration at least 5 years, and the coverage global but with emphasis on less developed countries, which will continue to have increasing roles in supplying and using natural resources.

RFG will supplement current largely uncoordinated programs, which mainly have a more immediate focus, but it will emphasise new programs. It will have a staged approach and be designed to:

- conduct research on supply and demand over the very long term;
- generate new opportunities and synergies through providing an over-arching framework linking disparate but related studies;
- identify and pursue new opportunities for research, training and capacity building;
- promote new public good geoscience surveys and arrange access to major archived datasets;
- help drive technology advances by participating in decision making forums;
- develop multi-disciplinary approaches;
- promote understanding of the benefits from responsible development of resources and ways to minimise lasting impacts;
- attract development funding through activities of broad societal importance.

RFG will be based on geoscience expertise and participation as appropriate in geoscience research priorities, but it will not be just another Earth science exercise. IUGS will bring a multi-disciplinary approach, particularly through its parent organisation, the International Council for Science (ICSU). It is hoped that the major social sciences components of RFG will form part of the major new ICSU-led initiative, *Future Earth* (http://www.icsu.org/future-earth).

Scoping mineral resources component of RFG

The Union has established a New Activities Strategic Implementation Committee (NASIC) to scope RFG and the roles of interested parties in more detail. NASIC comprises the authors of this report, who bring broad knowledge and strategic vision:

- Edmund Nickless (Executive Secretary, Geological Society of London), will be Chair;
- Ian Lambert (Secretary General of the IUGS) will present views from Australasia and be the principal IUGS contact for NASIC;
- John Ludden (Executive Director of the British Geological Survey) will represent the views of geosurveys and related bodies;
- Neil Williams (former CEO of Geoscience Australia and Honorary Professorial Fellow, University of Wollongong) will provide an economic geology, and small to medium sized company perspective;
- Roland Oberhaensli (Professor, Department of Earth and Environmental Science, University of Potsdam and President of IUGS) will provide an academic perspective and link with the International Council for Science (ICSU).
- Marcio Godoy (Global Director Exploration and Project Development, Vale) will represent large industry and South America;
- Pat Leahy (Executive Director, American Geosciences Institute) will bring perspectives from the US, Canada and Mexico;
- Wang AnJian (Chinese Academy of Geological Sciences) will bring a perspective from China, which is a major driver of the rapidly increasing demand for mineral and energy resources, and central and Eastern Asia more broadly;

- Mxolisi Kota (CEO Council for Geosciences, South Africa) will provide an African perspective;
- Ray Durrheim (Research Chair in Seismology at the University of Witwatersrand and CSIR Centre for Mining Innovation, and Co-director of AfricaArray) will provide geophysical, capacity building and training inputs.

In May 2013, IUGS charged NASIC with:

- developing a visionary report by mid-October 2013 setting out a roadmap of opportunities in technologies, geological understanding, and training and capacity building;
- and addressing threshold questions on the viability of RFG, gaining widespread support and leadership options.

To this end, each member of NASIC engaged a small consultative group of their choosing to maximise the information and perspectives available to the committee.

This White Paper has been drafted by NASIC to provide background and discussion supporting its initial report to IUGS, which is a more concise document summarising the main opportunities for RFG as discussed herein, and answering threshold questions relating to the viability and leadership of such ambitious initiative RFG, and gaining support for it. The intention is that this White Paper [and the initial draft NASIC report to IUGS???] will be distributed to interested parties for feedback, which will be taken into account by NASIC in preparing its final RFG report to IUGS.

After considering the IUGS concept, NASIC agrees that RFG is worthy of development as a long-term initiative with a staged approach. While RFG should eventually cover energy and water resources, NASIC recommends that minerals activities should be the initial focus. Accordingly, this White Paper concentrates on the mineral resources component of RFG. It firstly discusses the challenges in sustaining supplies of mineral commodities to meet future needs, before outlining and discussing the four major themes that NASIC proposes for RFG:

(i) Future supply-demand;
(ii) Mineral potential evaluations of under-explored regions;
(iii) Enhanced understanding of the subsurface; and
(iv) Capacity building and socioecomomic considerations.

It includes case studies(?) derived from abstracts of presentations invited by IUGS for the Geological Society of America Pardee Keynote Symposium P12, Denver, 29 October 2014.

The final section brings together the NASIC recommendations and their implementation.

PROBLEMS IN RELATION TO SUSTAINING MINERAL COMMODITY SUPPLIES

Throughout human history, societies have used mineral commodities to support their daily activities. As societies have become more sophisticated the consumption of mineral commodities has not only grown, but also diversified. Whereas Stone Age societies used commodities such as flint to manufacture arrowheads for hunting and defence, and ochres for decorative purpose, today we consume massive quantities of a wide range of mineral commodities in the construction of buildings, roads and bridges, in the production and transmission of energy, in transport, and in a myriad of tools and electronic devices.

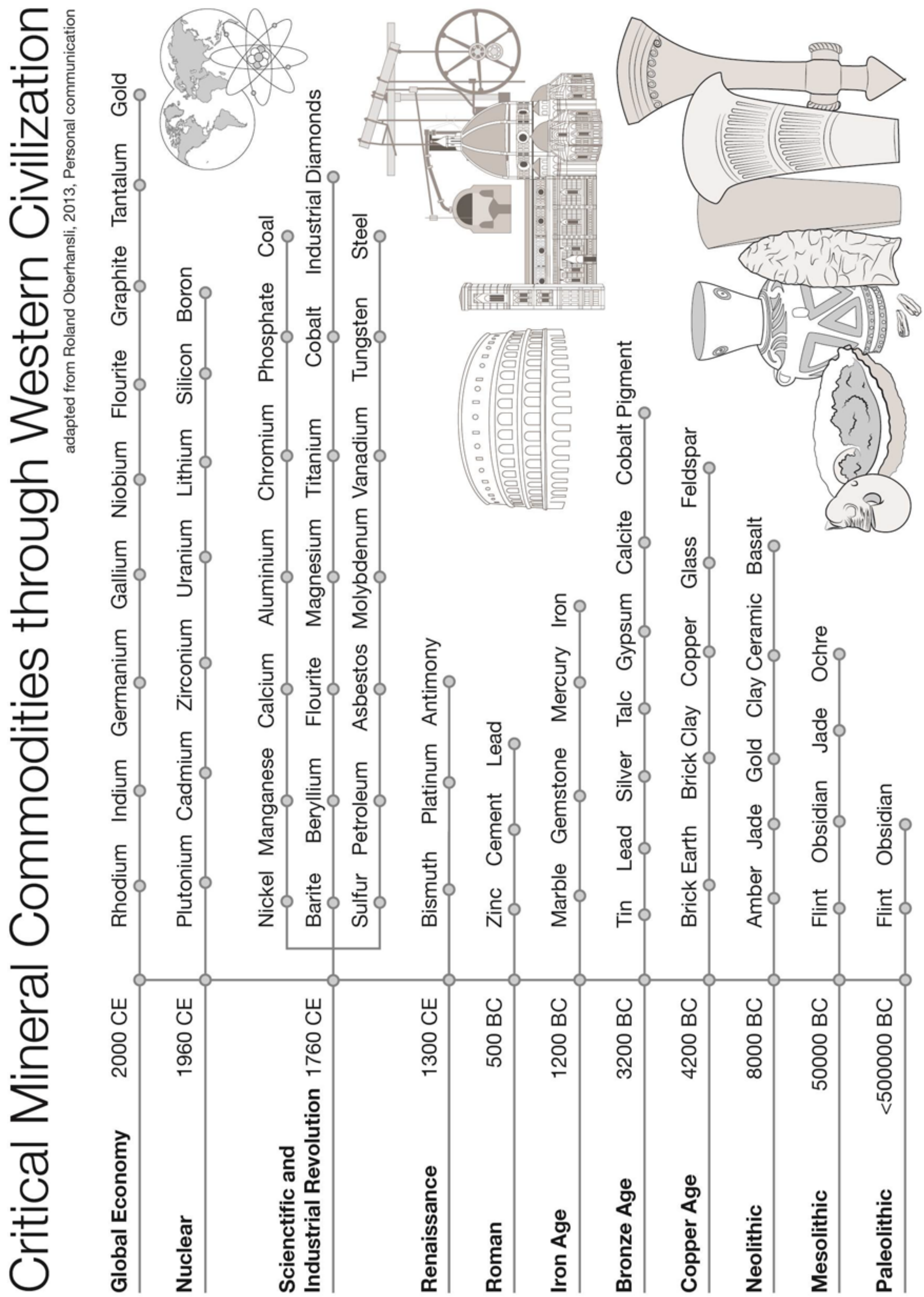

Figure 1. Critical Mineral Commodities through Western Civilization

The discovery of new resources of mineral commodities, coupled with increasing recycling, improved efficiency of use, and substitution of one commodity in place of another has been broadly adequate to meet demand to date. However, the unprecedented growth in demand for some commodities over the past decade has caused pressures on the supply chain, which have resulted in the prices of the sought after commodities rising to their highest levels ever, in 2012. In addition, these pressures have also created critical dependencies on unstable sources of supply for some important commodities, creating political tensions.

These price rises have raised concerns about the future supplies of commodities in high demand. High prices make it more difficult for many countries to afford the commodities necessary for development. Other concerns are:

- the decreasing land area accessible for exploration and production as more land is tied up around the world for housing, feeding and servicing people and sustaining natural systems
- the importance of securing supply including through multiple source regions for key commodities
- the falling rate of discovery of large mineral deposits over the past quarter of a century, despite high levels of exploration expenditure.

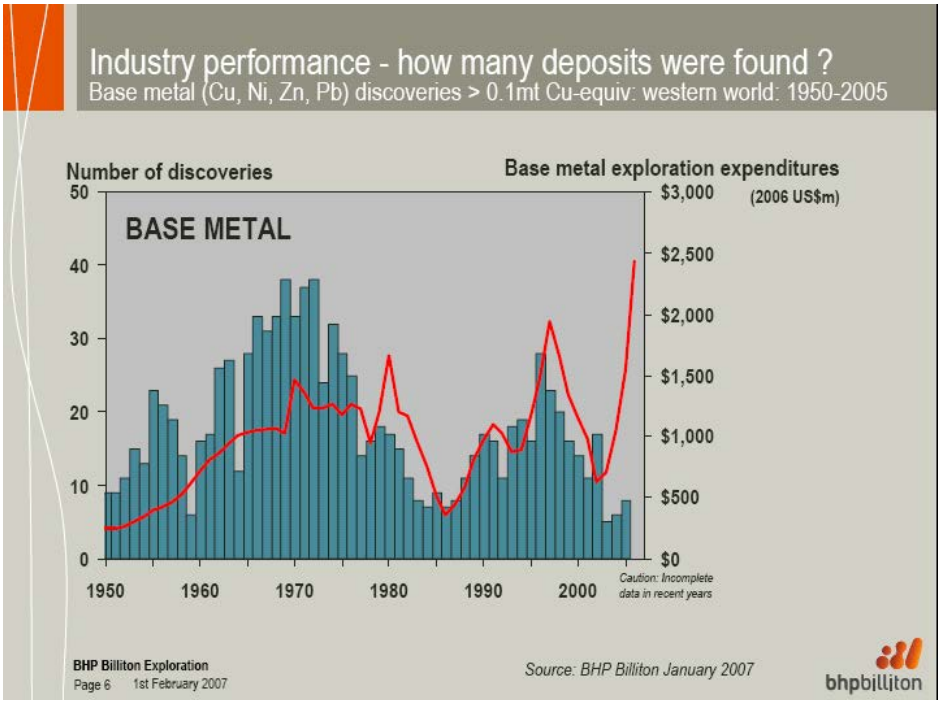

Figure 2. Diagram showing trends since 1950 in the number of discoveries (blue histogram) and exploration expenditure (red line). Note the decreasing rate of discovery over the last two decades and the marked decoupling between exploration spend and discovery this century.

- the need to minimize environmental and social impacts of resource development and address the growing community attitude of “no mining in my back yard” and the lack of understanding of the importance of mineral resources to economic growth and quality of life.

So there are substantial challenges associated with discovering major new mineral resources. However, this will be necessary because – even with optimal levels of recycling, efficiencies of use and substitutions of some commodities – it appears inevitable that the demand will continue to rise for most commodities as the global population continues to burgeon, populous countries such as Brazil, Russia, India and China (the BRIC economies) continue their rapid development, and Africa strives to develop its cities and deliver services that will enable its people's dreams for better life styles to be realized.

RFG MINERALS THEMES

NASIC recommends that the minerals component of RFG be developed under four principal themes:

Theme 1. Comprehensive evaluation of future global mineral resources, demand and supply for selected commodities, to provide enhanced information on which commodities are of concern post 2030.

> Collation and analyses of all available mineral resources data by commodity to provide better indicators of future availability and relate this with reasonable scenarios for demand.This will build on available data and research by the Institute for Sustainable Futures, the USGS annual summaries of identified resources, the USGS collaborative assessments of undiscovered mineral resources; the International Resource Panel estimates of long-run geological stocks of metals; etc. It will include research on undiscovered resources and substitution of selected commodities. The Chinese government will provide funding for this research, which will be more than just an updated Club of Rome exercise.

Theme 2. Enhanced information on the geology of the uppermost crust, for more effective delineation of new mineral, energy and water resources, managing wastes and assessing environmental condition, particularly in lesser developed countries.

> This will involve collation, acquisition and analyses of large regional-scale geological, geophysical and geochemical datasets; modern digital geological/thematic maps/GIS; influencing/promoting development of new sensor systems for enhanced surface and subsurface geological/geophysical information, better digital terrain models and environmental monitoring. IUGS will draw on its links to global observation programmes and expertise in integrating, analysing and modelling of 'big data' systems.

Theme 3. Improved evaluations of resource potential, with emphasis on new mineral systems, regions that have not been comprehensively explored, and sedimentary basins as repositories of mineral, energy and groundwater resources.

> This will involve systematic evaluations of whether there are likely to be significant mineral deposits in regions of interest; innovative approaches to understanding how and why mineral deposits occur where they do; and any technological, geological and environmental issues that may need to be taken into account . Priorities will be Central Asia, much of Africa and remnants of Tethys belt. In addition, innovative thinking will be promoted on new mineral exploration frontiers for key minerals (including sea floor, etc.), and for non-conventional mining and processing.

Theme 4. Capacity building and socioeconomic considerations in the developing world. This major component of RFG is necessary for effective exploration and mining as well as for good governance and socioeconomic benefits.

It will include drawing on IUGS member countries, World Bank and others to forge meaningful resources-related partnerships between the first world and interested countries in the developing world. These should involve training in the earth sciences, good governance and socio-economic considerations to enable lesser developed countries to reap social and economic benefits from mining, with minimal long term environmental impacts. In part this will be through providing a focus, framework and emphasis for capacity building and specialist training initiatives, many of which are currently "scattergun". It will promote and build on good examples of facilitating establishment of world class mining industries to boost overall economic development and mitigate social and environmental concerns, taking account of the characteristics of participating nations.

These Themes are summarised in tabular form in Attachment 1, which indicates potential activities and links to existing activities, and each is discussed in turn in the following sections.

Theme 1: Comprehensive evaluation of future global mineral resources, demand and supply for selected commodities

Critical to any discussion of the sustainability of mineral commodities is a comprehensive global view of both the demand and the supply of mineral in the recent past and an assessment of likely future trends beyond 2030, by which time concerns of supply shortage for some commodities can be expected to have increased markedly. Supply will depend on discovering and producing new resources, which cannot be turned on rapidly – for a world class deposit in a region with little infrastructure, or with social and environmental sensitivities, the period from starting exploration to production commonly takes over a decade.

Future supply and demand modelling will involve getting the right data together and presenting them in a form to support planning/policy makers. It will need consideration of technical change and adaption, and to understand the impacts of these shifts (economically and impact/cost to environment, etc). Activities will also need more than collation/analysis but will require research and development of methodologies to undertake improved evaluation/risk analysis and to provide these in forms that can be readily used/understood by policy makers/planners (including 3D visualization and tools to help present information on changing technologies how quickly and extensively we might need to develop them, and what their impacts could be – risk modelling). This theme should start with a focus on a small number of key commodities and then broaden out as appropriate from a record of success.

Today we have a good knowledge of the present global demand for mineral commodities but only a partial knowledge of the supply side of the equation. There is comprehensive information on the mineral stocks for countries like Australia, Canada and the USA, where today mining is an important economic activity and comprehensive reporting by the minerals industry is required. The European Union is also compiling a minerals inventory, but there is very little information for developing countries where mining has not been an important activity. The US Geological Survey, in its Annual Mineral Commodity Summaries, publishes its estimates for identified global stocks of a wide range of mineral commodities using the McKelvey system (Attachment 2).

In this report we use “resources” as materials likely to be available for commercial production from the present to the very long term. In this White Paper we avoid using the term “Reserves” because of potential for confusion stemming from its use with different meanings in USGS national/international reports and in company reports on individual properties (Attachment 2).

A snapshot of our present knowledge of known resources [need to check whether this is USGS Reserves] of six important mineral commodities is provided in Table 1, based on USGS, World Coal Association and BGR data (*references spelt out)*. However, the information contained in the table does not provide an accurate indication of remaining resource lives because of the inadequacies in the availability of data just described, production can vary considerably from one year to the next, some deposits will prove uneconomic to develop, and there will be new discoveries.

Table1. Global production, resources, remaining years of production and percent of yearly production over resources.

Commodity	Mine production 2012 (Mt)	Global resources (Mt of contained commodity)	Remaining years of production	% of yearly production over resources
Iron Ore	3.000,0	80.000	**26,7**	3,8%
Nickel	2,1	75	**35,7**	2,8%
Copper	17,0	680	**40,0**	2,5%
Coal*	7.678,0	1.004.000	**130,8**	0,8%
Phosphate	210,0	67.000	**319,0**	0,3%
Potash	34,0	9.500	**279,4**	0,4%

Source: USGS commodities statistics information, 2012
*Coal: World Coal Association, 2011. Resources from the German Federal Institute for Geosciences and Natural Resources (BGR)

Another insight comes from Australia, which has amongst the world’s highest iron ore resources and is a major exporter to Asian markets. With the major increase in demand since 2003, in particular driven by China, the resource life (as indicated by Resources to Annual Production ratio) halved by 2010.

To overcome the inadequacies new information is needed on the quantities of mineral commodities in regions where the presently available data is inadequate or substandard. This challenge will require collaboration with resource economists because economic value or cost is a critical component of resource definition (See Figure 1). More importantly, a rigorous methodology must be developed so that estimates of supply are uniform and comparable across countries and regions. The supply analysis should ultimately be comprehensive, including both the high value commodities such as gold but also low-value bulk mineral commodities like sand and gravel. However, initial emphasis should be on a small number of key commodities. The USGS initiatives to map out the strategic mineral resources of the world could be revisited in the larger context of RFG.

A key consideration should be the extent to which metals that are abundant in the Earth's upper crust can be mined at progressively lower grades – can this satisfy the world's needs indefinitely, or will mining of poorer quality deposits face difficult economic, environmental and social pressures from high energy and water use, contamination, high waste production, and environmental disturbance of large areas?

A comprehensive compilation of the global availability of mineral commodities should include information on significant mineral deposits that cannot be mined because of external factors such as distance from markets and/or a lack of supporting infrastructure, or because of metallurgical problems with the mineralization. A comprehensive data base of such problem deposits would be of value to the research community as a source of ideas for new research projects to develop solutions to the problems impeding development.

While we have a good knowledge of the present global demand for mineral commodities, the same cannot be said of future demand. Good estimates of future demand will require a significant input from not only resource economists, but also from material scientists, technologists and environmentalists who can respectively advise on possible future substitution trends, on future changes driven by new technologies and recycling possibilities, and on the environmental desirability of reducing the use of commodities that are detrimental to the environment. Again, a rigorous methodology must be developed so that estimates of demand can be uniform and comparable.

Better-informed estimates of demand will have an impact on estimates of supply discussed above, particularly regarding estimates of the cost side of resource definition which are being increasingly influenced by issues such as recycling, substitution, and environmental impact. Therefore work to standardize both supply and demand estimates need to proceed in unison. For example, the definition of resource recycling and substitution might need to be revisited to include the emerging impact of environmental and social values in mining. However, the effort of doing so will be rewarded with better estimates of future supplies, and together with better estimates of demand, will generate new insights into potential future shortages of particular mineral commodities and therefore priorities for future exploration.

Case studies 1:

(i) Resources and supply-demand over the very long term, Damien P., MOHR, Steve H., and MUDD, Gavin M. Derived from abstract of presentation at Geological Society of America Pardee Keynote Symposium P12, Denver 29 October 2014.
Resourcing future generations requires an understanding of (i) resource availability; (ii) resource demand and impacts from production and use; and (iii) options to increase resource availability or to reduce or substitute resource demand. A quantitative approach using the Geologic Resource Supply-Demand Model of Mohr (2010) can used be to project future resource production for selected commodities, and has been applied to iron/steel, coal, copper, and lithium. This implies that global copper production is expected to peak before 2040 and coal before 2020.

(ii) Tracking resources and estimating future supplies. MEINERT, Lawrence D.
Mineral resources are the building blocks of civilization and understanding their distribution, production, and future supplies is necessary for decision making on many different levels. The U.S. Geological Survey supports data collection (e.g., annual Mineral Commodity Summaries) and research on a wide variety of nonfuel mineral resources (e.g., SIR-5220:

The Principal Rare Earth Elements Deposits of the United States—A Summary of Domestic Deposits and a Global Perspective). Research is conducted to understand the geologic processes that control how and where ore deposits form and to probabilistically estimate (or assess) quantities, qualities, and areas of undiscovered mineral resources that can serve as potential future supply.

Estimating future supplies of mineral resources can be done in several different ways including extrapolating from detailed compilations of known deposits, theoretical models and the USGS 3-part assessment protocol. The first step is the creation of global grade and tonnage models to establish frequency distributions of tonnages and average grades of well-explored deposits of the type being assessed. The second step is delineation of permissive tracts for each deposit type under consideration. The third step is estimation of the number of undiscovered deposits in each tract based upon known geology and deposit models outlining the essential characteristics of that deposit type. These can then be aggregated for an overall estimate of the undiscovered resource in a given region.

All of these methods are constrained by historical trends of price and technology. Radical changes in prices such as in 1971 when the US dollar was no longer pegged to gold at $35/oz or in technology such as the advent of open pit mining or the use of heap-leaching have enabled mining of rock that was previously considered “worthless”. Future developments such as direct extraction of elements from sea water also have been proposed as game changers. Thus, estimates of future supplies of mineral resources should be viewed as a snapshot of a moving target rather than of a fixed quantity.

(ii) Analysis of Chinese and global supply and demand for key minerals in the coming 20 years WANG, Anjian, LI, Jianwu, , YAN, Qiang and FEI, Hongcai. Derived from abstract of presentation at Geological Society of America Pardee Keynote Symposium P12, Denver 29 October 2014.

With rapid growth of the economy, China has become one of the world’s largest consumer countries for key minerals. In 2012, China’s consumption of coal, crude steel, copper and aluminum was 3.64 Bt, 0.67 Bt, 8.84 Mt and 21.45 Mt, respectively, which accounts for 50.2%, 44.1%, 43% and 46% of world’s consumption of these commodities. China’s huge demand for resources has vigorously driven fast development of the global mining industry. The quantities of minerals China and other BRIC economies will need in the coming 20 years has become a highly sensitive topic in both the mining and other industries. The following forecasts have been made by Chinese experts:

1. China’s demand for crude steel will reach a peak during 2013 to 2015, with an estimated amount of 680–720 Mt per year, and thereafter will run high for seven to ten years. China’s cumulative demand in the coming 20 years will amount to 11.5 to 12.0 Bt for crude steel and 18.0 Bt for iron ore after deducting recyclable resources.
2. China’s demand for copper and aluminum will hit a peak during 2022 to 2025, with an annual demand of 130–150 Mt and 260–290 Mt, respectively. China’s cumulative demand in the coming 20 years will amount to 240–250 Mt for copper and 480–530 Mt for aluminum, with 1.5–1.6 Bt for bauxite after deducting recoverable resources.
3. In the coming 20 years global cumulative consumption of crude steel will reach 39 Bt, which can be converted into 65 Bt of iron ore. By 2030, global cumulative consumption of iron ore will exceed 120 Bt.
4. In the coming 20 years global cumulative consumption of copper and aluminium have ben

estimated to reach 560 Mt and 1.3 Bt (equivalent to 5.0–5.5 Bt of bauxite). By 2030, global cumulative consumption of copper and bauxite will approach 1.3 Bt and 10 Bt, respectively.

By 2030, countries which have become “industrialized” including BRIC group) will account for one third of world population, and the remaining >5 billion will consumemineral resources at increasing rates in pursuit of better lives. For the moment, many key mineral resources are far from adequate to meet the long-term human demand and sustainable development.

Theme 2: Enhanced understanding of the subsurface

Discovery tools

Depending on whether exploration is taking place in an immature exploration terrain or a well-explored mature terrain, the explorer has available a range of tools extending from simple prospecting methods through to geological mapping, a range of surface geochemical exploration techniques and tools, and onto a whole arsenal of geophysical tools that include air- and space borne multispectral imagery, ground and airborne magnetic tools, ground and airborne gravity tools, ground and airborne radiometric tools, ground and airborne electromagnetic methods, and a growing number of down-hole adaptions of these tools. The available evidence suggests that the arsenal is very effective and makes up for the exploration weaknesses inherent in ore deposit and ore-system models discussed above. However, given the slowing rates of discovery (Figure 3) it is clear that more can be done in the development of better exploration tools and this is a subject of a considerable amount of present day research in industry, including its service sector, and in universities and government agencies around the world.

IUGS should use its influence to ensure new global sensor platforms are appropriate for applications in locating new natural resources and assessing environmental condition.

Data Management

As a result of the growing application and sophistication of techniques and tools for understanding the geology of our planet and exploring for new mineral deposits, new data are being collected and stored at a rapidly growing rate *(anyone have references to the absolute growth-rate values?).* The geosciences are now very much a part of the “Digital Age” and data management and availability are growing areas of concern and an emerging area of research that will provide opportunities for collaboration with other disciplines. Specific topics for research relevant to mineral resources include “big-data” mining and analytical techniques and capabilities. From a user perspective issues of relevance include real-time online access to suitable data, access to suitable data manipulation routines, adequate band width, and possibly security.

The need for new geophysical tools, drones, LIDAR, and other new techniques is clear, but there is scope to challenge the physics and chemistry communities to suggest techniques that take advantage of cutting-edge research in their disciplines. Improving tools that would be capable of making in-situ measurements would have an enormous impact, and drilling remains the gold standard and hasn't changed fundamentally in 100 years – could a laser drill be developed to quickly penetrate to several hundred meters and the resulting vapour produced analyzed in real time? Also in the geophysical tool arena, can RFG stimulate vendors of oilfield seismic, borehole, and directional drilling techniques to develop tools specifically for the minerals industry?

Such toos and approaches have other applications and IUGS should promote the “community good” aspects to help garner support.

Case Study 2:

Mineral exploration under deep cover. WILLIAMS, Neil, Derived from abstract of presentation at Geological Society of America Pardee Keynote Symposium P12, Denver 29 October 2014.

To resource future generations, new mineral deposits must be found to replace deposits currently being mined, and to meet anticipated increases in the global consumption rates of many mineral commodities. Throughout the 20th century there has been a growing trend in the discovery of buried deposits (generally within a few hundred meters of the surface), and the trend is predicted to grow as the stock of near-surface mineral deposits further diminishes.

Finding deep mineral deposits is difficult, and the exploration methods used to find new deposits at or near the surface will not all be useful for discovering deposits under deep cover. What is required are: better tools and techniques to accurately describe the geology of the Earth’s crust in four dimensions (the three dimensions of space plus time); new and improved targeting models to guide ground selection; new insights into the geophysical characteristics of mineral systems and mineral deposits; more powerful geophysical exploration tools to directly detect possible mineralization of a wide variety of types at depth; and more cost effective drilling technologies to test for deep mineralization.

Good progress is being made to overcome some of these challenges, but more needs to be done. For example, current ore deposit models are useful in identifying prospective terrains at a regional scale, but are of little use in predicting the location of deposits at the local scale. A new generation of predictive targeting models is needed, based as much on the geophysical characteristics of ore types and their host rocks as on the ore-type mineralogy and chemistry emphasised in current deposit models.

Theme 3: mineral potential evaluations - where will new supplies of mineral commodities be found?

Introduction

An often quoted phrase in the exploration industry is “always search for elephants in elephant country” and this advice has worked well in many exploration programs in areas of known mineralization where earlier prospecting or exploration has revealed one or more “elephants”. In well-explored or mature exploration terrains, such as the Achean Cratonic regions of Canada and Australia, the probability of finding new mineral deposits at or near the surface is low, but the potential for finding new deposits at depth is still high. By contrast, in immature exploration regions, the highest probability of finding new mineral deposits will be in parts of the regions where the geological environment is similar to well-mineralized environments in mature exploration environments. The little explored Tethyan belt is a good example and in an immature exploration terrain such as this the probabilitly of finding significant new mineral deposits at or near the surface is far higher than it is in mature exploration terrains. However, irrespective of the exploration maturity of a terrain, the better the understanding of the geology of the terrain, the easier it is to explore it for new mineralization. Modern exploration relies on ground selection exercises that match the geology of a terrain, elucidated by geological mapping with geological environments, with the geology permissive of the target mineral deposits determined using mineral-deposit models.

Geological mapping

A basic requirement of the modern exploration process is good geological maps at appropriate scales. As with current knowledge of the distribution of reserves and resource of mineral commodities, the quality and adequacy for exploration and resource assessment of existing geological maps is very variable around the world. New and better regional geological maps of immature exploration areas would do much to help locate new mineral deposits and this is something that IUGS is well placed to influence, in collaboration with the Commission for the Geological Map of the World (CGMW; http://ccgm.free.fr/index_gb.html).

Following the revolution in global geological thinking in the late 1960's triggered by the plate tectonic theory, geologists realized that the present configuration of the land areas of the world is ephemeral. Through geological time the configuration of the land areas have changed dramatically, with continents breaking up and reforming in different ways that are only now are beginning to be understood. Because many mineral commodities show a bias to abundance in rocks of a particular age (metallogenic epochs) or particular regions (metallogenic provinces) our ability to make reliable reconstructions of past continental configurations will be an important guide to future exploration.

Good geological maps help to elucidate to the relative ages of rock sequences, but often the absolute ages of rocks are difficult to determine. With the development of new and improved geochronology tools, great progress is being made in dating rocks, but again coverage and quality is variable, even in well-mapped countries, where significant age reassignments are still being made. Geochronology should also be an important part of assessing standards for geological mapping.

In countries with advanced exploration industries, exploration is increasingly being directed to areas where the prospective bedrock geology is concealed by younger cover. In these areas geophysical mapping (particularly magnetic and gravity mapping) is growing in importance as a surrogate for geological mapping. At the same time, geophysical tools are being used more and more to generate three-dimensional geological models using geophysical inversion techniques. Research to improve inversions is occurring in the mining industry and its associated services sector, and also in many universities and geological surveys. The skills base needed to perform good inversions is limited, the quality of inversions is variable, and they can be expensive. The time taken to process the large datasets have decreased greatly with advances in computing power and, if successful, research on integrating physical properties sensors into drill bits, will provide better constraints on the models. In areas where there is good age control, a fourth dimension of time is being added to three-dimensional models, and in theory four-dimensional models will be of great value in exploration. Unfortunately, the availability and/or quality of geophysical data to aid geological modeling varies widely around the world, and new surveys to overcome inadequacies would do much to improve future exploration.

In some regions, especially in Africa, considearble amounts of pre-competitive geoscience data have been collected to stimulate investment in mineral exploration, but the data are not freely available due to government policies of cost recovery through data sales, and because extensive African geological and geophysical datasets are archived in institutions in Europe and North America that are also difficult to access, particularly.by African geoscientists. This means that data mining and analysis to assist exploration, for example by way of producing three- and four-dimensional geological models, are not common. Information on the extent of this issue is an important first step to overcoming the problems.

Assuming the availability of appropriate geophysical data to produce three and four dimensional geological models using geophysical inversion techniques, an inherent weakness in the approach is that inversions provided non-unique solutions, and the ensuing models may not by very realistic. The more geological constraints that can be applied during modeling the better the end result will be. The development of standards for validating geophysical inversion models and their use in geological mapping under cover would do much to assist future exploration and this could be achieved by establishing a series of standard geoscience mapping regions around the world – something that IUGS us well plced to achieve. Ideally these regions should cover a range of situations where the subsurface geology is well understood through extensive drilling and/or mining, to help validate, calibrate, and standardize new deep mapping methods and equipment, and help to develop new deep mapping technologies.

A growing problem facing present day mineral commodity explorers is a lack of field geologists and it is likely this will become a more serious issue in the future (see theme 4). To help overcome the problem it is suggested that a part of each standard mapping region should also include areas of good outcrop where state-of-the-art field mapping skills can be taught. Such standard mapping regions would serve as field class rooms to teach field mapping skills and facilitate the transfer of knowledge and skills to assist future exploration.

IUGS is ideally suited because of its global reach to stimulate the implementation of such activities. Similarly with the growing of availability of airborne and space-borne remote sensing systems, the outcropping parts of standard geoscience mapping regions could also be used to validate, calibrate and standardize the systems as tools for geological mapping and possibly even as tools for directly detecting mineralization.

Mineral deposit exploration models

The origin of mineral deposits is a topic of on-going research and requires a thorough understanding of stress and strain, fluid circulation and chemical and mineralogical changes in the subsurface at the time the deposits were formed. If is often difficult to identify all of the processes involved in the formation of a deposit and in place of a good understanding of why mineral deposits occur where they do, mineral explorers and resource assessor make do with mineral deposit models.

Mineral deposit models are defined by Berger and Drew (2002) (http://link.springer.com/chapter/10.1007/978-94-010-0303-2_6#) *(reference needs better definition)* as being “systematic syntheses of descriptive and genetic information regarding a group of deposits with sufficient attributes in common to be considered of the same type". The models guide the identification of terrains permissive for the occurrence of particular deposit types. The models therefore attempt to help explorers to select favorable areas in which to explore for specific ore deposit types, and help resource assessors to try and better determine the potential of a terrain to contain a particular ore deposit types. The value of ore deposit models in exploration and resource assessment is therefore limited when the geology of an area is poorly understood and by the simplifications inherent in the construction of ore deposit models. At best the models are only approximations of actual mineral deposits and their origin.

Ore deposit models rose to prominence in the late 1970's, that is, around the time that ore-deposit discovery rates began to tumble from their all-time highs in the early 1970's (see draft Figure 0). The reasons for the decline in discovery rates is probably due more to the falling number of easy-to-find near-surface deposits due to earlier exploration success, rather than to the growing use of ore deposit models in exploration. However, the declining trend in discovery suggests that while current models seem useful in identifying at a regional scale where a particular deposit type may occur, they are of little use in predicting the location of deposits at the local scale. In the last decade, ore deposit models have been supplemented by ore system models that cover a broader region that ore deposit models *(references needed)* suggesting that they too are of little use in predicting the location of deposits at the local scale. There is now scope for geoscientists, data scientists, and others in non-geoscience disciplines to collaborate to challenge and deconstruct the current "dominant logic" model-based approach and develop new and innovative approaches.

Sedimentary basins provide a logical initial focus, as they are major sources of mineral, energy and groundwater resources and the focus of many challenges arising from competing use of resources in these – for example, coal seam and shale gas, groundwater issues allied with health concerns, waste disposal, land use and mining (coal, phosphate, base metals, uranium and other sediment-hosted deposits). Virtually every country in the world faces the issue and it is important that we get better at managing sedimentary basins.

It is suggested that there should also be consideration of what constitutes economic deposits in the context of local needs, and what should be the preferred extraction techniques that are consistent with local needs and development trajectories – this would directly feed into how you delineate a mineral resource and is better done up front than retrospectively.

There is also need for research on new types of ore deposits and ore-forming systems. That is, can we predict, either from fundamental geochemical principles or from general knowledge of low-grade materials, what some of the future resources may be? As an example, 60 years ago we may have been able to have predicted that high-Li brines would be a major source of lithium.

The organisations that should be involved in regional resource assessments must be identified and named as partners and potential collaborators - the likes of major geosurveys and research groups multi-national companies; Australia's International Mining for Development Initiative, World Bank, UNESCO, plus local organisations who should be involved – to get genuine buy-in from countries whose resources are to be assessed.

Case Study 3:

Mineral discovery in known and as-yet-unknown mineral systems. HITZMAN, Murray W., Derived from abstract of presentation at Geological Society of America Pardee Keynote Symposium P12, Denver 29 October 2014.

Individual ore deposits are the result of mineral systems that generally include a metals and sulfur source, a means of element transport, a chemical and/or more rarely physical trap, and the energy required to enable the system. Research during the 20th century led to reliable models for some mineral systems such as those for porphyry copper and volcanogenic massive sulfide deposits. Developing robust mineral systems models are a key to future mineral potential evaluations of both mature and under-explored regions. Due to our focus on the economically productive portions of the mineral system (i.e., the mineral deposit itself), we have less understanding of the broader geologic components of many mineral systems including systems that are relatively well understood. The sedimentary rock-hosted stratiform copper system provides an example of the challenges in developing more holistic mineral system models. Perhaps even more intriguing for mineral exploration in the 21st century will be development of models for as-yet-unknown mineral systems. The discovery of the Olympic Dam deposit in the late 20th century spurred development of new mineral system models and continued chance discoveries, such as that of the HREE-rich clay deposits of southern China or the Enterprise sediment-hosted nickel deposit in Zambia, illustrate that we must continue to be open to investigating currently poorly understood processes for mineral deposit formation.

Theme 4: Capacity building and socioeconomic considerations in the developing world

This is a prerequisite for effective exploration and mining, as well as for good governance resulting in socioeconomic benefits.

Capacity building

As the first major initiative developed to provide international collaboration with a global reach, RFG will need to build true partnerships across major cultural, economic and political divides. IUGS is well-placed to pursue these.

Because RFG has a long time frame and will involve many countries, it is paramount that social and environmental issues be addressed in tandem with the geology of mineral resources, within the context of resource development.

RFG must be perceived as more than just another externally funded exercise in data compilation executed by first world geological organisations to the benefit of a global mining industry, where the benefits that accrue to the developing world will be questioned. This is a common criticism, at least in Africa, and to get genuine buy-in and ultimately achieve success, the issue of tangible benefits through true partnerships must be addressed clearly.

Social responsibility aspects of mining with respect development need to be clearly addressed. Facilitating establishment of world-class mining industries will depend on both mineral potential and the attitude of a country’s government and its people. The socioeconomic, political and historical context will differ between high and low population density regions.

In summary, RFG should look critically at the socio-economic aspects of resource development and it is important that such discussions are informed by good geological data. For example, what is needed to attract in-country collaboration and to attract funding from various development banks, endowment funds within large companies, large foundations and national governments of participating countries, and to internalise capacity building as much as possible. As RFG is genuinely for the common good, it must consider carefully how to interact with organisations that represent differing interests.

RFG should be informed by what has been done in the past in the developing world, and how little of it has stuck. It should look at things differently and more clearly articulate the needs and aspirations of the developing world - moving beyond the paradigm of development aid where the first world appears to hold all the trump cards, which has clearly not worked over the past 50 years.

In Africa, since the late 1980's there have been many World Bank, EU and Canadian-aid sponsored initiatives aimed at building geoscience capacity, which have largely come to nothing. Concurrent initiatives to build up the geological surveys in African countries, including the compilation of GIS mineral databases, again with few lasting benefits. For example, building large pre-competitive exploration datasets, such as the SEAMIC initiative (http://www.seamic.org/) headquartered in Tanzania, have largely fallen into disrepair and some stumble along.

Mapping countries has been more successful, but follow-up tends to be problematic. Whilst extremely useful datasets have been produced in these exercises, the capacity building components attached to these initiatives have generally failed, and as a result the benefits accrued locally are minimal. External groups have obtained and even maintain the data, which is commonly perceived to be a problem. AusAID's Mining for Development initiative, which is relatively new, is attempting to co-ordinate a range of activities across multiple themes, including the availability and management of public geological data, developing a partnership with the new Africa Minerals Development Centre (http://www.uneca.org/amdc), which has been given the remit of the implementation of the Africa Mining Vision (http://www.africaminingvision.org/).

Progress cannot be made in resourcing future generations without a highly trained workforce possessing field and interpretive skills to develop the 'state of the science' products that are necessary. Some urgency is now being attached to this issue because of the growing retirement from the mineral commodity workforce of highly qualified and very experienced "baby boomers" and every effort needs to be made to capture as much of the knowledge of the "baby boomer" specialists ahead of their retirement. However, as the future world of mineral commodities continues to evolve and become more complex geoscientists, for example, will require training in scientific disciplines that were not part of training received by "baby boomer" geoscientists. For example, because of the growing environmental awareness of communities worldwide, knowledge of the environmental sciences, hydrology, forestry and agriculture will be valuable, as will social sciences knowledge.

Resource nationalism will very likely increase, particularly in developing countries that are rich in mineral commodities. Such countries are likely to insist on greater benefits from the exploitation of their endowment, and this will mean greater indigenization at the professional and technical levels, as well as use of local goods and services, and less harm to the environment. The challenge will be to develop mechanisms to train and retain talented individuals in their countries of origin. Today, assistance in education too often means luring the brightest and best to first world economies - strategies are needed to train talented individual in a way that encourages them to contribute to the development of their home countries.

In addition to earth sciences, training priorities to achieve these outcomes include land-use planning, economics, law, social science, ‘big data’ information technology, game theory, decision support modelling, and community development.

A useful initial goal of a project on data systems management for Africa could be simply a survey to determine what data sets are potentially already available for a subset of African countries with perceived high mineral potential for a wide range of commodities. Such surveys might be developed to determine:

- The percentage of a country that has available modern geologic bedrock maps;
- The percentage of a country that has available modern surficial geological maps;
- The percentage of a country that has modern hydrologic surveys and maps:
- The percentage of the a country that has modern geophysical datasets (and at what scales) – aeromagnetics, gravity, radiometrics.
- The geological capabilities of the country –
    - size and funding of any geological survey (including bedrock geology, surficial geology, hydrogeology, environmental geology);
    - Academic capabilities of the country in bedrock geology, surficial geology, hydrogeology, environmental geology.
- Whether the country has a well-developed legal framework for mineral exploration and exploitation as well as a well-developed environmental regulatory structure.

This survey would not only include identification of data sets but also tabulate their availability and document how they can be accessed.

Having data on the status of geological/hydrological/geophysical data within a number of countries as well as data on their legal framework would then allow analysis of what might be needed for developing a robust, environmentally sustainable minerals industry. Such data could be utilized by potential major funding groups to develop and prioritize potential intervention points for future funding and support. Such data would also be useful to industry when integrated with operational data on specific countries (corruption indices, logistical considerations, etc.) to determine where they might choose to invest.

Social Acceptance

Negative societal attitudes towards mining are a threat to mining today, and the threat is likely to grow as the increasing demand for mineral commodities from new mines creates increased tensions between mineral resource production and other land uses like agriculture, urbanization, and conservation of the environment. Education at many different levels is required to overcome these challenges and develop good governance arrangements that allow for evidence-based policy develop, and sound land use regulation. It appears that there would be benefit in endorsing generic international guidelines, principles and case studies for environmental, economic, social, and cultural sustainability in relation to mineral-resource development. IUGS and ICSU are well placed to do this with a view to establishing the basic conditions for mining and rehabilitation where there are no appropriate legislation or regulations enforced. Engaging industry on this front should be easy, because several industry groups have developed or adopted these. The research needed is mainly socio-economic. Coordination and focus of disparate activities, achieving collaboration between governments, research groups, academia, companies and industry groups, will be key.

A staged approach to mining, with full involvement of the local community in projects that integrate mining benefits directly into the local community causing minimal disruption to other economic activities. A carefully scaled approach may work in many cases, although the capacity to deal with major developments involving multi-national companies must be addressed. In addition to benefits to the local communities, mining must be benefit the country more broadly. Corruption is a major challenge that cannot be ignored.

Resource nationalism and indigenisation policies in which local stakeholders hold a major if not majority share in mining ventures, is becoming increasingly important. Care is needed to ensure this does not lead to conflicts of interest which result in maximising short-term financial returns to the detriment of broader social and environmental outcomes. In many parts of the world, a social licence to operate will be more important than resources in the ground. A pre-competitive approach to resource development, that also includes water, will require a general understanding of what best practices should really be for the country concerned.

It will be necessary to articulate the link between sustainable mining practices, social responsibility, resource availability (i.e. geological setting) and development objectives. In other words if a mineral resource data base is created this must be translated into a plan that enhances development objectives of the affected countries including infrastructural development, environmental conservation objectives, agricultural development and local participation. In Africa, via the AU, there is much talk about the creation of development corridors to unlock Africa's interior. These corridors are largely motivated on the basis of real or perceived mineral wealth and the challenge is going to be to develop these resources in a manner that will develop the country around it.

Case Studies 4:

(i) The challenges for resourcing future generations from an african perspective.
KOTA, Mxolisi, HEIN, Kim, MASTER, Sharad, ABIYE, Tamiru, and DURRHEIM, Raymond. Derived from abstract of presentation at Geological Society of America Pardee Keynote Symposium P12, Denver 29 October 2014.

There is an urgent need to sustainably manage the depletion/replenishment equilibrium of Africa's vast natural resource endowment in view of the social and economic well-being of the continent and its people. The African Mining Vision is one such initiative which aims to achieve the Millennium Development Goals through the responsible management and beneficiation of the continent's natural resources. In order to achieve these goals, including poverty eradication and economic development, access to information needs to be improved by producing appropriate maps and by overcoming challenges related to the governance of the mining and minerals industry. Data analysis, integration and management will be greatly enhanced by the adoption of open collaborative research approaches, such as demonstrated by WAXI, ANESI and AfricaArray, for the greater good of the continent.

Small-scale mining represents an important source of income for the poor and developing communities. However, the sector is hampered by various challenges, including a lack of appropriate regulatory frameworks and knowledge about responsible management practices. Therefore, the sector will greatly benefit from inputs by experts in the establishment of a framework to address environmental and socio-economic challenges.

Most African countries are categorised as water-stressed. In addition, metallogenic entities and aquifers on the continent are often spread over several countries with multiple administrative languages, entailing different geo-data sets with varying degrees of reliability and accessibility. There is an urgent need to implement integrated water management policy interventions to mitigate the challenges of variable rainfall and climate, rapid population growth, damage to water systems and quality and poor mining practices so as to ensure the sustainable management of this scarce resource into the future.

These initiatives can be significantly enabled by integration and dissemination of available and new geo-data sets and information gathered through modern high resolution airborne geophysical and space-borne Earth Observation surveys across the continent.

(ii) **A major company perspective. GODOY, Marcio L.S.**, MASOTTI, Fabio S., and ARAÚJO, Ivan M.C. P. Derived from abstract of presentation at Geological Society of America Pardee Keynote Symposium P12, Denver 29 October 2014.

Major companies play an important role in the global mining industry, being responsible for producing and trading a large proportion of the minerals that society consumes. These companies can manage large exploration and project development investments; work in an integrated way with different knowledge areas; maintain their own exploration and technology development teams and have access to large capital pools required to develop world-class deposits. Major companies however face specific challenges when compared to junior companies, including greater social and governmental pressures. Nevertheless, during the last decade, the mining industry returned significant production results. Is this trend sustainable?

The mining industry is subjected to the cyclic nature of economic, social, environmental and regulatory trends. It is challenging to maintain long term, consistent investment levels during these cycles. These challenges must be surpassed to make future resource supply sustainable. A more stable legislative environment will be required in order to stimulate capital intensive investments in mining and logistics. Training and retaining skilled workforce will represent an important matter, since most exploration and operations occur in remote areas. Mining companies have the key role of developing projects which promote sustainable development for all stakeholders. Government, society and mining companies must work together to clarify the importance and necessity of each other in resourcing future generations.

(iii) **Geogovernance - preparing for the unpredictable. STRECKER, Manfred R.** Derived from abstract of presentation at Geological Society of America Pardee Keynote Symposium P12, Denver 29 October 2014.

Countries most vulnerable to natural hazards and mining impacts are not necessarily those in the zones of greatest danger, but rather those with a lack of knowledge and institutional capacity to respond to changes within the Earth system. Even in technologically advanced societies governance challenges remain that demand a well-trained workforce capable of bridging the gap between the geosciences and politics as societies are confronted with complex natural and manmade problems. Although the geosciences have augmented our understanding of the processes underlying such changes, attempts to translate scientific findings into political strategies for coping with change often fail. This problem results from the difficulty in translating scientific knowledge into practical solutions and also from inflexibility and lack of knowledge among administrations attempting to deal with change on different timescales. Understanding and coping with inherent uncertainties in the Earth system, however, is a prerequisite to ensure the safety and economic viability of an increasingly complex global society.

An important step in ultimately reducing vulnerability and increasing adaptive capacity is requiring geoscientists to better combine and communicate geoscientific knowledge and to promote geoscience literacy in the realm of political-administrative organizations. In this context the next generation of geoscientists can play a pivotal role in an effort to help administrations confront risks and opportunities of change and move toward a geogovernance of preparedness.

DISCUSSION AND RECOMMENDATIONS:

How can RFG initiative best contribute to the challenges facing the future supply of mineral commodities?

From its early deliberations, NASIC considered that the RFG concept is very much worthy of developing, and that for it to be successful it should:

- not be seen as “business as usual”, or “more of the same”;
- be done in a fully integrated context that recognises the contributions from all partners;
- consider both short-term goals and longer-term aspirations – producing valuable outputs early on is likely to be critical to the long-term viability of RFG;
- be aware of the likelihood that financial investments required in R&D by governments and industry will only occur once there is a broader perception that the world faces mineral resource constraints, so establishing this should be an early focus;
- realise that collaboration and in-kind support from other disciplines – notably economic, social and environmental – will be optimised where individual programs have clear focus and deliverables within a few years, and where Earth sciences do not dominate to the extent that the other disciplines will not want to participate.
- document a long list of potential projects under an RFG banner as a worthwhile reference point, but give early emphasis to concrete accomplishments within the first few years;
- be aware major funding agencies are most attracted to real world problems that can be tackled and solved – digestible and workable projects will be most likely to attract support; potentially fundable and achievable projects include the identified access to new ’big‘ data systems and breakthroughs in data management and modelling capabilities, including systems for integration of large geophysical and geological

data; and studies focussed on sedimentary basins, which contain minerals, energy and water resources.

Taking account of views received to date, NASIC recommends:

1. RFG should evaluate mineral supply-demand for selected key commodities, because (i) IUGS has a formal agreement with the Chinese government to fund such work, and (ii) a range of reasonable assumptions can be made for this modelling.

2. RFG should engage where appropriate with other current and planned programs, and should engage with social scientists, material scientists and other groups which are willing to contribute.
3. The emphasis should be on lesser developed regions, where there is genuine interest in collaborating.
4. The scope of activities on enhanced knowledge of the upper crust, mineral potential evaluations, data collation, capacity building and training, etc. should be developed through consideration of what is available/of interest to the countries concerned.
5. There should be a serious attempt to provide a framework for and synergies between programs, and a focus to attract "development" funding.

Introduction

As the RFG is intended to focus on new activities, the issues described above relate to the longer term challenges associated with the discovery, development and rehabilitation of the future mines of the world. From this perspective priority for the work of the RFG is very much at the basic and precompetitive end of the scientific spectrum, that is, ones that lead to outputs that are public good in character, that is, outputs that are both non-excludable and non-rivalrous in that individuals or groups cannot be effectively excluded from their use and where use by one individual or group does not reduce availability to others (http://en.wikipedia.org/wiki/Public_good).

Because IUGS is in the unique position of representing some 120 countries, a second focus of the RFG is activities that give priority for activities that have applications globally and will be of value to all member countries.

Some of these activities are core to the IUGS, some will have dependencies on other scientific disciplines (Anjian's "Internal layer") and some will have dependencies on non-science disciplines (Anjian's "External layer"). *(once the actions are agreed, I suggest an edited version of Anjian's excellent diagram be inserted here, colour coded to highlight the three layers and their activities. Could we give the second and third layes more descriptive names? Any suggestions?)*

Possible Core Activities

1. Regarding the inadequacies in our current understanding of the future supply and demand for mineral commodities, it is proposed that:
   a. A high priority for the RFG be to encourage the development of better compilations of the global availability of mineral commodities that include information about those regions where data is presently inadequate or of a poor standard.
   b. A comprehensive data base of known deposits of mineral commodities that are presently sub-economic be a part of the compilation proposed in (a)

above to provide information and encouragement to the research community to undertake work to improve the economic viability of these known deposits

c. A rigorous methodology be developed to estimate the future demand of mineral commodities so that the estimates of demand are uniform and comparable across countries and regions

2. Regarding the variability in coverage and quality of regional geological maps around the world, it is proposed that:

a. A high priority for the RFG be an assessment of the current state of geological mapping worldwide, and to develop a set of standards for acceptable maps to underpin the assessment. This work will provide good information on where geological mapping is inadequate, and what future mapping priorities should be. Because of the growing importance of social and environmental factors in mining, the proposed assessment would benefit from the inclusion of these factors in assessment standards. Because many mineral commodities show a bias to abundance in rocks of a particular age (metallogenic epochs) or particular regions (metallogenic provinces), our ability to make reliable reconstructions of past continental configurations will be important guide to future exploration. This aspect of geological mapping should also be factored into assessment standards for geological mapping. Geochronology factors should also be an important part of assessment standards for geological mapping.

b. Regarding geophysical inversion techniques to produce three and four dimensional geological models to assist future exploration at depth, a second mapping priority for the RFG is to undertake an assessment of the current state of geophysical mapping worldwide, and to develop a set of standards acceptable geophysical maps and data sets to underpin the assessment. As in the case of geological maps this work will provide good information on where geophysical mapping is inadequate, and what future mapping priorities should be. Information on policies on the accessibility of existing geophysical data should be included in the assessment to identify where access policies are retarding the use of the data. A complementary assessment of geophysical inversion techniques and the quality of the input data and its impact on inversion modeling should also be undertaken.

c. A third mapping priority for the RFG is to develop standards for validating 3 dimensional modeling and geological mapping under cover to help improve the effectiveness and efficiency of future exploration at depth. An appropriate way of doing this is to develop of a series of standard geoscience mapping regions around the world that cover a range of geological situations where the subsurface geology is well understood though extensive drilling and/or mining. Such regions will be invaluable for validating, calibrating, and standardizing new deep mapping methods and equipment.

d. Assuming the availability of appropriate geophysical data to produce three and four dimensional geological models using geophysical inversion techniques, an inherent weakness in the approach is that inversions provide non-unique solutions, and the ensuing models may not by very realistic. The more geological constraints that can be applied during modeling the better the end result will be. . A growing problem facing present day mineral commodity explorers is a lack of field geologists and it is likely this will become a more serious issue in the future. To help overcome the problem it is suggested that a part of each standard mapping region just suggested should also include areas of good outcrop where state-of-the-art field mapping skills can be taught. Such standard mapping regions would serve as field class rooms to teach field mapping skills and facilitate the transfer of knowledge and skills to assist future exploration. Similarly with the growing of availability of airborne and space-borne remote sensing systems, the outcropping parts of standard geoscience mapping regions could also be used to validate, calibrate and standardize the systems as tools for geological mapping and possibly even as tools for directly detecting mineralization.

3. Regarding the inadequacies in the use of ore deposit models and ore system models in exploration it is proposed that the RFG encourage geoscientists, data scientists, and others in non-geoscience disciplines collaborate to challenge and deconstruct the current “dominant logic” model-based approach and develop new and innovative approaches to understanding how and why mineral deposits occur where they do. *(this is Mxolisi’s strongly expressed view and is also Neil W’s view, but it would be nice to have a formal reference or two to give the view more credence).*

4. Regarding the use of currently available exploration tools and the development of new ones it is proposed that the RFG develop and maintain a data base of what is available, where access can be obtained, and where training can be undertaken. The development and use of such tools is very market driven, and is therefore not precompetitive public-good activity. However, when and if the various activities proposed under the RFG throw up ideas for new and novel tools, these should be fed back to the appropriate R&D communities.

5. Regarding the challenge of managing and using big data sets, it is proposed that the RFG facilitate appropriate research to ensure that the available data are used to the fullest extent possible. Specific topics for research relevant to mineral resources included “big-data” mining and analytical techniques and capabilities. From user perspective, issues of relevance also include real-time online access to suitable data, access to suitable data manipulation routines, adequate band width, and possibly security.

6. Regarding the importance of training the issue of the loss of knowledge caused by the retirement from the mineral commodity workforce of highly qualified and very experience “baby boomers”, mechanism and opportunities should be developed to capture as much of the knowledge of the “baby boomer” specialists ahead of their retirement.

7. Regarding the training and retaining of indigenous professional in the resources industry, it is proposed that the RFG support the development of sandwich programs in which, for an example an African student spends say three months a year at a first tier institution in a developed country, and the remainder of the year at an institution in their home country where they can transfer their newly-acquired knowledge immediately and be role models for local students. Also, where possible the use of on-line training should be investigated, as well as the use of research instruments on line.

Possible Internal Layer Activities

1. Regarding the challenges of education in scientific disciplines beyond the geosciences it is proposed that*….(Ian, I suggest you and others have a go at this one and key it into your table)*

Possible External Layer Activities

1. Regarding the challenges of education in non-scientific disciplines *(another one for input from others)*

LOGISTICS OF DOING ALL OF THE ABOVE

Issues to be covered here – how to we link with ISCU and other unions and initiatives? How do we engage with research grant funders, industry, decision makes etc etc. More thinking and writing by others needed!

Attachment 1

Table summarising recommended priority themes for the minerals component of RFG, along with indicative activities and links to relevant current activities

Proposed Priority Themes	Potential Activities and Links to Current/Planned Activities
1. Comprehensive evaluation of future global mineral resources, demand and supply for selected commodities To provide enhanced information which commodities are of most concern post 2030	• Collation and analyses of all available resources data for selected commodities to generate better indicators of future availability. Relate these data to reasonable demand scenarios. o Can metals which are abundant in the Earth's upper crust, be mined at progressively lower grades to satisfy the world's needs indefinitely, or will mining of poorer quality deposits face difficult economic, environmental and social pressures - from high energy and water use and waste production, and environmental disturbance of large areas? • Involve material scientists through ICSU and Institute for Sustainable Futures http://cfsites1.uts.edu.au/isf/research-areas/waste.cfm. in consideration of substitutes for selected commodities. Key references to available studies are: • Institute for Sustainable Futures http://cfsites1.uts.edu.au/isf/research-areas/waste.cfm. Recent ISF PhD Thesis on Economically Recoverable Resources. USGS Annual summaries of identified resources http://minerals.usgs.gov/minerals/pubs/mcs/2013/mcs2013.pdf • USGS collaborative assessments of undiscovered mineral resources http://minerals.usgs.gov/news/newsletter/v1n2/1gmrap.html • International Resource Panel - estimation of long-run geological stocks of metals http://www.unep.org/resourcepanel/ ; http://www.unep.org/resourcepanel/Publications/AreasofAssessment/Metals/tabid/106450/Default.aspx - some good reports on global stocks/flows of metals but also cover areas like environmental impacts, water, decoupling. • Geoscience Australia's annual assessment of identified resources with international comparisons http://www.ga.gov.au/minerals/mineral-resources/aimr.html. • Steel stewardship forum http://steelstewardship.com/.
2. Step change in understanding of the geological features to depths of several kilometres or more For identifying and managing new minerals, energy and water resources,	Collation, acquisition and analyses of large multi-disciplinary regional-scale geoscience datasets: • Will include drawing on major datasets (e.g. funded by international agencies) from less developed regions that have not been readily available. • Make case for broad community-good benefits of pre-competitive geoscience surveys, cheaper and faster drilling technologies, and development of new inter-drill hole surveying techniques, development of new sensor systems for enhanced surface and subsurface

managing wastes and assessing environmental condition	geological/geophysical assessment, better digital terrain models and environmental monitoring – including miniaturisation of sensors for deployment on unmanned drones and for applications in drillholes. • Facilitate modern geological maps (including thematic) and GIS. • Promote benefits and approaches for large regional scale geochemical surveys. • Demonstrate benefits of integrating, analysing and modelling 'big data' systems, using advances in data management and modelling capabilities, including systems for geologically constrained geophysical inversions for 3D geology. Links to global observation programmes such as the Group on Earth Observations (GEO), GARS, the International Continental Drilling Program (ICDP) and Deep Exploration Technologies Cooperative Research Centre: http://detcrc.com.au/); international data initiatives, such as the NSF Earth Cube, http://earthcube.ning.com/, European (http://www.epos-eu.org/ , http://geoportal.onegeology-europe.org/), Australian (UNCOVER: http://science.org.au/policy/documents/uncover-report.pdf and other international initiatives.
3. Improved evaluations of resource potential in under-explored regions Basis for future exploration in areas that have not been comprehensively explored and new frontiers	Systematic evaluations as to whether there are likely to be significant mineral deposits in regions of interest, how these can be located and what technological, geologic, social and environmental constraints must be addressed. • Promote innovative approaches to understanding how and why mineral deposits occur where they do. Build on Centre for Exploration Targeting (www.cet.edu.au/) and USGS and Geoscience Australia activities. For selected under-explored regions, facilitate compilation of all available regional scale (pre-competitive data) geoscientific data and information for use in evaluating mineral potential Build on existing initiatives, CGMW, OneGeology, BGS International, International Geoscience Program (IGCP= joint IUGS-UNESCO initiative), etc. Address important data/information gaps – partly in collaboration with World Bank, etc. • Facilitate access to geological and geophysical data bases that are not readily accessible, and training and support in analysing and interpreting data for multiple applications o Many datasets were gathered under development contracts funded by organisations such as the World Bank, or multi-national companies, and are archived in institutions in Europe and North America, etc. • Apply and refine deposit models and mineral systems approaches, including research into previously unrecognized systems, and information from all sources including IUGS-facilitated international programs, in better assessments of mineral potential in less developed regions. o Regional mapping;

	o Applied geophysics (gravity, magnetics, radiometrics, electrical and electromagnetic methods, seismology, signal processing); o Remote sensing; GIS; radiometric, LIDAR, hyper-spectral, thermal, etc. surveys; o Locations/features of historic mines and currently uneconomic mineral and energy resources and rock alteration. o Review and refine information on tectonics, geodynamics, metallogenic provinces, metallogenic epochs/ geochronology, deposit models, mineral systems, alteration, rock properties, and geochemical features. ▪ Including craton boundaries, metallogenic significance of dispositions of paleo-continents. ▪ Sedimentary basins as sources of mineral, energy and groundwater resources. • Priority highly prospective regions include much of Africa and remnants of Tethys belt (through Middle East to eastern Asia) • Develop and maintain a data base of “recalcitrant” bodies of mineralisation and actively challenge the science community to tackle the production/processing problems they present (raise awareness of possible topics for research, innovation etc. - including potential opportunities for using bacterial processes for *in situ* mining and/or metallurgical processing). • Consider possible influences of climate change on mining and related activities (e.g. disposal of sulphidic wastes). • Options for sourcing construction materials and industrial minerals On and off shore Environmental and social impacts Recycling.
4. Capacity building and socioeconomic considerations in the developing world Necessary for effective exploration and mining as well as for good governance and socioeconomic benefits.	This major RFG program will create meaningful partnerships between the first world and interested countries in the developing world by actively seeking to build capacity, infrastructure and institutions, and provide incentives for those trained abroad to return to contribute to the development of their country: o Promote schemes in which students register at universities in their home region, but spend periods each year at first their partner; as most of their time is spent in their region they are able to transfer their knowledge immediately and be role models. Once they have graduated they continue to involve alumni in workshops and interesting projects so they can build their networks and do cutting-edge science. Provision of on-line access to analytical equipment such as spectrometers, after appropriate training. • Link with AfricaArray (http://www.africaarray.psu.edu/), etc. Training needs in the developing world include: o Fundamental underpinning role of geosciences for discovery of mineral and energy resources, groundwater, disaster reduction, siting infrastructure, building cities, etc. o Geological mapping/GIS based on remotely sensed data; o Recognising mineral systems; o Planning and managing geophysical and geochemical survey; o Integrating, analyzing and modeling geological, geophysical and geochemical data;

	o Downstream mining-related disciplines; o Environmental science and relating bioregions to geology Good governance and socio-economic considerations to enable interested countries to countries to reap social and economic benefits from responsible mining, without long term environmental impacts. Building on Australia's International Mining for Development initiative (http://im4dc.org/) and others which provide good examples of facilitating establishment of world class mining industries to boost overall economic development. Considerations include: • Geo-governance and education in relation to conflicts between resources (minerals *vs* water *vs* energy), and between production of resources and other land uses (agriculture, urbanization, conservation); o Land planning using GIS, digital terrain models, and new satellite sensors and any other technical applications that facilitate or improve relevant land use and infrastructure development decisions. o Mineral economics and law; social science and community development. • Better analysis of the life cycles of minerals and development of a recycling based economy for key metals and geological commodities; • Education of the public in acceptance of the need to use the subsurface for responsible mineral and energy extraction and waste management. • Explaining the importance of, and opportunities offered by, responsible mining. • Promoting case studies of how responsible mining can be very beneficial to the economic development of resource-rich countries • Constructively addressing negative perceptions of mining. o Given IUGS develops and promulgates international "geostandards", it could endorse and promulgate ICMM's ten principles (http://www.icmm.com/our-work/sustainabledevelopment-framework), and case studies of good practices - particularly through Australia's "Leading Practice Sustainable Development Program for the Mining Industry" (http://www.ret.gov.au/resources/resources_programs/lpsdpmining/pages/default.aspx). These could become de facto conditions for mining in countries where nothing appropriate is in place Could be integrated into Future Earth program http://www.icsu.org/future-earth

Attachment 2.

The USGS uses the McKelvey system for categorizing and reporting mineral and energy commodties in terms of geological and economic assurance (Figure 1.i). The McKelvey system is the basis for the national reporting system used by Geoscience Australia (Figure 1.iii) as well as the commercial reporting systems for individual properties used by companies, including Australasia's JORC and derivative codes (Figure 1.iii).

Unfortunately, the different terminologies within these related systems can be confusing when used out of context. The USGS national scale reporting term "Reserves" is used in a broader sense than the same term as reported by companies for individual properties. Companies use “Reserves” to describe materials that are considered to have been established to be available for mining in the foreseeable future. These “Reserves” are a component of a broader category of “Resources” reported by companies, which are generally less well-defined but are considered likely to prove after further assessment to be economic now or in the future. In fact, the USGS “Reserves” are equivalent to “Resources” as used in company reporting and Geoscience Australia’s national reporting. In this report we use “resources” as materials likely to be available for commercial production in the very long term.

The USGS has also conducted activities on quantifying undiscovered resources based on the likelihood of occurrence of a range of deposit types for which the geological features are reasonably well established.

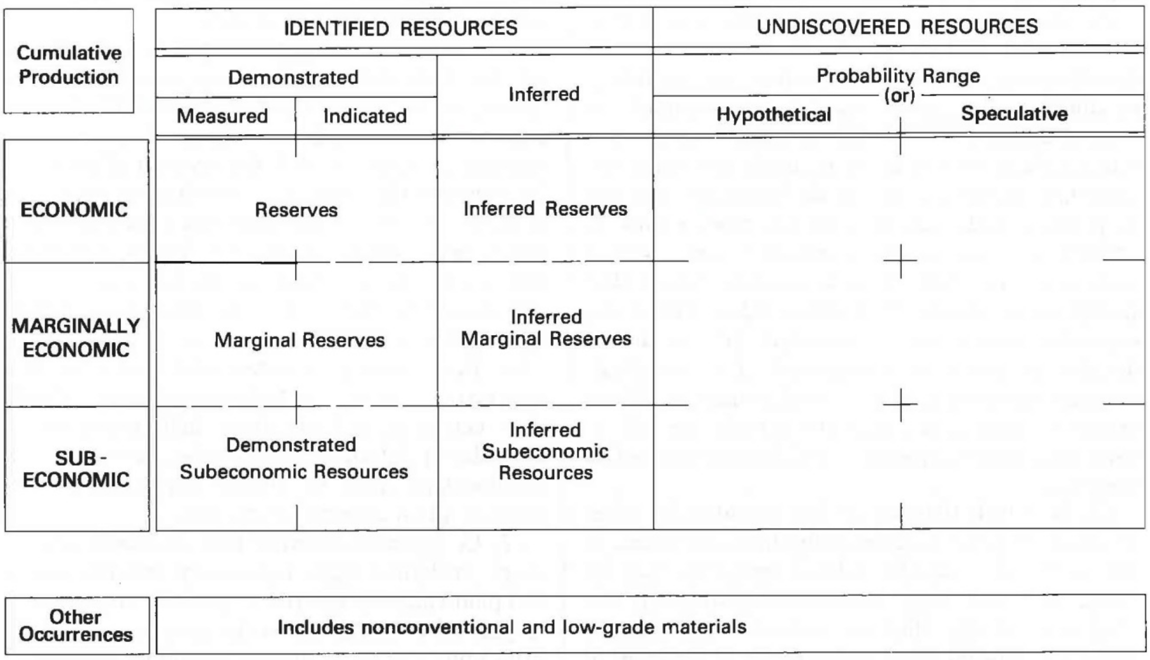

Figure 1. The McKelvey system as developed and used for systematic classifying and reporting of national and global stocks of mineral and energy commodities in terms of geological and economic assurance. For some years the only category systematically reported by the USGS has been “Reserves”.

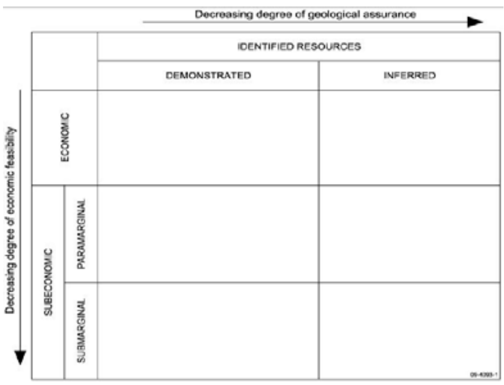

Figure 2. The adaptation of the McKelvey system for nationa-scale classification and reporting of mineral resources in Australia. In contrast to the USGS, Australia does not use “Reserves” in national reporting, as this

term has been accepted for use in commercial reporting in a more restricted sense: Economic Demonstrated Resources are used in Australia in place of the USGS' "Reserves".

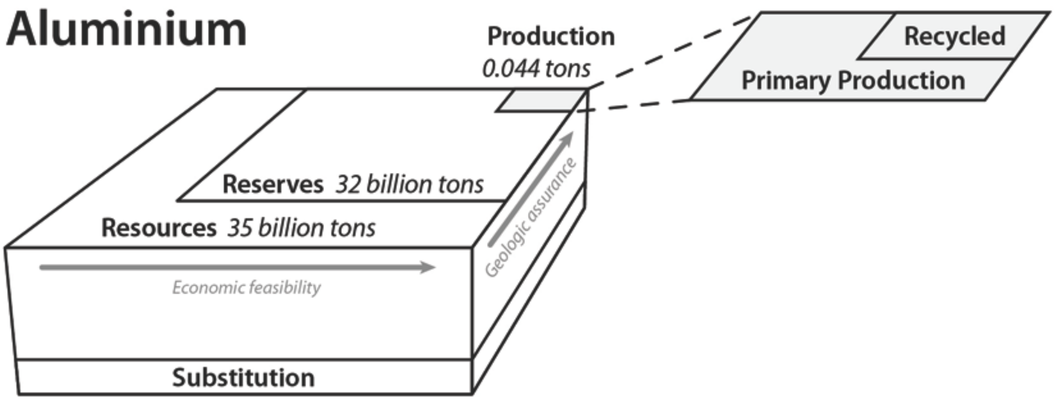

Figure 3.

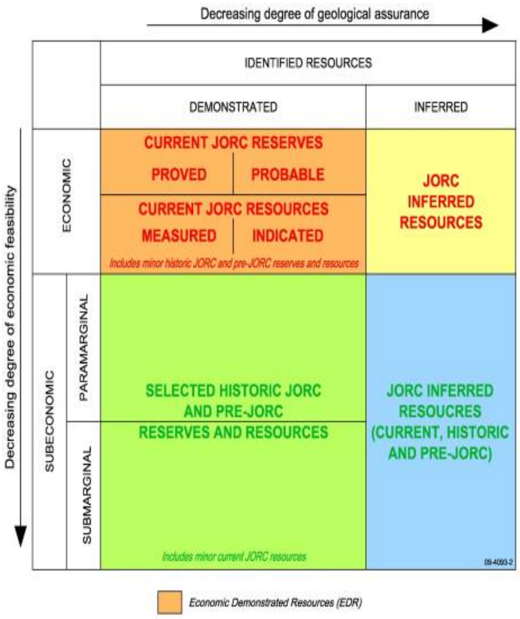

Figure 4. Relationships between the JORC Code reporting by companies and the national scale reporting by Geoscience Australia, which analyzes the data reported for individual properties by companies and aggregates Reserves and additional Resources into the main national reporting category of Economic Demonstrated Resources.