Mineral Supply and Demand into the 21st Century

By Stephen E. Kesler[1]

Introduction

World population is growing faster than at any time in history, and mineral consumption is growing faster than population as more consumers enter the market for minerals and as the global standard of living increases (fig. 1). Does this mean that we will face a mineral supply crisis in the 21st century? If so, can we solve this mineral supply crisis by increased mineral exploration, and will this exploration require more geological information and better land access? Answers to these questions must be based on predictions of world demand for minerals into the 21st century, along with a better understanding of the relation between global mineral reserves and those in individual deposits. Where, exactly, are our future mineral reserves and what do we know about them?

World Demand for Minerals

World demand for minerals will be affected by three general factors—uses for mineral commodities, the level of population that will consume these mineral commodities, and the standard of living that will determine just how much each person consumes. As new materials and applications are found, markets for mineral commodities can expand considerably. An example is seen in strontium, which was not widely used until the 1960s, when it was found to be the most cost-effective means of preventing radiation from escaping from color television picture tubes. This new market stimulated extensive exploration and the discovery of many new strontium deposits.

Although it is impossible to foresee all of the new products that will be developed for use by society in the future, they certainly will be composed of chemical elements and minerals from Earth because there is no other source from which they can be obtained. Furthermore, energy constraints will require that most of these products consist largely of elements and minerals that can be obtained from Earth with a minimal investment of energy. Thus, minerals will retain their dominant role as the basis for products used by society and, therefore, as the basis for world manufacturing and agriculture. Until new and significantly cheaper energy sources become available, global mineral demand probably will focus on the same metals and minerals that are of interest today.

Population will have a bigger effect on future mineral demand than the creation of new products and markets. Projections of future population range widely, depending on estimated fertility rates. For low fertility rates of 1.5 to 1.6 children per female, which are below the "replacement rate" of 2.1, world population is projected to increase from about 6 billion to about 7 billion people and then to decline after that, reaching the 1950s level of 2.5 billion in about 2150. If, on the other hand, global fertility rates remain at 2.5 to 2.6, world population will reach about 25 billion in 2150. For 2050, these two extremes would yield world populations of 7 billion or 11

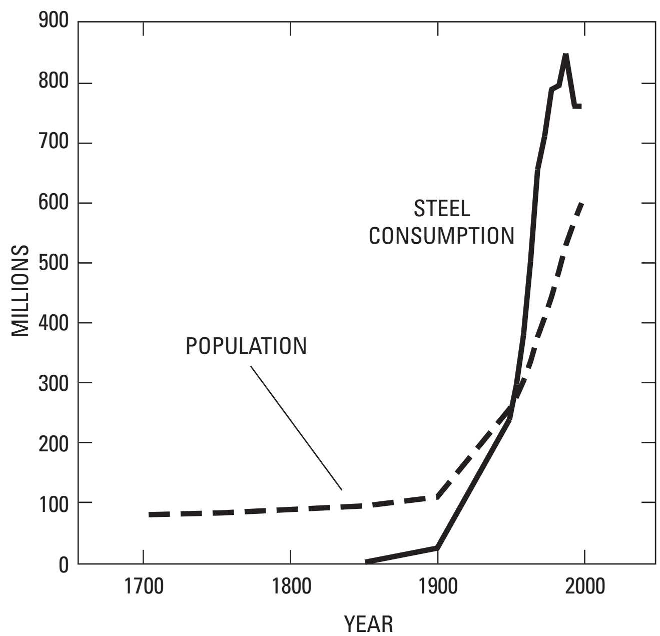

Figure 1. Schematic illustration of the change in world steel consumption and population since 1700. Dashed line shows world population (millions of people divided by 10), and solid line shows steel consumption (millions of metric tons). As for all mineral commodities, the growth of steel consumption has greatly outpaced the growth of population, reflecting increasing per capita demand for minerals. Data for this plot are from United Nations (1966, 1973, 1995) population reports and the U.S. Bureau of Mines (1953–93) and U.S. Geological Survey (1997 and 2002) "Minerals Yearbooks" for 1950, 1955, 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, and 2000.

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billion, largely because population changes related to low fertility rates will not yet have begun to decline and those related to high fertility will not have begun to accelerate.

Although these two estimates of world population in 2050 differ greatly, they are not likely to result in mineral demand that differs by the same amount. This is likely because there generally is a negative relation between per capita mineral demand and population for most countries (fig. 2). For instance, China and India had per capita copper consumption in 1998 of 0.6 and 2.7 pounds, respectively, whereas South Korea and Taiwan, with significantly smaller populations, had per capita copper consumption of 29.2 and 66.7 pounds, respectively. This relation reflects the greater difficulty of raising the standard of living of large populations compared to small populations, a point that is well illustrated by Singapore, which has a higher per capita income than many western countries, in part because it has a very small population. Because most future population growth will result from increases in developing countries where the standard of living is low, the effect of higher populations on total mineral consumption will not be great, at least within the range of present estimates through 2050. Taking a middle estimate of about 9 billion for global population in 2050 and assuming that each additional person will demand slightly less than the one before him or her suggest that increasing population could increase mineral demand by about 25 percent between 2000 and 2050.

Variations in the standard of living could affect future mineral demand more than population increases will. Per capita consumption of almost all minerals has increased in most areas during the last century, and the biggest differences and changes were related to increased standards of living. Asian countries have shown particularly impressive growth over the last few decades (fig. 3). The increase in per capita copper consumption in Asia ranged from a low of about 40 percent in India to a high of about 82 percent in Taiwan between 1985 and 1998. Changes in per capita copper consumption in developing countries in other parts of the world have been smaller, but still positive, although only barely so for Brazil and South Africa (fig. 4).

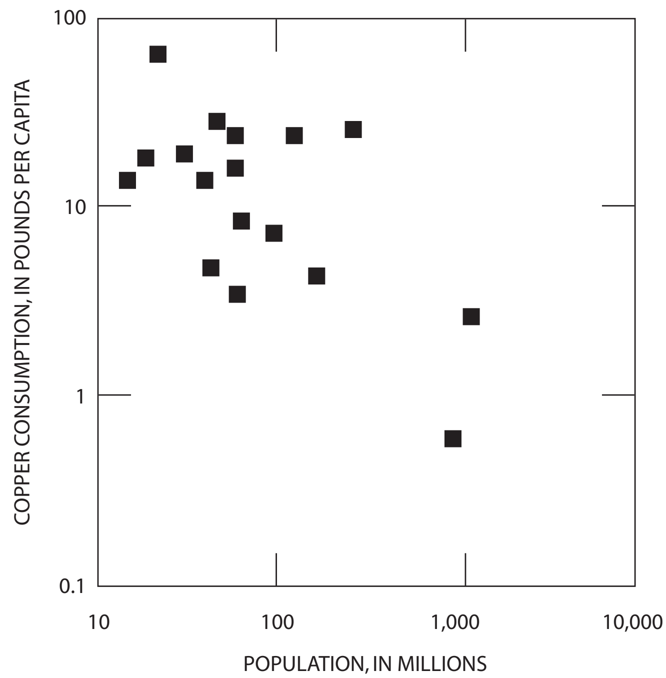

Figure 2. Graph showing per capita copper consumption vs. population in 1998 for the United States, Canada, Mexico, Brazil, Chile, France, Spain, United Kingdom, China, Korea, Thailand, Taiwan, India, Japan, Turkey, South Africa, and Australia. Data from American Bureau of Metal Statistics (various years) and the U.S. Census Bureau Web site at http://www.census.gov/ipc/www/idbrank.html.

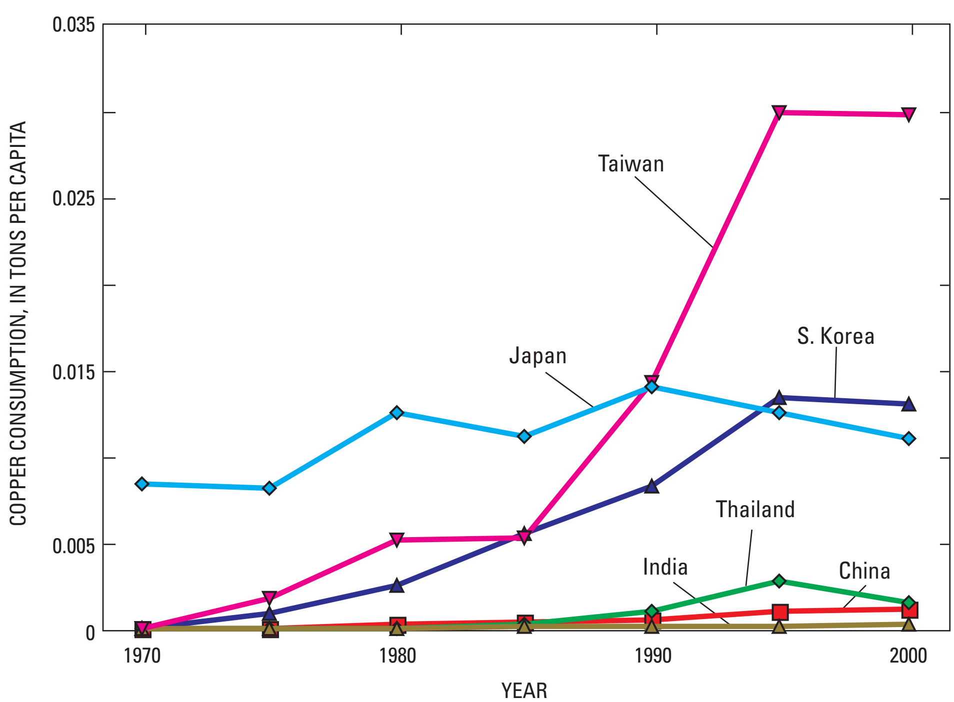

Figure 3. Graph showing changes in per capita copper consumption in China, Thailand, South Korea, Taiwan, India, and Japan during the period 1970–2000. Data from American Bureau of Metal Statistics (various years) and the U.S. Census Bureau Web site at http://www.census.gov/ipc/www/idbrank.html.

Changes in per capita copper consumption in most developed countries also have been small and over the period 1970–2000 have ranged from positive for the United States, France, and Spain to negative for the United Kingdom, Canada, and Australia (fig. 5). Despite these regional differences, there have been overall increases in per capita copper consumption for the entire world of about 11 percent between 1985 and 1998 and 13 percent over the period 1971 to 1998 (fig. 6).

These rough comparisons suggest that the increases in population and standards of living will have relatively similar effects on global mineral demand. With each of these amounting to about 0.5 percent annually, the combined total increase in global mineral demand should be approximately 1 percent per year. Economic cycles, recycling, and other factors are likely to be second-order controls on overall demand for new minerals over this time span, although they will be important locally and for shorter periods. Although per capita mineral consumption does vary with economic cycles, the trend toward gradually increasing global demand has been clear for many decades and is likely to remain in place. Thus, regardless of exact demand, it is almost certain to be higher than it is today, even if population does not increase. Some of the increased demand caused

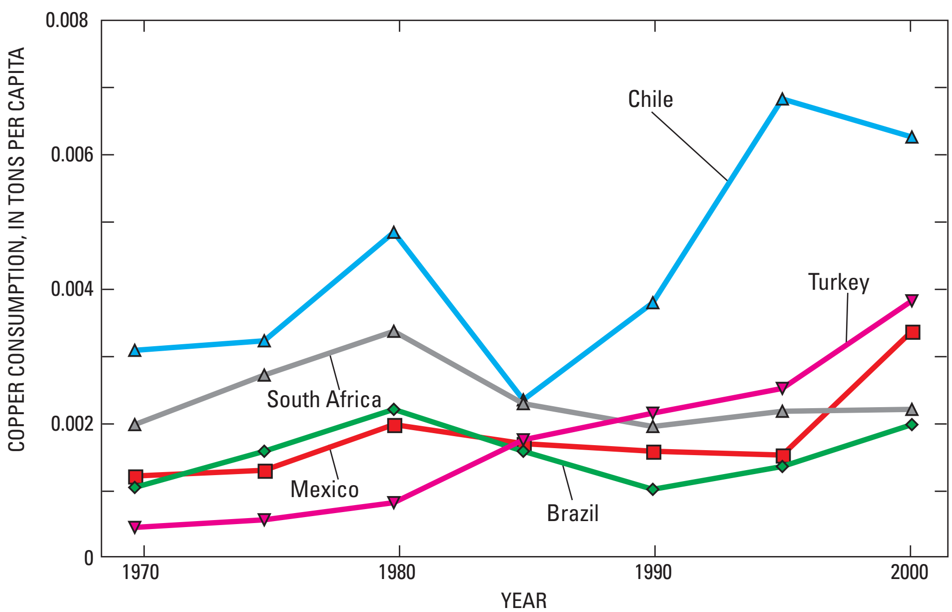

Figure 4. Graph showing changes in per capita copper consumption in Mexico, Brazil, Chile, South Africa, and Turkey during the period 1970–2000. Data from American Bureau of Metal Statistics (various years) and the U.S. Census Bureau Web site at http://www.census.gov/ipc/www/idbrank.html.

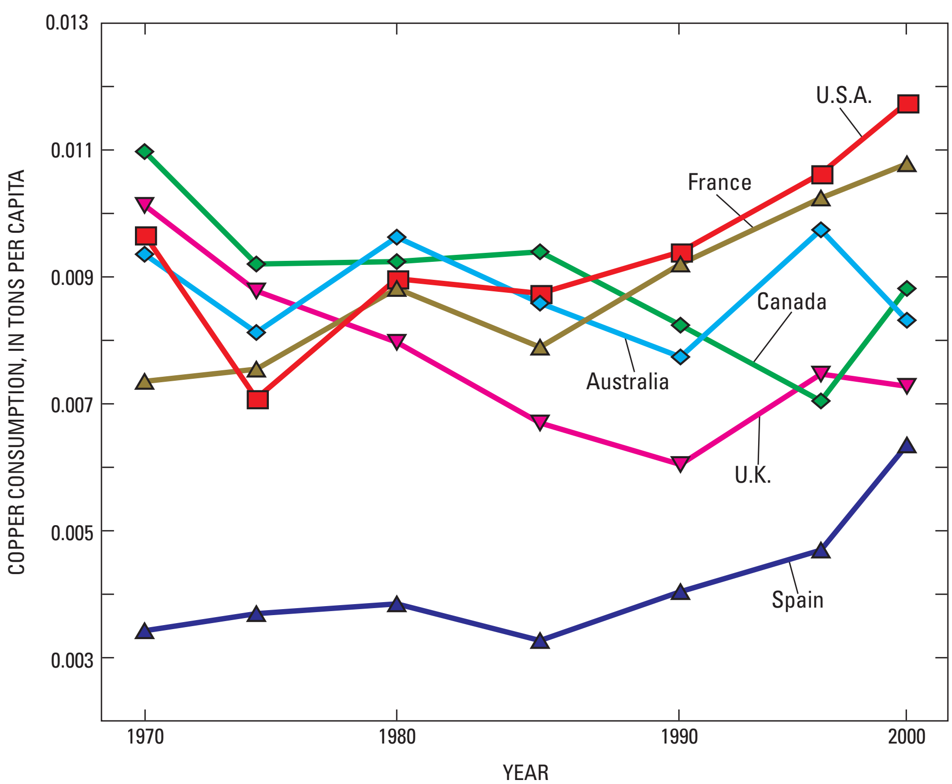

Figure 5. Graph showing changes in per capita copper consumption in major developed countries during the period 1970–2000. Countries are the United States, Canada, Spain, France, Australia, and the United Kingdom. Data from American Bureau of Metal Statistics (various years) and the U.S. Census Bureau Web site at http://www.census.gov/ipc/www/idbrank.html.

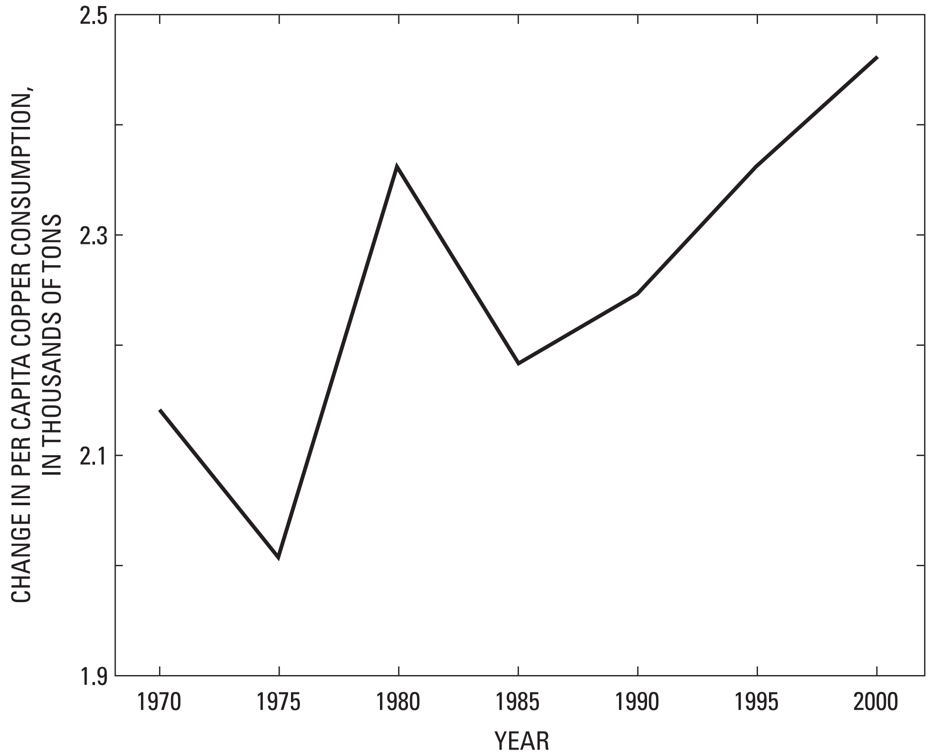

Figure 6. Graph showing change in world per capita copper consumption during the period 1970–2000. Data from American Bureau of Metal Statistics (various years) and the U.S. Census Bureau Web site at http://www.census.gov/ipc/www/idbrank.html.

by population increase will be met by more effective recycling, but this can be applied only to some commodities and cannot meet overall demand as long as both population and standards of living increase. These comparisons indicate that increases in demand for minerals are almost inevitable for the next 50 years or so unless there is a major breakdown in global economic activity or a catastrophic decrease in world population.

Global Mineral Reserves

Global mineral reserves are adequate to supply world mineral demand for the next 50 years, at least in theory. Presently estimated global mineral reserves are 20 to almost 1,000 times larger than present annual production, depending on the commodity of interest (fig. 7). Commodities having the lowest ratio of reserves to annual production in 1992 include diamonds and gold, which have been the object of very successful global exploration programs since that time.

If mineral demand increases at a 1 percent annual rate, as estimated above, it will be about 60 percent higher than today by 2050, which is not enough to change the general conclusion that Earth has adequate minerals to supply its population through 2050. Thus, demand is likely to remain the dominant factor in world mineral supplies for the next few decades. Exactly when supply will become the dominant factor is difficult to predict and will undoubtedly vary from commodity to commodity and be heavily dependent on the form and cost of industrial energy. In fact, the failure of earlier predictions of mineral supply and demand relations, many of which foresaw mineral shortages by the year 2000, has led to a dangerous complacency about future world mineral supplies and might lead us to misinterpret these reassuring reserve figures.

Although mineral reserves are large and seem adequate for the next 50 years or so when considered as a single global number, it is important to remember that these reserves are made up of many separate deposits, all of which have to be considered in the local context of which they are a part. Each of these deposits is subject to geologic, engineering, economic, environmental, and political constraints that undergo continuous change.

Geologic factors are of first-order importance and can range from new discoveries to changes in mining, beneficiation, smelting, or other treatment processes. Discoveries are the most important stimulus to exploration because they provide a reason to explore areas or geologic environments that were considered previously to be without potential. Discoveries range from recognition of a new, completely unfamiliar type of deposit, through realization that a familiar deposit type might be found in a new area, to recognition of possible lateral or depth extensions of known deposits or districts. For instance, discovery of the Olympic Dam deposit in Australia and recognition of its similarity to deposits in other parts of the world led to recognition of a new class of iron oxide-copper-gold deposits in other parts of the world and encouraged widespread exploration of terranes that previously were of little interest to copper geologists (Hitzman and others, 1992).

Discoveries of diamond-bearing kimberlites in northern Canada expanded the geologic terrane thought to be favorable for diamonds and considerably increased global diamond reserves (Levinson and others, 1992). On a smaller scale, deep drilling during the last 20 years in the Carlin area of Nevada in the United States has shown that gold ores originally considered to have formed in shallow, near-surface environments

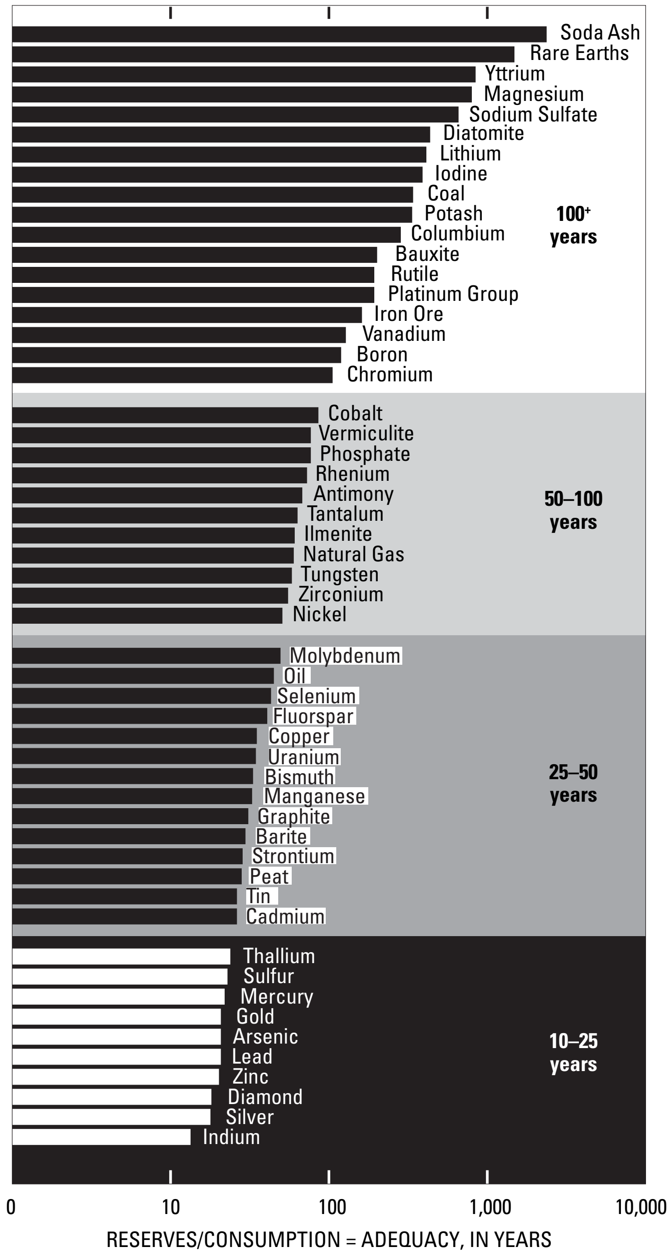

Figure 7. Graph showing ratios of global reserves to annual global production (consumption) for most mineral and energy commodities for 1992; the ratios provide a rough indication of the adequacy (in years) of currently known global reserves (from Kesler, 1994).

actually extend to significant depth. This new information opened completely new areas at depth to exploration and produced large new reserves (Teal and Jackson, 1997).

Related engineering factors can also have a big impact on mineral reserves. Introduction of heap-leaching methods during the 1970s and early 1980s permitted mining of much lower grade gold ores and considerably expanded global gold reserves. Similar changes affected the copper and zinc industries during the 1990s, making oxide deposits economically attractive and adding smaller amounts to global reserves.

It is important to understand that all these discoveries and developments resulted from increased exploration that took place in response to favorable economic frameworks. Without this encouragement, the large expenditures necessary to make these discoveries would not have taken place. Thus, political, economic, and environmental factors also are important to exploration. The importance of these factors cannot be overemphasized. As shown in figure 8, there generally is a good correlation between land area and the number of mineral commodities produced for most large countries having stable economies and regulatory structures. Countries having less stable systems do not show a similar correlation between area and mineral production, although they probably contain geologically favorable areas. Although mineral explorationists are accustomed to risk and commonly enter areas or countries earlier than most other investors, they expect an economic environment that will allow them to profit from large discoveries. Recent changes in the political and economic landscape in many Latin American countries have led to increased mineral investment and large increases in mineral exploration and production. Other countries, notably Cuba, which opened briefly for exploration in the 1990s, have found it more difficult to move exploration projects to production at least partly because of excessive revenue expectations on the part of government.

Environmental and land access regulations also play an important role in encouraging or discouraging exploration. For example, initiatives to ban the use of cyanide that have been put forward in South Dakota, Montana, and Colorado in the United States could remove large volumes of gold-bearing rock from our current reserve and are definitely discouraging exploration in these areas. Such initiatives may also place an emphasis on ores that are amenable to other forms of treatment, possibly even low-grade placer deposits. Because mining of placers causes more extensive surface disturbance, elimination of cyanide processing can lead to greater rather than less environmental damage. Initiatives to tax reserves have a similar short-term discouraging effect that has not proved to be insurmountable in most areas.

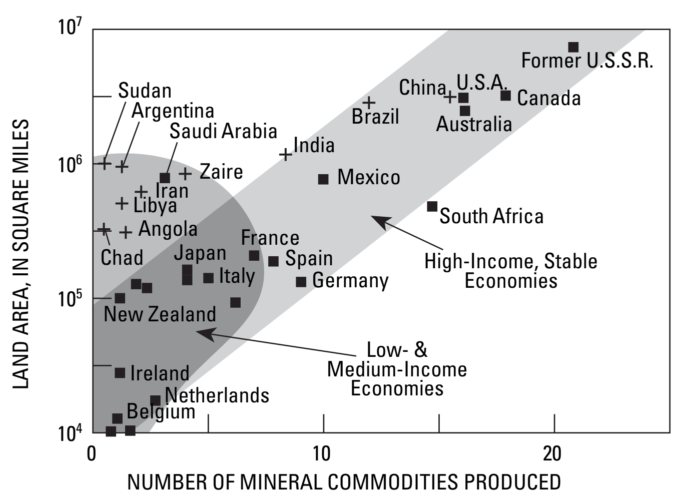

Figure 8. Graph showing the relation between land area and number of mineral commodities produced for developed and developing countries (from Kesler, 1994, based on original from Govett and Govett, 1977). +, less developed countries; ■, more developed countries.

Future Mineral Supplies

The factors that affect mineral exploration and reserves can change in a very short time. Discoveries and new mapping can change the geologic landscape, processing breakthroughs can make poor ore more attractive, and changes in political, economic, and regulatory environments can take place with the stroke of a pen. As a result, assessments of mineral reserves are ephemeral and must be revised continually to reflect these continuing changes.

The ultimate egalitarian goal would be for all countries to show a good correlation between mineral production and area, or, in other words, for all countries to share the burden of supplying the world's population with minerals rather than to expect others to shoulder the environmental burden. For this to happen, we need not just a leveling of the environmental and economic playing fields but also more basic geologic information. At this point, the quantity and quality of geologic information relevant to mineral exploration vary greatly across the globe. As a result, it is difficult to prioritize areas for exploration, especially in comparison to competing uses for land.

From a geologic perspective, the most important things that can be done to assure that world mineral reserves meet the challenge of the new century are the following:

1. Conduct research into the nature of processes that form mineral deposits
2. Conduct geologic mapping and related geochemical and geophysical surveys and compile data on known deposits, prospects, and favorable geologic environments
3. Conduct subsurface mapping and sampling

These three topics are discussed below.

Conduct research into the nature of processes that form mineral deposits with the goal of increasing our understanding of processes that cause ores to form and our ability to recognize far-field (distant) indicators of deposits and perhaps totally new ore-forming processes and environments.—A few far-field patterns of alteration zoning have been delineated locally, largely for porphyry copper and epithermal systems (Williams-Jones, 1986; Darce, 1990; Dilles and Einaudi, 1992). Isotopic patterns of similar size related to fluid flow have been mapped around a few hydrothermal deposits (Taylor, 1973; Cathles, 1993; Vázquez and others, 1998). Even larger scale patterns of fluid flow have been suggested by studies of organic matter maturity and illite crystallinity around Mississippi-Valley-type deposits (Bertrand and others, 1998). At least some of the measurements used to delineate these far-field patterns cost about the same as an assay, suggesting that further research might be possible to delineate fluid flow patterns and provinces over large regions.

Completely new deposits are more difficult to identify but probably are out there. For instance, water and other volatile constituents lost during prograde metamorphism are thought to move gold and possibly arsenic (Powell and others, 1991) and may form completely new deposits. Zinc may move similarly, as indicated by systematic regional depletion and enrichment patterns in metamorphic terranes (Ague, 1994). Zinc is a common trace constituent of many greenstone gold deposits and may form concentrations of its own in metamorphic terranes.

Sea-floor hydrothermal systems also offer possibilities. Only half of the heat lost from midocean ridge environments is accounted for by high-temperature hydrothermal systems along the ridges (Stein and Stein, 1994). The rest of the heat is transferred by lower temperature hydrothermal, off-ridge systems. Because of their lower temperatures, these systems must have very large water fluxes, although little is known about their capacity to transport and deposit ore elements.

Conduct geologic mapping and related geochemical and geophysical surveys and compile data on known deposits, prospects, and favorable geologic environments.—This work will provide critically important background data on the surface and near-surface part of our planet to guide future exploration. Despite the many good geologic maps that have been made over the years, there is a continuing need for new maps as the list of things that we need to describe grows. At this point, we have regional-scale geologic maps of most of Earth's surface, but we must progress from that overview to detailed maps that show not only the geology but also geochemical and geophysical patterns and features. The large volumes of data that will be produced by this activity must be put into a format that can be accessed widely and manipulated easily. Although some data will remain proprietary for various periods, most should eventually be merged into these databases and made available to the public.

Conduct subsurface mapping and sampling.—The main goal of mapping on the surface is to develop a better idea of the geologic characteristics of the subsurface. This information will lead, in time, to maps and sections that show the geologic, geochemical, and geophysical features of the subsurface and that provide much more detailed guidance for mineral exploration. Construction of these maps and sections must be based on samples that are recovered by drilling done for mineral exploration and other purposes.

Although subsurface exploration by drilling is a disruptive process, it is essential to discovery. It requires regulatory approval in most areas, which is often delayed or prevented by individuals with a poor understanding of how such exploration is carried out. This lack of understanding leads to exaggerated estimates of damage from the drilling process and reluctance to see it undertaken, just at the time in world history when we need more subsurface exploration to assure future mineral supplies. Efforts must be made to educate decisionmakers and the general public about the exploration process, what it can realistically achieve, and what type of damage it may cause to the environment.

At the same time, efforts also are needed to limit the environmental impact of subsurface exploration through directed drilling and other approaches that yield more information per unit of land area that is disturbed. Several important steps can be taken to limit the environmental impact of drilling. First, samples obtained by drilling should be characterized in as many ways as possible. Although most exploration projects do not require complete characterization, such efforts may provide information useful for future exploration with different objectives, thus eliminating the need for some new drill holes. Tax credits or other incentives can be offered to encourage more complete characterization of drill samples. Second, drill samples should be retained in a collection for possible later study and characterization. Maintaining collections of this type is very expensive, and new ways to do it should be sought. Finally, databases and sample libraries resulting from this drilling should be made widely available to the public or to qualified groups, thus eliminating the need for additional drill holes.

Conclusions

The actions discussed above are essential if we are to be good stewards of Earth's mineral endowment and if demand is to continue to rule the global mineral supply and demand equation. As we enter a century that will be marked by greater world trade, these actions and studies must be conducted at the scale of continents and even the entire Earth, rather than individual countries, as has been the practice up to the present.

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