# Environmental Planning Issues and a Conceptual Global Assessment of Undiscovered Nonfuel Mineral Resources

By Joseph A. Briskey,[1] Klaus J. Schulz,[1] John P. Mosesso,[1] Lief R. Horwitz,[2] and Charles G. Cunningham[1]

## Introduction

Global demand for materials, including nonfuel mineral resources, will continue to increase (fig. 1) for the foreseeable future because of the continuing growth of global population and efforts to improve living standards worldwide. About 89 percent of these materials, as reported by Matos and Wagner (1998), consist of nonfuel mineral resources. Copper consumption in China exemplifies the growing global consumption of nonfuel mineral resources (fig. 2). If China grows and develops over the next 25 years at a rate like that of South Korea in the past 25 years, then China could consume more copper in 2025 than was produced in the world in 1995 (Menzie and others, 2003, 2005). Moreover, "industrialization is central to economic development and improved prospects for human well-being … . A substantial share of industrial growth in developing countries revolves around the transformation of raw materials into industrial materials" (World Resources Institute and others, 1998, p. 51).

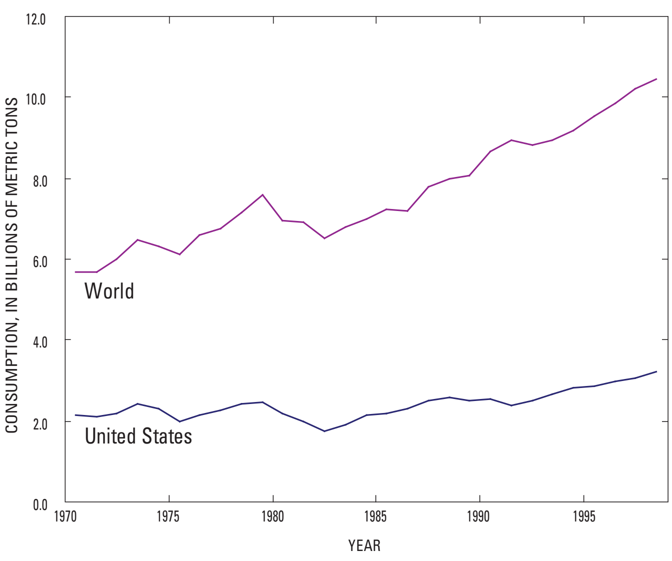


**Figure 1.** Graph of world and U.S. consumption (use) of nonfood, nonfuel, and nonrenewable materials, including construction materials, industrial minerals, primary and recycled metals, nonrenewable organic materials, primary and recycled paper, wood products, and material derived from agriculture (Matos and Wagner, 1998; Brown and others, 2000, p. 28; Grecia Matos, U.S. Geological Survey, written commun., 2002).

No global shortages of nonfuel mineral resources are expected in the near future. However, society's ability to meet the continuing and growing demand for minerals requires sustained exploration for, and development of, new mineral deposits. At the same time, mineral exploration and development increasingly are constrained by a variety of real and perceived factors that have begun limiting the availability of mineral resources. Among these factors are (1) other competing land uses; (2) limited local economic and social benefits of mining, especially to populations in developing countries; (3) wasteful or inefficient use of mineral materials; and (4) adverse environmental effects of mining, together with distrust of those who promise that such effects can be prevented or

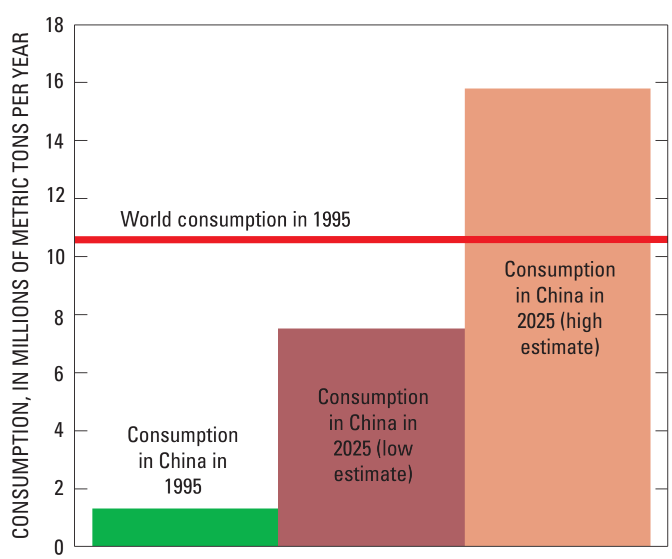


**Figure 2.** Graph of copper consumption in China (in millions of metric tons per year). If China grows and develops in the next 25 years as South Korea has in the past 25 years, then China could consume more copper in 2025 than the whole world used in 1995 (Menzie and others, 2003, 2005).

[1]U.S. Geological Survey, 954 National Center, 12201 Sunrise Valley Drive, Reston, VA 20192–0002, U.S.A. (e-mail: jbriskey@usgs.gov).

[2]U.S. Geological Survey, 909 1st Avenue, Seattle, WA 98104–1055, U.S.A.

effectively and permanently mitigated. In particular, mineral development is affected especially by growing concerns about possible environmental degradation associated with mineral exploration and production.

Unanticipated, and therefore unplanned, mineral exploration and development, especially in sensitive ecosystems and other environments, can add to the ongoing fragmentation and destruction of habitats required for the long-term maintenance of key plant and animal communities and to an overall reduction in ecosystem health. Increasingly, human populations and their activities "are disturbing species and their habitats, disrupting natural ecological processes, and even changing climate patterns on a global scale" (President's Committee of Advisors on Science and Technology, 1998). "We are modifying physical, chemical, and biological systems in new ways, at faster rates, and over larger spatial scales than ever recorded on earth" (Lubchenco, 1998, p. 492). "If current trends continue, humanity will dramatically alter virtually all of Earth's remaining natural ecosystems within a few decades" (Daily and others, 1997, p. 3). One measure of these concerns is shown by the extent to which domesticated land has replaced much of the Earth's original land cover, as illustrated in figure 3. Another measure is the decline of Earth's forests, as shown in figures 4 and 5.

What is the one thing the average person is most likely to believe about mining?

- Is it that we are running out of nonfuel minerals with some dire consequence? Probably not. There is no global shortage of nonfuel minerals at present.
- Is it that mining is an important part of the global economy? Probably not. By some measures, the mining sector appears to be a small player. Pierre Lassonde, Chief Executive Officer (CEO) of Franco-Nevada Mining, recently pointed out (Kral, 2000, p. 46) that "adding together all of the global gold, copper, aluminum, nickel, zinc, and diamond producers represents a business with a total market capitalization of about US$200 billion. Some individual companies like Microsoft and Cisco Systems are valued at more than US$400 billion. Rio Tinto, the biggest mining company in the world, has a market capitalization of about US$25 billion."
- Is it that a number of mining companies are making major new advances in mitigating, remediating, and preventing much of the environmental impact of mining? No, probably not.
- Is it that mining causes environmental and sometimes social disasters? Probably yes.

The negative image of mining has reached the point where leaders of some major mining companies are beginning to recognize and promote the necessity and benefits to

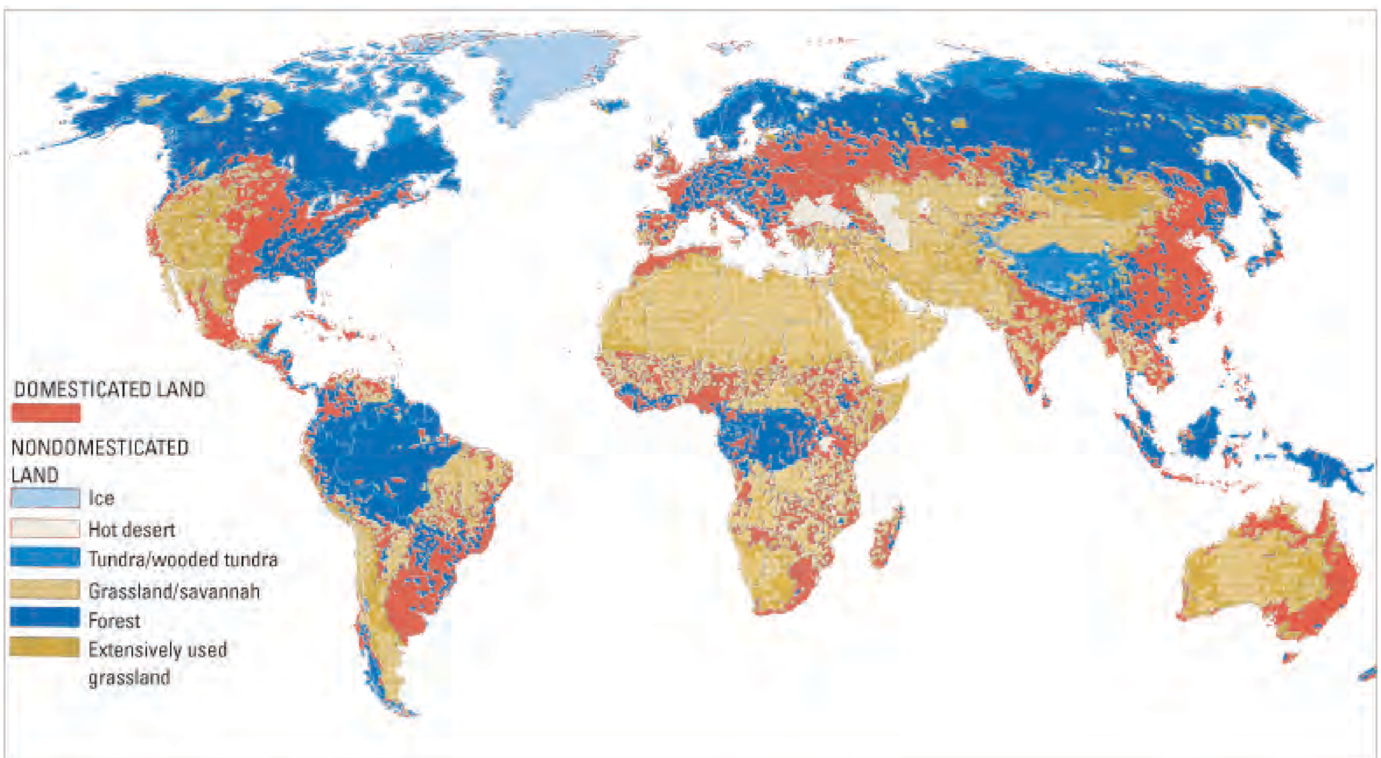


**Figure 3.** Map showing global distribution of domesticated and nondomesticated land areas. "Domesticated land has replaced much of Earth's original land cover. Over time, humans have converted forests and natural grasslands to croplands, pasture, urban and suburban areas, and industrial zones" (World Resources Institute and others, 1998, p. 222). Map from World Resources Institute and others (1998); reproduced by permission of the World Resources Institute. Red stippling along some continental margins, mainly in the Northern Hemisphere, is an artifact of computer colorization.

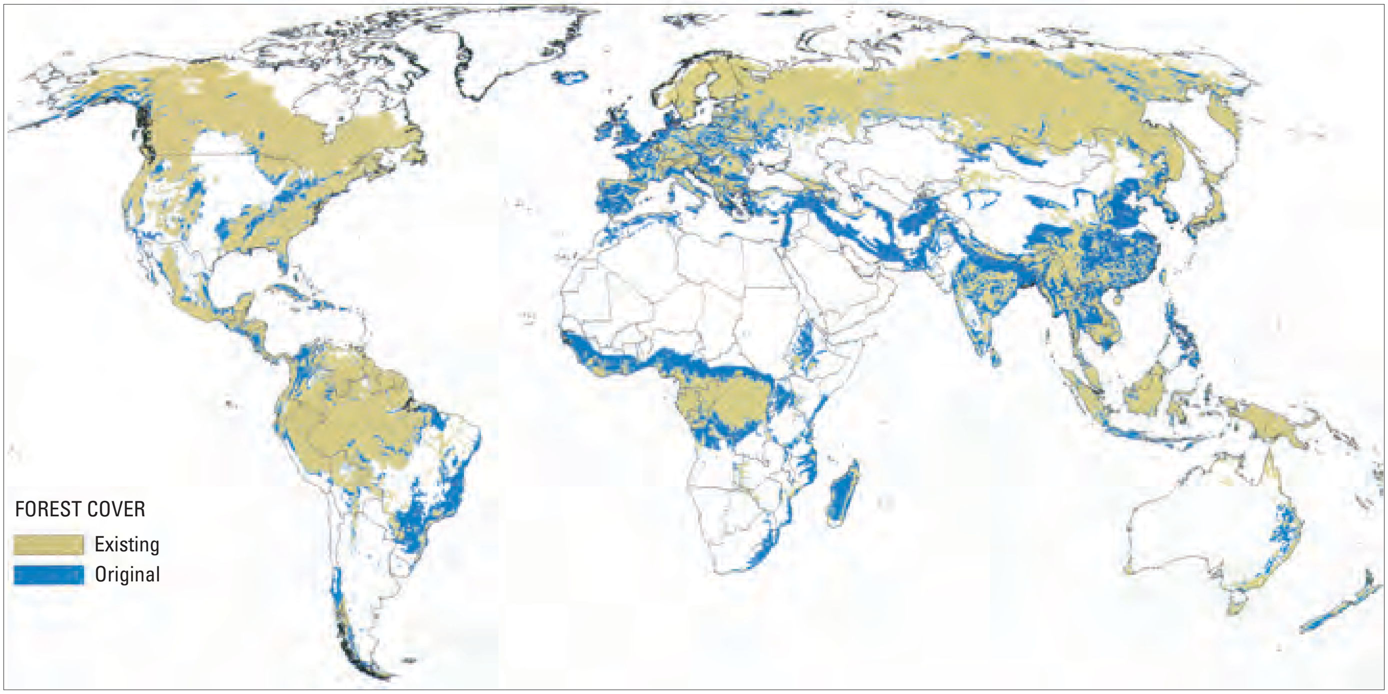


**Figure 4.** Map showing decline in forest cover around the world. Over the last 8,000 years, the world's forests have shrunk by nearly half with the clearing of boreal and temperate forests in the early centuries, followed today by high deforestation rates in the tropical forests. Map from World Resources Institute and others (1998); reproduced by permission of the World Resources Institute.

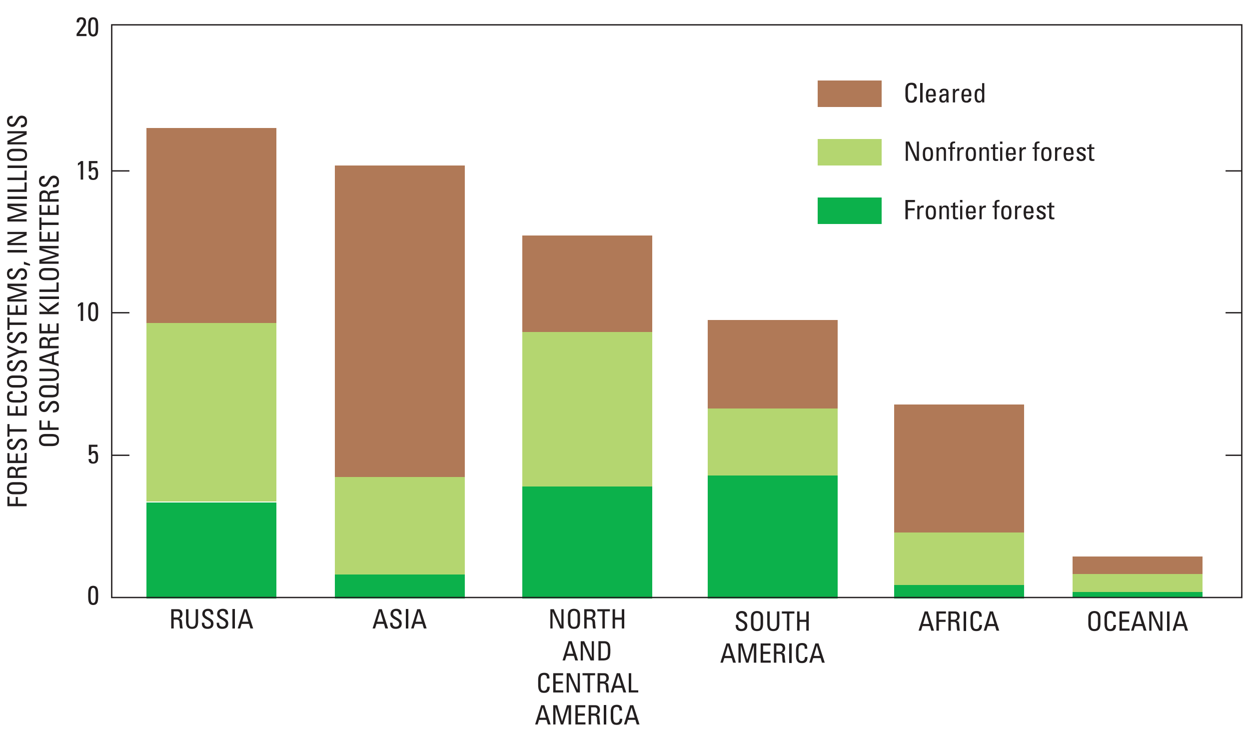


**Figure 5.** Graph showing the decline of global forest ecosystems. "Just one fifth of the Earth's original forest remains in large, relatively natural ecosystems—what are known as frontier forests" (World Resources Institute and others, 1998, p. 187). Graph from World Resources Institute and others (1998); reproduced by permission of the World Resources Institute.

the mining industry of admitting to past shortcomings and embracing environmental and social values and responsibilities in the cause of sustainable development. Patrick James, CEO of Rio Algom Ltd, was among the first voices (James, 1999) to urge that mining, like other forms of development, must contribute not only economic value to stakeholders but also environmental and social value. He emphasized that, "as an industry, we will gradually find ourselves unable to operate anywhere if we are incapable, or reluctant to effectively combine economic, environmental, and social goals everywhere we do business" (James, 1999, p. 90).

Sir Robert Wilson, Executive Chairman of Rio Tinto, in summarizing the major challenges facing the mining industry (O'Neil and others, 2000), asserted that mining finds itself in increasing disfavor in the United States, Canada, Europe, and many other parts of the world. Industry's traditional responses—to say that criticisms are ill founded, to remind critics that they depend on mineral products, and to engage in education, advertising, and public relations campaigns—have all been to little or no avail. Mining's reputation continues to deteriorate. Sir Robert urged the mining industry to change the nature of its dialog with stakeholders, especially with nongovernmental organizations. He supported a new global mining initiative to seek independent analysis of issues that will determine the future of mining, and he recognized that these issues are social and environmental as well as economic (O'Neil and others, 2000). The global mineral resource assessment discussed herein is an important component of such an analysis.

# Global Land and Resource Planning

Informed planning and decisions concerning biological sustainability and resource development require a long-term perspective and an integrated approach to land use, resource, and environmental management worldwide. This approach, in turn, requires unbiased information on the global distribution of identified resources and, especially, of undiscovered resources; the economic, social, and political factors influencing their development; and the environmental consequences of, and requirements for, their use.

The world's current approach to land and mineral resource planning appears to be piecemeal and haphazard rather than comprehensive and integrated. In separate actions by diverse governmental and nongovernmental organizations over the years, mineral development has been prohibited or has been proposed to become prohibited, in large parts of the world, including Antarctica; the Arctic Islands; numerous national and international parks, wildlife preserves, and wilderness areas; tropical rainforests; temperate old-growth forests; a variety of alpine and desert regions; and many other sensitive or endangered habitats, ecosystems, scenic vistas, and roadless areas. Concomitantly, and ironically, as countries grow, develop, and use more mineral products, mining can become increasingly unwelcome at home. Sources of future mineral supply rapidly are becoming more restricted, while national and international governmental and nongovernmental organizations appear to be devoting little effort to identifying and assuring access to areas of future mineral supply that might best sustain the environmental effects of mining.

The economies of highly industrialized societies use tremendous amounts of materials per capita—45 to 85 metric tons per person per year in one study cited by the World Resources Institute and others (1998). Further, the use of these materials requires moving or processing huge amounts of natural resources not actually used in the final product. As much as 50 to 75 percent of this hidden materials flow, and associated environmental effects, often takes place in other countries (World Resources Institute and others, 1998). Highly industrialized societies can help plan global mineral development and ecosystem sustainability by helping initiate and conduct an international assessment of the probable regional locations, amounts, and types of the world's remaining undiscovered nonfuel mineral resources in relation to sensitive ecosystems and habitats. With such information, mineral development could be encouraged in those areas most able to sustain the environmental effects of mining and mineral processing and discouraged or carefully managed in especially sensitive areas. If the choices for future supplies of some minerals prove to be limited mostly to areas where maintaining ecosystem health and sustainability may be difficult, then international cooperation could be justified and accelerated to (1) optimize materials flows and recycling of materials derived from these minerals, (2) promote research into alternative materials and technology to replace these minerals or minimize their use, and (3) develop advanced new mitigation techniques for exploration, mining, and processing for these minerals. "An electorate that does not understand the natural world or the nature of the tradeoffs that must be made in managing it wisely and sustainably cannot make informed decisions" (President's Committee of Advisors on Science and Technology, 1998, p. xviii).

# A Global Mineral Resource Assessment

In response to growing concern about the global sustainability of nonfuel mineral production and environmental quality, and the concomitant increase in demand for global mineral resource information, the U.S. Geological Survey (USGS) is joining with international collaborators to identify the regional locations and estimate the probable amounts of the world's undiscovered nonfuel mineral resources at a scale of 1:1 million on land in conventional deposit types to a depth of 1 kilometer. The assessment will begin with copper, platinum-group metals, and potash. Potash will be assessed to a depth of 2 kilometers.

Teams of experts following the USGS three-part protocol for mineral resource assessment (Singer, this volume) will delineate areas where geology permits the occurrence of a given type of undiscovered mineral deposit. The teams then will make subjective, probabilistic estimates of the numbers

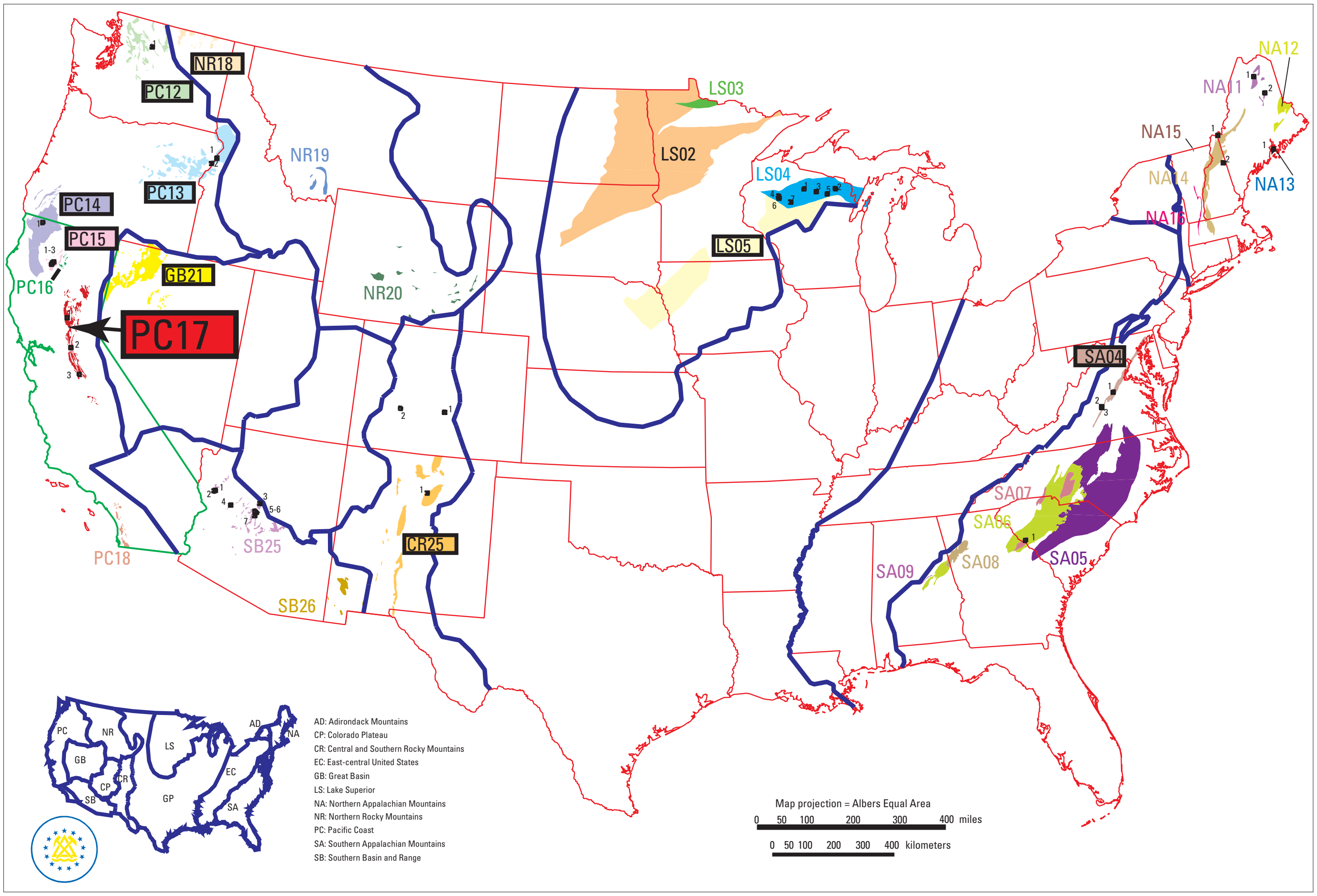


**Figure 6.** Tract map for kuroko massive sulfide deposits in the conterminous United States showing areas where the geology is permissive for the occurrence of this type of deposit. Favorable areas are shown by different colors and labels. From Luddington and others (1996). Estimates of undiscovered deposits and metal resources in tract PC–17 are shown in figures 7 and 8.

of undiscovered deposits they believe to exist in each area. To help interpret results such as these, a computer program called MARK3 (Root and others, 1992; Duval, 2001) was developed. The program uses Monte Carlo simulation to combine the estimated numbers of deposits with appropriate grade and tonnage models to produce a probability distribution of the quantities of contained metals or other mineral commodities. The net present value of the undiscovered resources will be analyzed by using new economic filters under development for addition to MARK3 (J.S. Duval, USGS, oral commun., 2000).

The three-part assessment protocol was used by the USGS to produce the first assessment of conventional undiscovered deposits of gold, silver, copper, lead, and zinc in the United States (Ludington and others, 1996). Illustrative examples of products from this national assessment are shown in figures 6, 7, and 8 for undiscovered kuroko massive sulfide deposits. At a minimum, three types of data are needed for an assessment of undiscovered mineral resources: (1) maps showing the locations, sizes, and geologic types of significant known mineral deposits and occurrences; (2) geologic maps compiled to show rocks permissive for the occurrence of undiscovered mineral deposits by type; and (3) as much information as possible about mineral exploration history.

# Conceptual Assessment Products and Some Potential Environmental Planning Issues

Assessments of undiscovered mineral resources can be of great importance in helping society recognize, discuss, manage, and minimize or prevent environmental impacts associated with mineral exploration and mining, while maintaining or expanding mineral supplies. This section briefly describes a few of the potential environmental planning issues that might be identified and addressed in part by a global mineral resource assessment. A hypothetical example of such an assessment is illustrated conceptually in figure 9 and is intended only as a starting point for discussion of such issues.

## Biodiversity and Sensitive Habitats

With reference to figure 9, what are some examples of the potential consequences of mineral development that might be considered with respect to biodiversity and sensitive habitats?

### Estimated Undiscovered Deposits

There is a 90% or greater chance of 2 or more deposits.
There is a 50% or greater chance of 13 or more deposits.
There is a 10% or greater chance of 25 or more deposits.
There is a 5% or greater chance of 25 or more deposits.
There is a 1% or greater chance of 25 or more deposits.

### Estimated amounts of contained metal and mineralized rock, in metric tons

| Quantile | Cu | Au | Zn | Ag | Pb | Rock |
|---|---|---|---|---|---|---|
| 0.95 | 700 | 0 | 0 | 0 | 0 | 97,000 |
| 0.90 | 12,000 | 0 | 12,000 | 18 | 0 | 690,000 |
| 0.50 | 140,000 | 16 | 260,000 | 710 | 46,000 | 8,500,000 |
| 0.10 | 310,000 | 45 | 815,000 | 2,700 | 200,000 | 19,000,000 |
| 0.05 | 360,000 | 55 | 990,000 | 3,400 | 250,000 | 22,000,000 |
| Mean | 160,000 | 20 | 340,000 | 1,100 | 76,000 | 9,200,000 |
| Probability of mean | 0.46 | 0.43 | 0.40 | 0.38 | 0.38 | 0.46 |
| Probability of zero | 0.04 | 0.06 | 0.06 | 0.05 | 0.10 | 0.04 |

**Figure 7.** Chart summarizing probabilistic subjective estimates by experts of numbers of undiscovered kuroko massive sulfide deposits in tract PC–17, California (see fig. 6). From Ludington and others (1996). Corresponding amounts of contained metal and mineralized rock were estimated by Monte Carlo simulation.

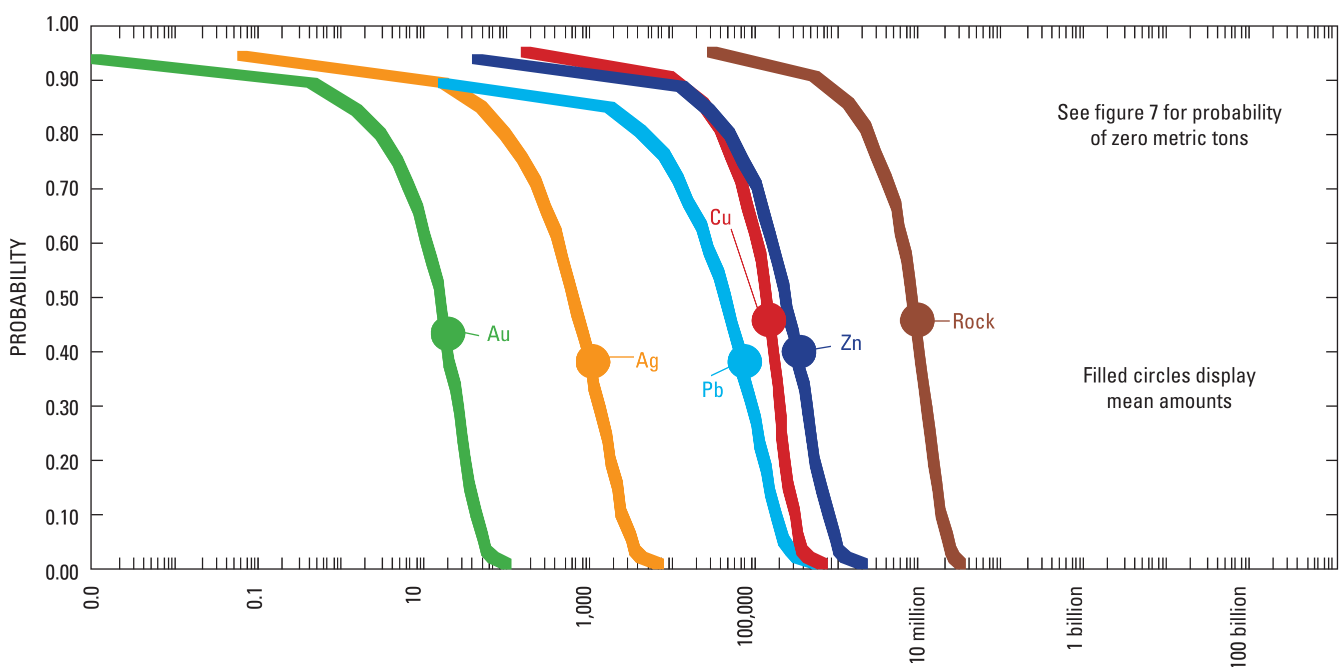


**Figure 8.** Graph showing cumulative distributions of contained metal and mineralized rock (in metric tons) in undiscovered kuroko massive sulfide deposits estimated in tract PC–17, California (see figs. 6 and 7). From Ludington and others (1996).

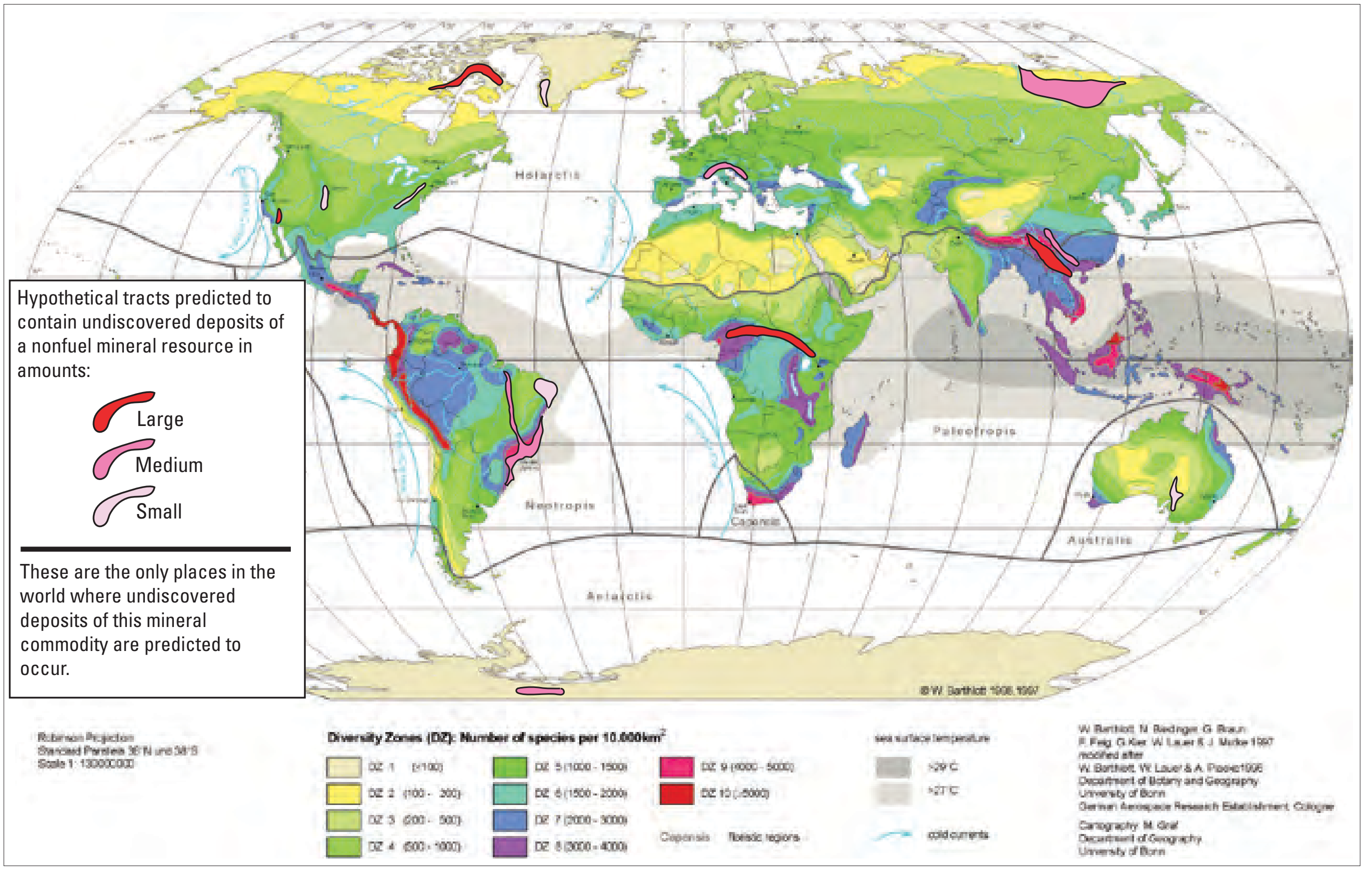


**Figure 9.** A conceptual global assessment in which tracts predicted to contain deposits of a generic undiscovered nonfuel mineral resource are plotted on a base map showing global biodiversity of vascular plant species represented by the numbers of vascular plants per 10,000 square kilometers. The base map is available online at http://www.biologie.uni-hamburg.de/b-online/e56/56b.htm (accessed June 15, 2005) and is modified from Barthlott and others (1999); reproduced by permission of the Finnish Zoological and Botanical Publishing Board.

- In the severe climates of high latitudes, fragile ecosystems disturbed by mining and associated infrastructure development are slow to recover (for example, see Forbes, 1997; Oksanen and Virtanen, 1997; Rapport and others, 1997). However, biodiversity is relatively low (fig. 9), and impacts on biodiversity potentially would be correspondingly low. Moreover, people whose livelihoods depend on mining are less likely to continue living in many of these harsh, isolated areas after mining and mining-related jobs end.
- Hypothetical undiscovered mineral resources that might occur as shown in Southeast Asia (fig. 9) would be in what presently is habitat for endangered tigers.
- Discovery and development of estimated undiscovered kuroko massive sulfide deposits in the foothills of central California (fig. 6) have the potential to adversely affect endangered species habitat and vulnerable plant communities that have been delineated by the USGS GAP Analysis Program (figs. 10 and 11).
- World tin resources in differing geologic settings have a high spatial correlation (Cunningham and others, this volume) with the distribution of biodiversity "hotspots" as defined by Conservation International (Mittermeier and others, 1999).

## Land Use

Habitat disturbance, fragmentation, and destruction resulting from infrastructure development are principal causes of species extinction. Ideally, mineral exploration programs would limit land disturbance globally by focusing mainly on areas assessed to have a high probability of containing an economic deposit (Sweeting and Clark, 2000).

Mineral exploration and development also might be encouraged where areas having a high probability of containing an economic deposit coincide with areas of existing infrastructure. Consequently, maps and other information showing the types and density of infrastructure development and associated land uses would be important ancillary databases, in combination with a global mineral resource assessment.

Large parts of the world are restricted or closed to mineral discovery and development. An example for the State of Idaho in the United States is shown in figure 12. All of the colored areas in figure 12 once were open to mineral exploration and development. By 1988, only the green areas were open. Similar maps for other parts of the world, together with a global assessment of undiscovered mineral resources, are critical for identification and analysis of remaining sources of future mineral supply, as additional areas are considered for closure.

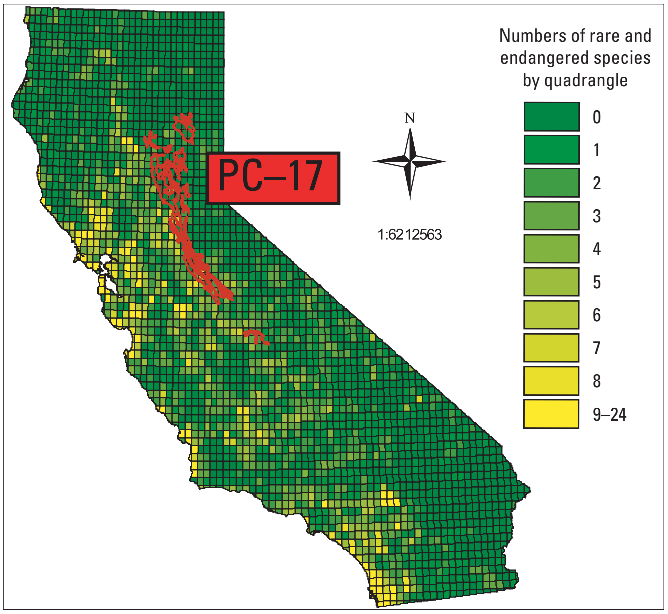


**Figure 10.** Map showing mineral resource tract PC–17 (fig. 6) in relation to numbers of rare and endangered species in California, U.S.A. (Davis and others, 1998).

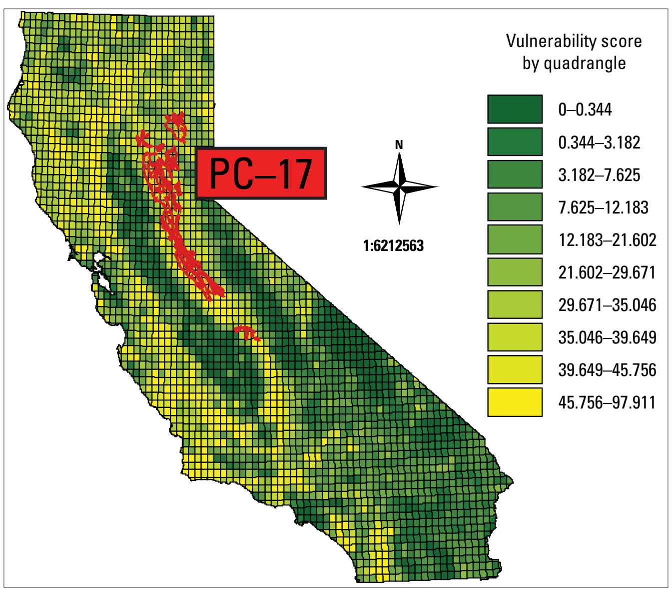


**Figure 11.** Map showing mineral resource tract PC–17 (fig. 6) in relation to vulnerable plant communities by quadrangle in California, U.S.A. (Davis and others, 1998).

## Water Resources and Quality

The boundaries of major drainage basins commonly are international, as illustrated in figure 13. A global mineral resource assessment can help identify future mineral resources in regions having adequate water supplies and hydrologic and geologic characteristics best able to maintain water quantity and quality during and (or) after mineral development. Such an assessment also has the potential to identify types of undiscovered mineral resources and climates least likely in combination to cause serious environmental challenges.

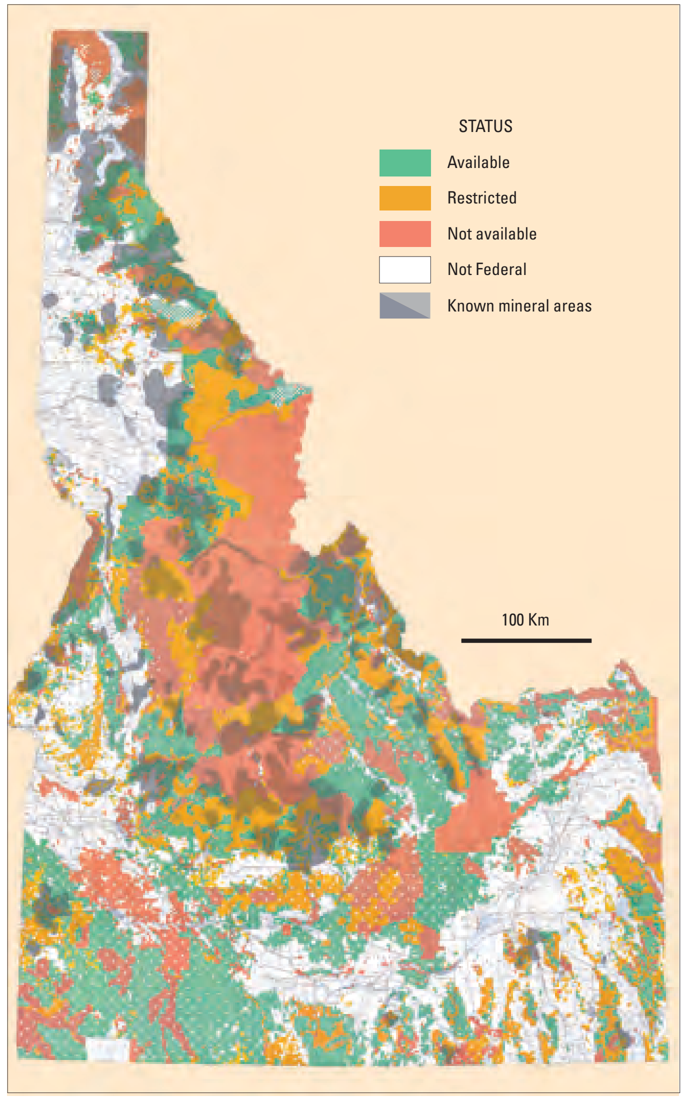


**Figure 12.** Map showing 1988 status of availability of Federal land for some locatable minerals (includes most metallic and nonmetallic minerals) in Idaho, U.S.A. (Hyndman and others, 1990).

## In the Final Analysis

Individual countries are becoming less free to develop their natural resources at the expense, real or perceived, of social and, especially, environmental quality; environmental concerns include clean air and water, protection of endangered species, biodiversity, global climate, and the ozone layer. National decisions about trade, including those made in the United States, often must follow laws requiring that associated environmental consequences be considered. Global environmental and trade agreements can be linked in ways restricting natural resource development. International funding agencies like the World Bank and the United Nations may withhold funding from projects seen as potential threats to environmental quality. Boycotts by consumers and national governments have been used effectively to influence, restrict, and even stop natural resource development. The charter for the World Trade

**Figure 13.** Map showing major drainage basins of Africa (Singh and others, 1997). The boundaries of drainage basins are not related to country borders (not shown).

Organization allows environmentalist import bans so long as the reason for them is not disguised protectionism.

Free trade no longer includes a number of resources such as whales, ivory, seals, furs, eagle feathers, and other parts of endangered species, to name only a few. It has become difficult to market tuna and shrimp unless they are caught in ways that protect dolphins and turtles, respectively. International pressure to protect the environment in all its aspects will only grow with time. Concomitantly, without the kinds of information that could be provided by a global mineral resource assessment, the world could unknowingly foreclose future mineral supply options that might otherwise have resulted in reduced environmental degradation, improved economic benefits, and enhanced social values.

## Acknowledgments

The authors are grateful for improvements to the manuscript suggested by their USGS colleagues Jane M. Hammarstrom and David M. Sutphin.

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