GLOBAL MINERAL RESOURCES, OCCURRENCE AND DISTRIBUTION

M. Wagner and **F. W. Wellmer**
Federal Institute for Geosciences and Natural Resources (BGR), Hanover, Germany

Keywords: Mineral Commodities, Mineral Deposits, Mineral Enrichment Processes, Mineral Availability, Mineral Supply and Demand, Natural Resources Hierarchy

Contents

1. Introduction
2. Statistical data
3. Characteristics of a mineral deposit
4. Mineral enrichment processes and formation of economic mineral deposits
4.1. Concentration in trap situations
4.2. Concentration by weathering processes
4.3. Favorable geometry of mineral bodies
4.4. Concentration of an element in amenable form for processing
5. Regional distribution of mineral deposits
6. Future developments in the regional distribution of mineral deposits
7. Concluding remarks
Glossary
Bibliography
Biographical Sketches

Summary

The world's population annually consumes about 32 billion tonnes of mineral resources valued at about $1,123 billion. All elements that comprise these economic deposits are present in the earth's crust, most of them in the range of parts per million, some even in percent range. Yet, to produce an element from the earth's crust economically, a mineral deposit must have undergone natural enrichment process.

A mineral deposit is a body, from which by size and concentration a commodity can be mined economically. It consists of reserves and is largely defined by its grade and its tonnage.

Enrichment and concentration processes are greatly influenced by geology. Each element and each commodity has a specific geologic association. This leads to a very uneven distribution of mineral deposits around the world. Enrichment basically either occurs in trap situations of varied origins or by weathering processes. The enrichment process can be conducive to mining if the mineral is concentrated in a favorable geometric form of considerable size or if the element is enriched in an amenable form for processing.

From the viewpoint of consumers, a large diversification of producers secures regular supply of minerals. Recent trend of mergers and takeovers has resulted in concentration

of companies in a particular country. Concentration of producers in a few countries must not necessarily have an adverse impact on the security of supply because the commodity could still be produced by different companies.

The future availability of resources is usually estimated using the expression lifetime, which is the quotient of known reserves and current annual consumption. However, reserves lifetime is not a suitable index for measuring the future availability of minerals but rather a snapshot in time. For all mineral commodities so far a stable balance has occurred between consumption and reserves during the past 50 years. This was largely achieved by the on-going mineral exploration. Another aspect is that humans do not need specific minerals as such, but products made from them, needed to perform a given function. Minerals provide all resources of the geosphere for human use. By combining the available resources of the geosphere and the technosphere with our ingenuity we can be assured of fulfilling our needs for the foreseeable future.

1. Introduction

In the EOLSS-Forerunner paper 1.12 *World Natural Resources Policy* (with focus on Mineral Resources) a hierarchy of natural resources was proposed with regard to the concept of sustainable development and a responsible future (Wellmer and Becker-Platen, 2001; Figure 1).

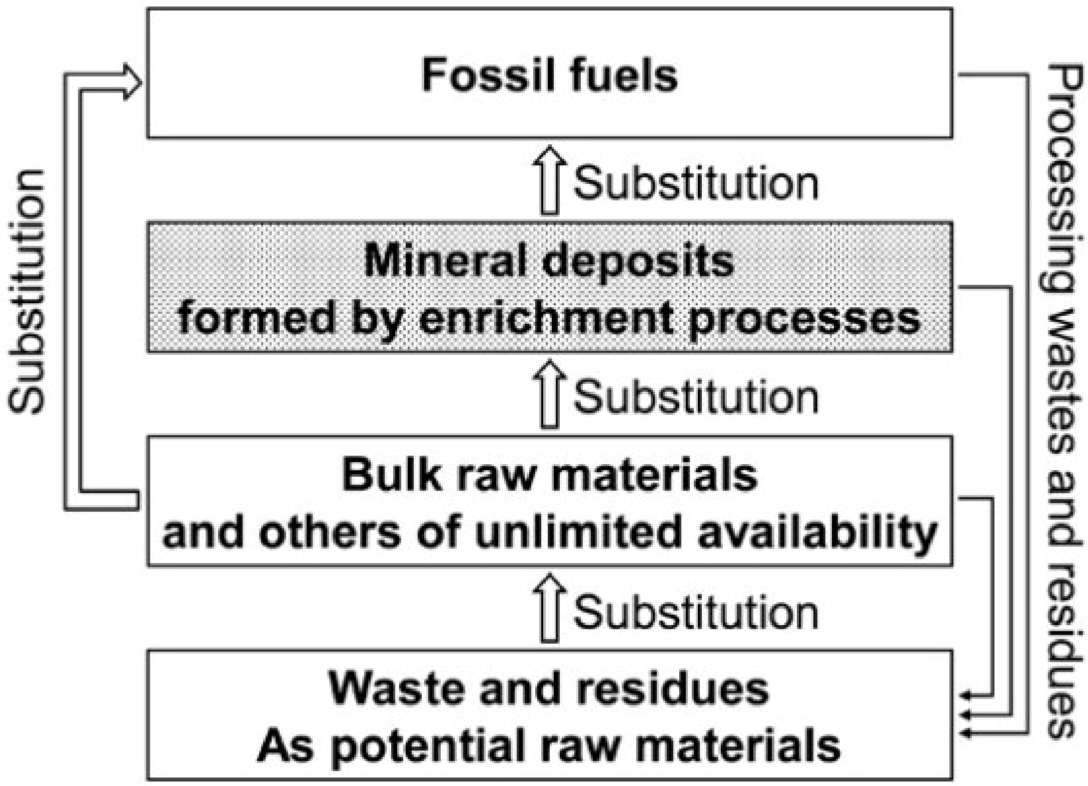

Figure 1. Concept of the natural resources hierarchy: resource management for sustainable development (after Wellmer and Becker-Platen 2001)

At the top of the hierarchy (Level 1) are the energy resources, followed by those resources which have to be produced from deposits based on enrichment processes that include nearly all metals and some non-metallic raw materials, like phosphate, fluorspar, or barite for example (Level 2).

The next one in the hierarchy (Level 3) is made up of those raw materials which by nature are available in an unlimited amount in the earth's crust, such as construction raw materials, potash and magnesium in sea water, or nitrogen in the air as a base for nitrate fertilizer.

The lowest level (Level 4) consists of waste and residue materials that can substitute for other primary materials higher up in the natural resources hierarchy.

Since energy is dealt with elsewhere in the EOLSS-series, only Level 2, 3 and 4 are being discussed here. Ways by which waste and residue materials from burning—ashes from coal fired power plants, used for cement manufacturing—or by-products from beneficiation of higher value metallic ores superior within the hierarchy, utilized in the construction industry, can replace primary resources, have also been discussed before (Wellmer and Becker-Platen 2001, 2002).

Also the availability of the resources in Level 3 which from the geological point of view are available in unlimited amounts in the earth's crust, but for which limitations result from man-made causes such as from competing land claims, has been dealt with in the same articles.

This present article therefore focuses on the raw materials in Level 2 which are derived from mineral deposits formed by geological enrichment processes.

2. Statistical data

The world's population annually consumes (or uses) about 32 billion tonnes of mineral resources (not including water) valued at about $1,213 billion in 2003 (Wellmer et al. 2003). The word "use" is applied here because some natural resources, including most metals, are recyclable, and in this sense are not consumed.

The quantities of the resources (in weight units) are shown in a pyramid form in Figure 2 indicating the level of hierarchy of natural resources to which they belong. An equivalent pyramid can be established in terms of value in 2003 Euros (Wellmer and Becker-Platen 2001, Wellmer et al. 2003).

For this article, reference was made to the 2003 price level, avoiding the period of high price volatility of recent years. The wide base of the pyramid in Figure 2 is based on weight and is made up of bulk construction materials, sand and gravel, as well as crushed rock (Level 3 commodities).

Just above these are the fossil fuels: coal, oil and natural gas (Level 1 commodities). The same two groups of resources would be situated at the bottom of the value pyramid, but in a reverse order.

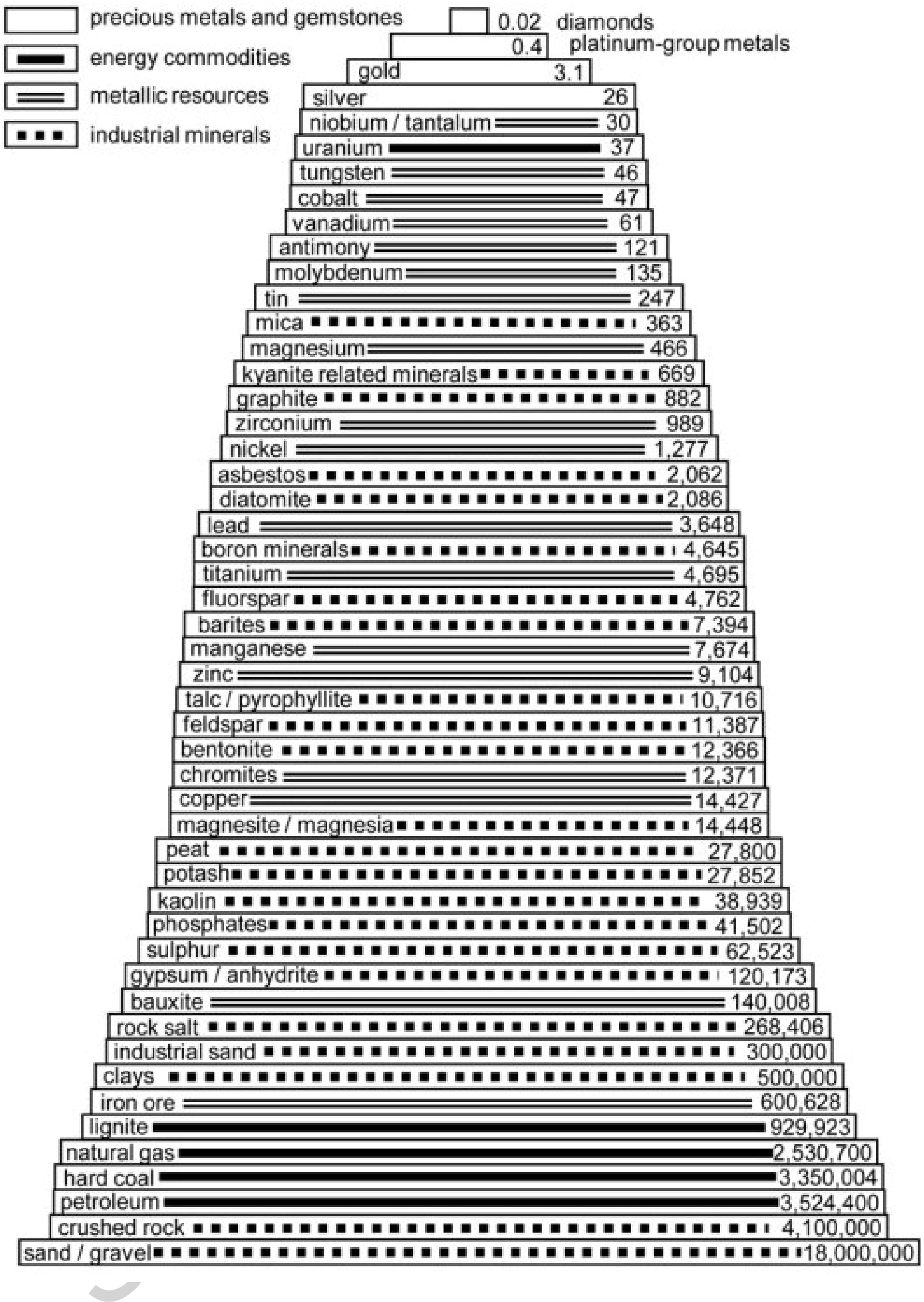

Figure 2. The 2002 raw materials pyramid based on weight – annual consumption in 1,000 t, natural gas in million m³ (datasource: BGR – databank).

Of the Level 2 commodities non-metallic mineral resources make up most of the bottom half of the pyramid by weight in Figure 2. The metals lie mostly in the upper half. Most of the 93 naturally occurring elements are metals. Of these metallic elements, most are not of significant economic importance as metals, but rather are important in their non-metallic form: examples include the elements potassium, sodium, and calcium, which are of great importance as salt ($NaCl$), potash [KCl or $KCl{\cdot}MgCl_2{\cdot}6H_2O$], and limestone ($CaCO_3$). Only nine metals are consumed in quantities of more than one million tonnes annually and include: iron (the most important metal by far), aluminum, copper, manganese, zinc, chromium, lead, titanium, and, since 1999, nickel. Iron and iron ore lie just above the construction materials and fossil fuels in the weight pyramid (Figure 2) with only gold in between them in the value pyramid (Wellmer et al. 2003). The 3,000 tonnes of gold (the metal with nearly the smallest amount produced annually) is of greater value than the 600 million tonnes of iron ore (the metal with the largest annual production). The noble metals and precious stones— resources produced in the smallest quantity—make up the top of the weight pyramid (Figure 2). Lately, another group of raw materials, the so-called electronic metals, are being added to the list. As these materials are at present indispensable in the high tech end of the industrial process, one may argue that they govern all material flows of mineral raw materials of the pyramid below, basically all minerals that are produced and consumed (Figure 3).

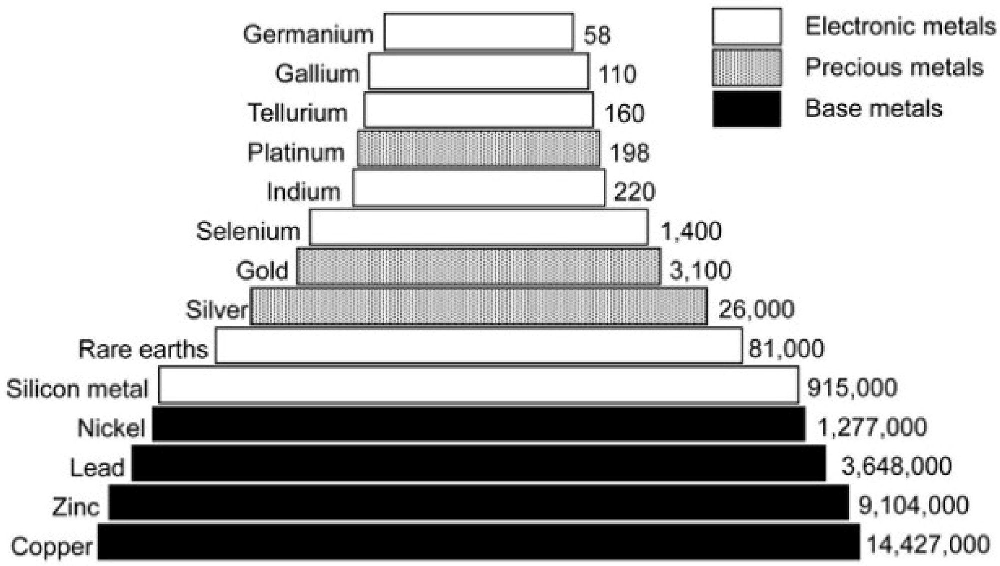

Figure 3. The electronic metals form the top of the raw materials pyramid, reference year 2002 – annual consumption in t (datasource: BGR – databank).

The following generalizations may be made about the patterns reflected by the mineral pyramids: The resources at the base of the pyramids provide for our basic needs, e.g. construction materials for our homes and infrastructure; and fuels for heating and transportation. The resources at the top of the pyramid, the so-called electronic metals and the noble metals, are needed in applications to make our resource utilization more efficient, particularly in the case of energy resources with the help of electronic control devices.

3. Characteristics of a mineral deposit

All elements are present in the earth's crust, most of them occur in parts per million (ppm, or grams per tonne) range; some, like iron or aluminum, in the range of percent. This, however, does not mean that they are available in unlimited amounts, because exploiting these metals at such low concentrations would entail prohibitive costs.

If one produces manufactured goods like automobiles, bicycles, or textiles and one operates in an area with the same legal, social, and economic framework the profitability of one's operation in comparison to the competitors mainly depends upon its creativity and management skills. This is not so in the natural resources economics: The economic viability and profitability is controlled by the natural geologic processes that result in the desired level of concentration or enrichment of the sought-after commodity. Economic theory suggests that a mineral deposit with the lowest concentration, that must be mined to meet the last increment of demand in a market economy, is also the last marginal deposit (Radetzki, 1990).

A mineral deposit is a body of naturally occurring geologic material, from which by concentration, enrichment or other processes, a commodity can be mined profitably, qualifying it to be categorized as reserve (United Nations, 1997). Resource, on the other hand, represents minerals with an inadequate concentration that render them uneconomic at the time of evaluation. Since technologies change over time, mining economics also change. Therefore, "deposit" is not an absolute term; it is rather a dynamic term. A deposit which was profitably mined in the past may become uneconomic today and could merely constitute a resource. The same holds true the other way around. Resources of today may become reserves of tomorrow. The following examples illustrate each case:

1. In 1960, 50% of the iron ore needed for the German steel industry was produced domestically, or in adjacent countries like France. At that time more than 70 iron ore mines, with an average grade of some 30% Fe, were operating in Germany. Today Germany has none and imports all iron ore it needs. The imported iron ore is of high grade containing above 60 % Fe. One of the largest German iron ore mines, the Konrad mine, about 80 km east of Hanover, operated from April 1965 to October 1976. Today the abandoned mine is being considered for a low- and medium-level radioactive waste repository. Although one of the two hoisting shafts of the Konrad mine stands next to a blast furnace of the Salzgitter steel works, the material (former "iron ore") being excavated for the underground waste storage facility, is not considered an ore of iron any longer. In fact, what was once an economic commodity is now a waste material that is being transported 10 km southwest of the Konrad mine site for disposal as a backfill material in an old mine.

2. Formerly, very fine-grained lead-zinc ores, typical in some sedimentary and volcanogenic deposits, could not be exploited economically because beneficiation techniques at that time did not allow separating the lead and zinc minerals-galena and sphalerite. Then in the 1950s the Imperial Smelting process was developed to treat combined lead-zinc concentrates. Hence, it became unnecessary to separate the lead and zinc minerals by ore dressing. Instead, the two metals could be separated during this innovative smelting process. Suddenly, these fine-grained lead-zinc deposits became economic: *Resource turned into reserve*. Examples are the sedimentary Anvil lead-zinc deposit in the Yukon Territory, Canada, and the McArthur River mine in the Northern Territory of Australia. Also, because the Imperial Smelting process is not affected by higher mercury impurities than other processes, it resulted in and thereby made the Song Tho lead-zinc deposits in Thailand to be of economic value instantly.

-
-
-

Bibliography

Ayres R.U., Ayres L.W. and Råde I. (2002). *The Life Cycle of Copper, its Co-Products and By-Products*. MMSD Report 24. 200 p. London: International Institute for Environment and Development. [This contains a global model of copper demand and supply and discusses the negative impacts of copper production. Available at: http://www.iied.org/mmsd/wp/]

Bardossy G. and Aleva G.J.J. (1990). *Lateritic Bauxites*. 624 p. Amsterdam, Oxford, New York, Tokyo: Elsevier. [This monograph is a detailed description of the features of lateritic bauxites as well as a compiled description of all major bauxite deposits or provinces].

Bates R.L. and Jackson J.A. (eds) (1987). *Glossary of Geology*. 788 p. Alexandria: American Geological Institute. [This presents a comprehensive dictionary of geologic terms.]

Cox D.P. and Singer D.A. (eds) (1986). *Mineral Deposit Models*. Bulletin U.S. Geological Survey 1693. 379 p. Washington DC: U.S. Gov. Print. Office. [The Bulletin provides standardized descriptive models and grade/tonnage distribution of basically all metal deposit types.]

Evans A.M. (1993). *Ore Geology and Industrial Minerals – An Introduction*. 390 p. Oxford: Blackwell. [This textbook gives an overview of mineral deposit forming processes.]

Franklin J.M. (1993). Volcanic-associated massive sulphide deposits. In: Kirkham R.V., Sinclair W.D., Thorpe R.I. and Duke J.M. (eds). *Mineral Deposit Modelling*, GAC special Paper 40. pp. 315-344. St. John´s: Geol. Assoc. Canada. [This presents encyclopaedic presentation on the specific deposit type with the focus on Canada.]

Friedensburg F. (1965). Entwicklungstendenzen im Weltbergbau – *Vierteljahreshefte zur Wirtschaftsforschung 1* 1965. pp. 84-96. [This retrospective paper reveals the trends in worldwide mining during the last 100 years.]

Giegerich H.M. 1986. Polaris and Red Dog. In: *Towns, Wheels or Wings For Resource Development?* 15 p. Vancouver: Institute for Research on Public Policy. [This conference paper presents the technical and financial project characteristics of two new base metal mines of the time.]

Gilmour P. (1982). Grades and tonnages of porphyry copper deposits. In: Titley S.R. (ed). *Advances in Geology of the Porphyry Copper Deposits, Southwestern North America*. pp. 7-35. Tucson: The University of Arizona Press. [This article describes grade and tonnage of porphyry copper deposits with special regard to the deposits in the South-western U.S. states]

Grunsky E.C. (1995). Grade and tonnage data for British Columbia mineral deposit models. In: Grant B. and Newell J.M. (eds). *Geological Fieldwork 1994 Paper B.C. Geological Survey* 1995-1. pp. 417-423. Victoria: B.C. Ministry of Energy, Mines and Petroleum Resources. [This paper discusses the advantages and shortcomings of computerized grade/tonnage models.]

Keays R.R. (1996). Nickel in a nutshell. In: *Proc. 64th Annual Convention and Trade Show of the Prospectors and Developers Assoc. of Canada*, 6 p. Toronto: PDAC. [This conference paper describes the features and enrichment processes of nickel sulfide deposits.]

Radetzki M. (1990). *A Guide to Primary Commodities in the World Economy*. 185 p. Oxford: Blackwell. [This textbook constitutes an introduction to the macroeconomic impacts of the mineral sector and the basic economic mechanisms that characterize it.]

Sames C.W. (1986). *Anaconda - Berichte aus der Rohstoffwelt*. 363 p. München: Wirtschaftsverlag Langen-Müller. [This book provides a general overview of the mining sector and reveals the mechanisms that govern by giving by illustrative examples.]

Singer D.A. and de Young, Jr. J. (1980). What can grade-tonnage relations really tell us? *Memoire du BRGM* 106. pp. 91-1001. [This contributes to the discussion on the pitfalls of grade/tonnage models.]

Singer D.A., Berger V.I. and Moring B.C. 2002. Porphyry Copper Deposits of the World: Database, Maps, and Preliminary Analysis. 62 p. *U.S. Geological Survey Open-File Report* 02–268. 62 p. Washington DC: U.S. Gov. Print. Office. [This publication contains a computer file of information on porphyry copper deposits around the world. It also presents new grade and tonnage models for three subtypes of porphyry copper deposits. Available at: http://geopubs.wr.usgs.gov/open-file/of02-268/]

Singer, D.A.: (1995). World class base and precious metal deposits: a quantitative analysis. *Econ. Geol.* 90. pp. 88-104. [This article analyses the grade/tonnage distributions of mineral deposits.]

United Nations (1997). *United Nations International Framework Classification for Reserves/Resources.* 23 p. New York: United Nations. [This presents a suggestion for an internationally standardized reserve classification taking into account the national classification systems.]

Wagner M. (1999). Ökonomische Bewertung von Explorationserfolgen über Erfahrungskurven. *Geologisches Jahrbuch* Heft SH 12. 225 p. Hanover. [This work analyses the development of reserves during the lifetime of a mine taking into account the concept of learning curves and provides an economic model for optimizing mine capacity.]

Wellmer F.W and Kosinowski M. (2003). Sustainable Development and the Use of Nonrenewable Resources. *Geotimes*, Dec. pp. 14-17. [This presents the global mineral consumption trends and links them to the concept of sustainability.]

Wellmer F.W. (1998). Lebensdauer und Verfügbarkeit energetischer und mineralischer Rohstoffe.- *Erzmetall* 51. pp. 663-675. [The geological and economic parameters usually used to estimate the future availability of a resource are discussed in relation to human creativity, e.g. recycling, substitution, and technological progress.]

Wellmer F.W. and Becker-Platen J.D. (2001). World natural resources policy (with focus on mineral resources). In: Tolba M.K. (ed). *Our fragile world –Challenges and opportunities for sustainable development*. pp. 183-207. Oxford: EOLSS Publ. [This presents an overview of international mineral trends with regard to future availability and proposes a hierarchy of natural resources with regard to the concept of sustainable development and a responsible future.]

Wellmer F.W. and Becker-Platen J.D. (2002). Sustainable development and the exploitation of mineral and energy resources: a review. – *Int. J. Earth Sciences* (Geol. Rundschau) 91. pp. 723-745. [This relates the global mineral industry to the concept of sustainability.]

Wellmer F.W., Dalheimer M. and Wagner M (2008). Economic Evaluations in Exploration. 250 p. Berlin, Heidelberg, New York: Springer [This gives rules for the economic evaluations of ore deposits.]

Wellmer F.W., Leifeld D., Röhling S. and Wagner H. (2003). Mineral and energy resources: Economic factor and motor for research and development. *Zeitschrift der deutschen Geol. Gesellschaft* 154. pp. 1-27. [This relates technological progress and development to the future availability of minerals.]

Biographical Sketches

M. Wagner is a geologist and industrial engineer by training with additional studies in mine management and ore dressing. He holds a doctorate in mineral economics from the Technical University of Berlin. Having worked as an exploration geologist and project manager in West African gold exploration for Hansa GeoMin Consult since 1997, he joined Federal Institute for Geosciences and Natural Resources (BGR) in 2000. Since 2003, he is heading the Section Metallic Resources, Mineral Economics of BGR.

F. W. Wellmer, president of Federal Institute for Geosciences and Natural Resources (BGR) and NLfB (Lower Saxony State Geological Survey) in Hanover from 1996 to 2005, studied mining geology and geology at the Technical Universities of Berlin and Clausthal and obtained his doctorate at Clausthal. He worked for Metallgesellschaft and its Canadian and Australian subsidiaries and was involved in mineral exploration projects in Europe, North Africa, North and South America, and the Far East, and was subsequently made Director of Exploration of the Australian subsidiary of Metallgesellschaft. In 1987, Prof. Wellmer joined BGR as Head of the Economic Geology and International Cooperation Division. He is Honorary Professor of Mineral Resources Policy and Economic Geology at the Technical University of Berlin. He has received honorary doctorates from the Mining Academy at the Technical University of Freiberg in 1999 and in 2001 from the Technical University of Clausthal.