Mineral Resources, Environmental Issues, and Land Use

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Contrary to predictions from the 1950s through the mid-1980s, persistent shortages of nonfuel minerals have not occurred, despite prodigious consumption, and world reserves have increased. Global availability of raw materials is relevant to policy decisions regarding mineral development and land use. Justification for environmental protection may exceed that for mining a specific ore body. Demand for environmental accountability is rising worldwide, and new technologies are enabling internalization of costs. Mineral-rich developing nations plagued by inefficient state-owned mining enterprises, high population growth rates, and environmental degradation could realize substantial benefit by reforming government policies to encourage foreign investment in resources and by appropriate allocation of mineral rents.

The extent to which U.S. nonfuel minerals industries, and thereby the nation, are adversely affected by land restrictions and environmental regulations, and public advocacy thereof, has long been debated (*1–4*). A presumed consequence of such restrictions is the departure of metal mining companies to less developed nations. The relative importance of factors such as labor costs, exploration potential, political stability, and investment incentives, as well as U.S. foreign policy interests, is seldom acknowledged in this debate.

In the five decades since World War II, the volume of nonfuel minerals consumed has exceeded the sum total extracted from the Earth throughout all of human history up to mid-century (*5*). The economic growth that ensued with the rebuilding of war-torn nations after 1945 fueled massive expansion of mineral extraction and utilization, generating widespread concern that the world's mineral endowment would soon be depleted. In 1968, Park (*6*) contended that growing world population coupled with ever-increasing consumption of the world's finite resources would lead inevitably to international conflict and that if steps were not taken to address the issue of pending resource exhaustion, such conflicts could well shatter the world before the end of the 20th century. Also in 1968, Ehrlich (*7*) forecast diminishing resources unable to sustain the exponential growth of human numbers, and Hardin (*8*) emphasized the grave environmental and social consequences of uncontrolled human reproduction. Soon thereafter, the Club of Rome issued *Limits to Growth* (*9*), with its gloomy predictions about minerals exhaustion in the face of ever-growing population and industrialization.

Yet, despite the specter of resource scarcity that has prevailed throughout much of this century, no sustained mineral shortages have occurred. Even the economically disrupting oil crises of the 1970s and 1980s were brought on not by pending global exhaustion of oil but rather by political grievances. Furthermore, the demise of the resource-rich Soviet Union has added another major variable to the equation of materials supply and demand.

Historically, the rate of increase in mineral consumption has consistently outpaced the population growth rate (*10*). For example, while world population doubled between 1950 and 1990, production of six major base metals (aluminum, copper, lead, nickel, tin, and zinc) increased more than eightfold (*11, 12*). Increasing at a rate of nearly 1 billion people per decade, human population is growing faster than ever and, at its present annual rate of about 1.7% (*13*), will double from 5.7 billion to 10 or 12 billion by about the year 2035. Thus, it is inevitable that mineral consumption will continue to increase. About 95% of global population growth is occurring in the developing world (*13, 14*), where consumption is growing rapidly, but the developed world still consumes the bulk of mineral commodities. The United States, with 263 million people (4.5% of the world total), is the third most populous nation, after China and India. In 1990, U.S. consumption of 10 major ferrous and nonferrous metals (including that in goods exported) was about 10% of world production (*12*).

Historical perspective. In 1900, the United States was essentially self-sufficient in most metals. Legal codes, notably the General Mining Law of 1872, and technological innovation fostered exploitation of the land's mineral wealth so rapidly and successfully that it was widely presumed North America possessed a unique abundance of minerals (*15*). Indeed, the United States remains the world's largest producer of raw minerals (*16, 17*), but it now relies increasingly on imports from a wide diversity of suppliers (Fig. 1), as do most other nations. World trade is expanding dramatically, including that in nonfuel mineral commodities (Fig. 2).

Shortly after World War II, concerns about future U.S. minerals vulnerability became paramount; resources had been stretched by two world wars, and war was then flaring in Korea. In 1950, President Truman appointed the Commission on Materials Policy to assess America's position and to recommend policy necessary to meet resource needs over the next 25 years. In 1952, this commission issued its comprehensive, landmark report *Resources for Freedom* (*18*). Many of its premises are pertinent today, even though the commission's forecasts of worldwide metals usage by the year 1975 were vastly underestimated: By the mid-1970s, consumption of most key metals (aluminum, copper, zinc, chromium, iron, manganese, and nickel) was at least twice that predicted. The forecasters had failed to anticipate the incredible rebuilding and economic boom in postwar Europe and Japan (*19*). In contrast, consumption of most metals in the United States was somewhat less than predicted, partly because the industrial infrastructure in this country after World War II was undamaged and thriving. The notable exception was aluminum, consumption of which was nearly eight times the 821,000 metric tons used in 1950, compared with the predicted twofold increase; the entire free world consumption of primary aluminum was more than nine times that used in 1950 (Table 1), whereas the forecast was for only twice as much (*18, 19*).

Such appetites for the world's resources led to the proliferation of warnings of impending crises in minerals availability (*4, 6, 9, 20–22*), but despite prodigious consumption of minerals since World War II, known world reserves of most major minerals increased from the 1940s through the 1980s (Table 2) (*19, 23, 24*) and, as currently estimated (*25*), are robust (Table 3). Furthermore, the prices of most metals today have changed little, in constant dollars, over the last 150 years (*11, 24, 26, 27*). Although cyclical, the trend (Fig. 3), exemplified by copper (Fig. 4), has been level or downward since about 1850, despite accelerated production, which might have hastened depletion.

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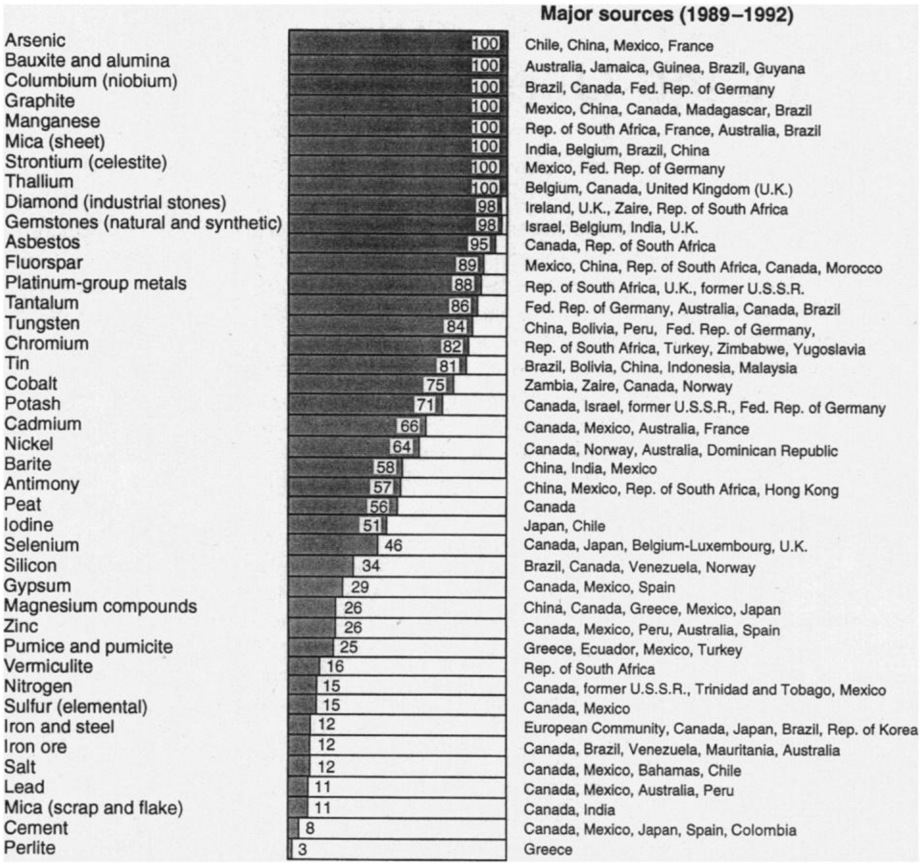

Fig. 1. Estimated U.S. net import reliance (1993) on selected nonfuel mineral materials as a percent of apparent consumption. Net import reliance = imports − exports + adjustments for government and industry stock exchanges; apparent consumption = U.S. primary + secondary production + net import reliance. [From (*25*)]

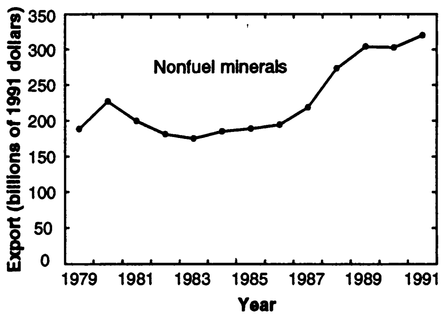

Fig. 2. World mineral commodity export trade. [Data from (*17*)]

Factors Affecting Minerals Availability

Most parts of the planet have proven generously endowed with useful mineral resources, but specific minerals are not evenly distributed, as is demonstrated by well-established metallogenic concentrations. Primary mineral resources, in anomalous concentrations and accessible on our human time scale, are nonrenewable and ultimately finite; their availability depends on technological innovation, production cost, and commodity price.

Despite an apparent limit to resources, adequate world mineral supplies have been maintained. Major new discoveries in recent decades—disseminated gold deposits in the American West, huge iron and bauxite deposits in Brazil and Australia, large ore bodies in Alaska, Ireland, Chile, and elsewhere—have resulted from advances in geologic knowledge, new technologies, and, in the case of gold, higher real prices, plus the fact that little exploration occurred during and between the world wars (*19*). Technological improvements in mining and metal recovery have enabled massive earth-moving operations, extraction of lower grade ores, and greater efficiency in production, with attendant reductions in costs. Gold provides an illustrious example, although its case is unique because of its monetary tie and fixed dollar price until 1971. World production, 47 million troy ounces in 1971, increased strongly after the price was allowed to float and has stayed high (74 million ounces in 1993) as price declined over the last decade (Fig. 5); the United States is now the second leading gold producer in the world (10.6 million troy ounces in 1993), after South Africa (20.2 million troy ounces) [China became the world's leading gold consumer in 1993, at about 11 million troy ounces (*28*)]. World reserves of gold were estimated at 1 billion troy ounces in 1971 (*29*), and after more than 20 years of rising production, world reserves now amount to more than 1.35 billion troy ounces (*25*).

A number of factors conspired to lower the growth of mineral demand after the mid-1970s throughout industrialized nations, although total consumption reached record levels by 1990 (*30*). Worldwide eco-

Table 1. Free world consumption* of primary metal in 1950 (*18*).

Metal	Consumption (10^3 metric tons)
Aluminum	1,440
Copper	2,787
Iron ore	192,000
Lead	1,865
Nickel	120
Tin	169
Zinc	2,011

*In 1950, data were available from the Free World only; production from countries with centrally planned economies, however, represented less than 25% of the global aggregate of most commodities (*30*). The purpose of the President's Commission was to assess raw material supplies, irrespective of scrap consumption. Therefore, the 1950 and 1990 data (Table 3) are not truly comparable but illustrate the relative magnitude of increased consumption.

Table 2. Growth of the world reserves base of selected commodities (contained metal near the end of the relevant decade). "Reserve base," as used by the U.S. Bureau of Mines, includes reserves, which are currently economic to extract, as well as resources, which are currently subeconomic and marginally economic but can reasonably be expected to become economically available. The data are from (*23*), based on that from the U.S. Bureau of Mines; 1993 data are from (*25*).

Decade	World reserves base (millions of metric tons)			
	Copper	Lead	Zinc	Aluminum*
1940s	91	31 to 45	54 to 70	1,605
1950s	124	45 to 54	77 to 86	3,224
1960s	280	86	106	11,600
1970s	543	157	240	22,700
1980s†	566	120	295	23,200
1993	590	130	330	28,000

*Gross weight of bauxite. †Reserve base in 1989.

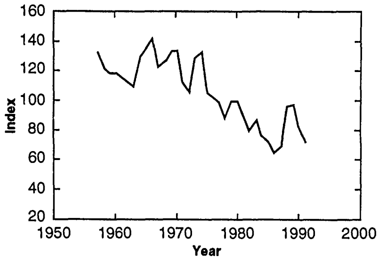

Fig. 3. Index of nonfuel mineral prices in constant (1980) dollars from 1957 to 1991. [Reprinted from (*45*) courtesy of Worldwatch Institute; data from International Monetary Fund and United Nations]

nomic expansion was extraordinary between 1950 and 1974 but then slowed considerably, in large part because of the oil crises; consequently, growth rates of metals consumption declined substantially (Fig. 6), resulting in worldwide surplus inventories (*30*, *31*). The economies of Japan and western Europe leveled off after their blazing recovery from World War II. Further, the trend in both per capita use and intensity of use (volume relative to gross national product) of minerals in industrialized countries is down; mature economies with infrastructures largely in place become increasingly tied to

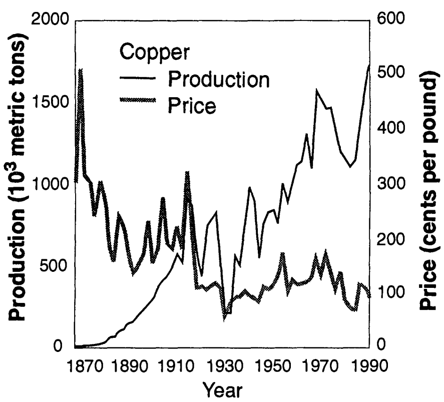

Fig. 4. U.S. copper production and price in constant 1987 dollars. [From (*87*)]

Table 3. Worldwide annual consumption in 1991 (*13*) and reserve base in 1993 (*25*) of selected metals [consumption includes primary and secondary (scrap) metal, except for iron, which includes only crude ore].

Metal	Annual consumption (10^3 metric tons)	Reserve base (10^3 metric tons of contained metal)
Aluminum	17,194	28,000,000*
Copper	10,714	590,000
Iron	959,609	230,000,000
Lead	5,342	130,000
Nickel	882	110,000
Tin	218	10,000
Zinc	6,993	330,000

*Bauxite (crude ore).

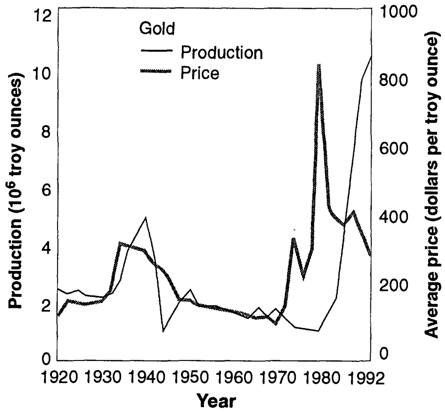

Fig. 5. U.S. gold production and world gold price in constant 1987 dollars; 1992 values are estimates. [From (*87*)]

high technology and service industries that require less intense use of raw materials, thanks to miniaturization, economies of scale, and substitution (*19*). This stage appears to represent a "structural saturation of demand" (*31*), not simply a temporary drop in demand. Rapid technological advances have delivered new materials and new products—ceramics and composites (derived from more abundant nonmetallic minerals), in addition to pervasive plastics—all substituting for metals to some degree (*32*).

Recycling has increased significantly throughout the industrialized world (*31*, *33*) (Fig. 7); recycled scrap is generally a cheaper source of metals, because of lower energy costs, and is profitable for many, particularly aluminum, for which production from scrap uses only 5% of the energy required to win the metal from bauxite ore. Recycling steel reduces energy consumption by 61%. In the United States, one metric

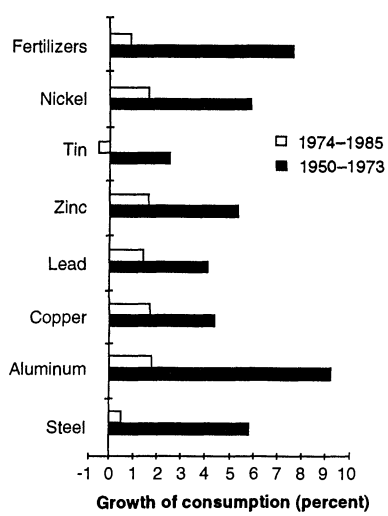

Fig. 6. Growth rates from 1950 to 1985 of world consumption of major metals and minerals. [Adapted from (*31*) with permission from the Natural Resources Center (CERNA), Paris]

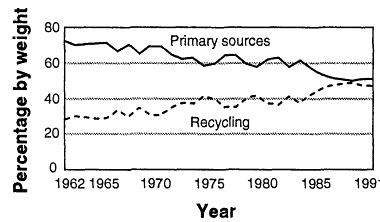

Fig. 7. U.S. metals consumption from primary resources and from recycled material. [From (*33*)]

ton of raw steel requires 0.60 ton of ferrous scrap. In 1990, recycled scrap accounted for a substantial fraction of total U.S. metals consumption (Fig. 8). Of all the gold ever mined, 85% is thought still to be in use, storage, or collections.

Contrary to mid-century expectations, mineral supplies, metallic and nonmetallic, are now thought to be adequate for the next 100 years or so (*19*, *34*, *35*). Markets will continue to be cyclical, but indications are that new production, recycling, substitution, and technological innovation will rise to meet the demands of a continually expanding population. In the last decade of this century, more urgent world concerns are likely to be loss of soils, water, biodiversity, and environmental degradation (*27*, *34*–*37*).

Environmental Concerns

A significant factor affecting minerals availability today is the environmental conscience that has arisen over the last three decades throughout the industrialized world and, increasingly, in developing countries. It has engendered controversy and antagonism within the extraction industries. Exemplifying the dispute in the United States is the proposed Crown Butte gold mine in

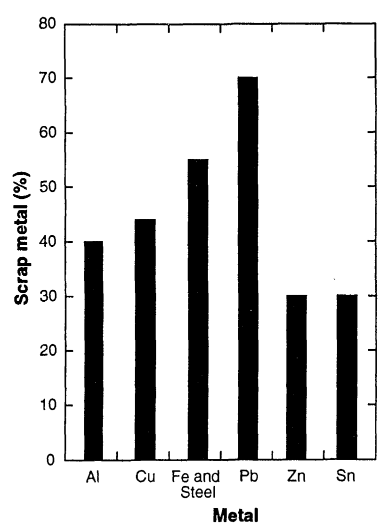

Fig. 8. Amount of scrap metal used in the United States as a percentage of total consumption. [Data from (*33*)]

Wyoming (4 km from Yellowstone National Park and surrounded by designated Wilderness), which has generated heated opposition and underscored arguments for Mining Law reform (*38*). Contrary to the mindset of 100 years ago, a growing segment of the U.S. population today places higher value on natural assets other than gold, particularly on public lands. Where once mining was widely regarded as the "highest and best" use of land, irrespective of its suitability for other purposes (the concept that underpins the Mining Law of 1872 still today), federal lands are now valued for multiple resources: wilderness, historic sites, wildlife, or scenery, for example (*39, 40*). Even though metallic and nonmetallic mining operations, past and present, occupy only a small fraction of total land area in any country (0.25% of the United States as of 1980, one-tenth of which was metal mining) (*41, 42*), the scars are long-lasting, and the environmental impact can extend well beyond the limits of disturbed ground through air pollution and water contamination. Mines are not perceived as compatible with wilderness or wildlife, and the lack of glaring shortages, together with shrinking employment in the industry [down 80% in the last 20 years (*43*)], has relegated mineral resources to a status of secondary importance in much of the public reckoning. Direct employment in metal mining in the western United States (including Alaska) now accounts for only 0.1% of total employment in the region (*40*).

Historically, environmental damage incurred in the course of extracting minerals worldwide has been largely an externality; these social costs have not been incorporated in the price of the product. For example, mining on U.S. public or patented land carries no obligation to address the environmental aftermath under the Mining Law of 1872 (although various regulations have subsequently been imposed, mainly by states). That law permits free access for exploration on public lands, filing of claims, and conveyance of title (patent) for fees of $2.50 (placer) or $5 (lode) per acre, with no subsequent royalty payments on production. These provisions, accorded for sound reasons in 1872, amount to government subsidy of mining operations on U.S. federal lands (*44*). Highlighting this legal legacy was the acquisition in May 1994 of 1800 acres in Nevada by a Canadian corporation, to whom a reluctant Secretary of the Interior conveyed title to gold resources reportedly valued at $8 billion to $10 billion, in exchange for $9000. In addition to this land and resource subsidy, federal tax law applies depletion allowances ranging from 5 to 22% to more than 50 mineral commodities. Other mining countries commonly also provide subsidies to domestic minerals industries operating at home or abroad (*44, 45*). This legal lack of full accountability has helped to keep metals cheap on the world market.

Environmental resources—such as water, land, air, and wildlife—have constituted a public commons, seen as free and unlimited, throughout most of the world (*8, 27*). But those commons have been visited by tragedy. In the United States, 52 abandoned mines have been designated Superfund sites by the Environmental Protection Agency (EPA), largely because of toxic effluent, notably acid mine drainage. Most are historic, but the latest case is Summitville, Colorado, where a Canadian company went bankrupt in 1992 after extracting 280,000 ounces of gold; the clean-up tab may be as high as $120 million. The total bill for all of these Superfund sites is estimated at $12.5 billion to $17.5 billion (*46*).

The mining industry's image has been damaged by its past record, but having been forced by regulation and public reaction to change its ways, and having found it cost-effective to do so, much of the industry today exhibits better environmental stewardship. The Homestake McLaughlin mine, north of San Francisco, California, is exemplary. With facilities in three different counties, Homestake required a total of 327 different permits before gold production could begin. Yet, by adopting a proactive strategy involving community members and potential adversaries at the beginning of the permitting process, only 6 years elapsed between discovery and the first bar of gold. Costs of meeting environmental requirements constituted less than 2% of the $284 million total capital cost of the mine. Furthermore, as the mine operates, reclamation is proceeding toward its final conversion to an environmental studies field station (*47, 48*).

Improved technology has permitted great strides in the mitigation of environmental impacts. The new $880 million Kennecott smelter-refinery complex at Bingham, Utah, is both environmentally correct and cost-effective (*49*). Expected to be among the cleanest in the world, the smelter will retain 99.9% of the sulfur produced, compared with 93% today. Production costs at the new plant will be reduced by 53%, making Kennecott one of the cheapest copper producers worldwide. Innovative, dynamic companies can gain competitive advantage by preventing pollution at the source, saving costly clean-up bills and accommodating environmental constraints with new, efficient technology (*50*). Increasingly, economic incentives relying on market mechanisms are the basis for encouraging minerals industries to address environmental priorities (*50, 51*).

If costs of environmental protection are thus internalized in the industrialized world, how likely are mineral-rich developing nations to follow suit? Are nations beset by poverty and growing populations so eager for the financial benefits of mineral exports that environmental degradation is inconsequential relative to gains from resource exploitation? Indications are that demands for environmental accountability are rising among Third World nations, and they are being heard by both policy-makers and industry (*42, 50–54*). In mid-1991, an international conference in Berlin on "Mining and Environment" established formal guidelines addressed to both the minerals industries and major funding agencies (*53*). Among these guidelines are (i) that all parties must "recognize environmental management as a high priority, notably during the licensing process . . ." and (ii) "Environmental accountability in industry and government must be established at the highest management and policy-making levels." There are 12 more guidelines addressed to the minerals sector and 10 to development assistance agencies, all directed toward ensuring protection of the "global environmental system."

The International Council on Metals and the Environment (ICME), comprising 27 national and multinational metal companies and representing 16 countries, was established in March 1991 "to promote sound environmental and related health policies and practices to ensure the safe production, use, recycling, and disposal of metals," to promote excellence within the global industry, and ultimately "to foster environmentally sustainable economic development" (*55*). Also in 1991, the Mining and Environment Research Network was launched in the United Kingdom, its goal being to help mineral-producing countries improve environmental management and protection by capitalizing on the lessons learned in industrialized nations (*56*). The *Mining Journal*'s Environment Supplement of 1991 (*53*) noted that neither pollution nor public opinion respects national boundaries and concluded that companies from the industrialized world will be required to adhere to environmental standards imposed by their own societies as they develop projects elsewhere around the globe, a conclusion voiced also by former EPA chief Reilly (*57*).

Although minerals were conspicuous by their absence at the highly publicized "Earth Summit" in Rio de Janeiro in June 1992, environmental sensitivity was not; the concept that the polluter pays for environmental damage was widely embraced (*54*). A 1993 seminar in Zimbabwe on small-scale mining further underscored demand for environmental responsibility on the part of investors in development projects (*58*). Even the World Bank has added, as of 1987, environmental assessments to its modus operandi (*59*); Bank President Preston has stated that paying too little attention to the environment was the worst mistake made by the World Bank in its first 50 years (*60*). Environmental regulation is here to stay and likely to become more widespread, more stringent, and better enforced (*42, 51, 54, 61*). Numerous mining projects throughout the globe have been canceled, deferred, shut down, or sued in the last 10 years because of environmental objections (*42, 62*).

Although worldwide environmental standards are neither feasible nor appropriate because ecological and social conditions vary, the establishment of industrywide codes of conduct could improve the industry's credibility in its efforts to demonstrate that mining is compatible with environmental protection (*61*). Standards are often minimal and poorly enforced in developing nations, but multinational firms are instituting comprehensive environmental management systems to minimize impacts in anticipation of more stringent regulation and to avoid criticism for "exporting pollution" (*42*). Newmont Mining Corporation recently announced that substantial investments will be made at their new gold mine in Indonesia to ensure that the mine operates under the same environmental standards applied to its U.S. projects (*63*). Increased emphasis worldwide will promote commercialization of innovative, "green" technologies (*54*). If major mining companies are constrained to operate in developing nations with the same expectations imposed in their home countries, broad-based internalization of the costs of sound environmental practice will be required. Improved technology may compensate for additional costs necessary for environmental protection; such costs escalate as ore grades decline, however, and higher mineral commodity prices may eventually result.

In the developing world, even in countries with existing environmental statutes, state-owned enterprises have been particularly egregious in ignoring environmental impacts, largely because of production inefficiencies, poor management, obsolete technologies, and obligations to provide social services (*30, 51, 64*). Multinational corporations in general have a far better environmental record, and competition in the global metals market encourages new technologies and efficient management (*54*). Nationalization of resource industries was extensive in emerging nations during the 1960s and 1970s, but the economic difficulties of the 1980s have led many countries to seek renewed private investment. Because of capital requirements, mining enterprises in Third World nations are likely to be increasingly operated by multinational consortia (*30*). Thus, leadership by the global mineral community in addressing environmental issues is critical.

Is the concept of sustainable development applicable to the extractive minerals industry? Can ever larger supplies of finite mineral concentrations be found and exploited without lasting damage to environmental resources, and how long can such ore bodies be sustained? According to von Below (*52*), "Sustainable development in mining can be achieved only through continuous exploration, technological innovation, and environmental rehabilitation." The first two requirements cannot be sustained over the long term without investment in the third, and all resources, environmental as well as nonrenewable, must be priced realistically in order both to accommodate the environment and to avoid wasteful production and consumption of minerals (*52*). Sustainable development requires that nonrenewable mineral resources be managed so that the wealth they generate effectively substitutes for the depleting mineral asset (*61*). Recycling is also key, contributing substantially to current supplies of most metals; greater stimulus through government policies that provide market incentives could undoubtedly increase the use of scrap. Nearly all metals can be recycled indefinitely from most uses (*23*), but even if the population were to stabilize, recycling could not meet all of society's needs.

Less Developed Countries and the Global Market

Since World War II, the overriding principle of the U.S. de facto minerals policy has been to obtain mineral supplies adequate for U.S. needs at the lowest possible cost, commensurate with the interests of friendly nations (*18*). That dictum still applies and will continue to require U.S. dependence on sources overseas. Irrespective of environmental constraints in the United States (and possible Mining Law reform), mineral development abroad is advantageous because of low labor costs, revised legal codes, and attractive exploration targets in newly accessible territory. Environmental mitigation and rehabilitation measures will increasingly be required of new mines (*51*).

The most critical environmental problem today is the inexorable growth of the human population (*65*) and attendant resource use, in both industrialized and developing worlds (Fig. 9). That reality must be of foremost concern to those charged with ensuring adequate supplies of raw materials. Some of the fastest growing populations are in less developed nations, a substantial number of which are dependent on minerals for a major share of their foreign exchange earnings (Table 4). If improved economic and social conditions (specifically the educational status of women) are incentive for reduction in fertility (*13, 14*), it may be that the minerals industries are well positioned to enhance the circumstances of minerals-rich emerging nations. However, mineral resource wealth does not have a good track record in post–World War II developing nations insofar as launching them toward economic prosperity (*66*). Low mineral prices have not helped, but the problem stems largely from the sort of political and economic difficulties so evident in many developing countries. Nonfuel mineral exports constituted 40% of the total exports from 16 "mining countries" at least once since 1975 (Fig. 10), but the economic plights of many such well-endowed nations are bleak (*66, 67*).

Consider Zaire: Not only is it the world's major supplier of cobalt, but until 1987, it was the world's largest producer of diamonds (now greatly surpassed by Australia). It also has substantial reserves of copper, tin, and tungsten, and yet, political turmoil has generated economic disaster. Its state-

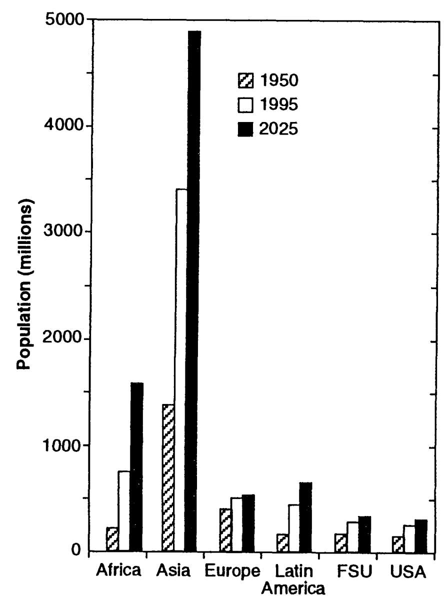

Fig. 9. Selected human populations. FSU, former Soviet Union. [Data from (*13*)]

Table 4. Population in 1995 and current growth rates in selected mining countries (*13*).

Country	Population (millions)	Growth rate (%)
Bolivia	8.07	2.4
Botswana	1.43	2.9
Guinea	6.7	3.0
Mauritania	2.34	2.9
Niger	9.10	3.3
Peru	23.85	2.0
Surinam	0.46	1.9
Zaire	43.81	3.2
Zambia	9.38	2.8

owned mining company produced over 400,000 metric tons of copper in 1989, which political interference had reduced to less than 50,000 tons by 1993 (*68*). Zambia has had a poor record as well, relying on its copper industry while permitting its agricultural infrastructure to collapse (*66*). Despite a sharp drop in mineral commodity prices in 1975, mining continued to siphon labor from agriculture throughout the 1970s; the Zambian government was forced to retain high wages for copper miners while relying on imports for necessary foodstuffs, thus consuming much of the rent acquired from mining and thereby falling victim to "Dutch Disease" (*54, 61, 69*). Today, per capita income in sub-Saharan Africa is less in constant dollars than it was in 1960 (*65*), when countries began to gain independence. A widespread decline in per capita income occurred in mining countries between 1975 and 1987 (Fig. 11) for several reasons, including the economic downturn throughout the industrialized world. More recently, these nations as a whole "have lost one-sixth of their commodity export earnings over the past two years due to falling commodity prices" (*70*). There was also the relentless increase in population. The World Bank (*71*) estimates that over the next 40 years, the population of sub-Saharan Africa will triple to 1.5 billion. The impact of these growing numbers (*72*) is cause for concern, particularly as industries strive to become competitive in the world market through increased productivity, often with consequent reduction in work force.

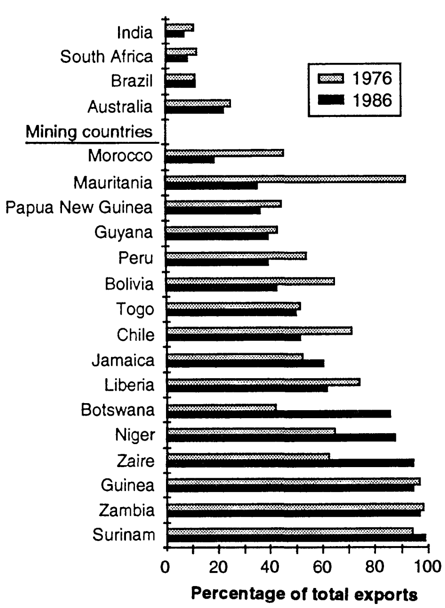

Fig. 10. Nonfuel mineral commodity exports as a percentage of total exports for selected countries. "Mining countries" are those whose nonfuel mineral exports have accounted for 40% of total exports at least once since 1975 (*66*). [Data from U.N. Conference on Trade and Development. Adapted from (*66*) with permission from Resources for the Future, Washington, D.C.]

The former Soviet Union is an exceptional case; its extraordinary mineral endowment made it virtually self-sufficient throughout the Cold War. Yet, despite vast natural wealth (and a low population growth rate of 0.5%), Russia and most of its neighboring states have experienced economic collapse, selling off stocks of mineral commodities at bargain prices and depressing the world market in metals such as aluminum, nickel, and chromium (*17, 25, 73, 74*). The metals sector is now the biggest foreign exchange earner after oil and gas in the former Soviet Union states collectively (*75*); it is also a notorious source of pollution (*76*).

There are more exemplary nations, however. Chile has overhauled its political, economic, and legal systems to capitalize productively on its resource wealth, diversify its economy, and address environmental concerns (*13, 41, 63*). Likewise, Mexico has made important changes to attract foreign investment in the mining sector (*77, 78*), now locked in by the North American Free Trade Agreement (NAFTA) (*79*). Bolivia, which enacted its General Environmental Law in 1992, has shown increasing support for privatization of mining interests (*80*), having recently put into place a new, broad-based capitalization law that advances privatization of five major state companies, including the state-owned tin producer (*81*).

The current situation in sub-Saharan Africa (exclusive of South Africa) is perhaps least conducive to foreign investment (*82*). Dependence on state-owned enterprises for mineral production in much of Africa has been counterproductive, to a large extent because of the ancillary social services such companies have been required to provide (*82*). In those developing nations endowed with a significant mineral resource base, governments must assume the obligation to maximize rents derived therefrom by attracting foreign investment and reforming fiscal and regulatory policies. Rents captured from mineral development and export can improve the economic well-being of impoverished nations if directed toward stimulating more diversified economies, ensuring continued viability of mining industries through the infusion of private capital, and building independent structures dedicated to enhancing social welfare and education (*83*). Internalization of environmental costs by the private sector must be required to mitigate the current environmental toll. South Africa and Russia, both major minerals producers and both embodying elements of the First and Third Worlds, now have the opportunity to reverse the historical record of mineral-dependent nations by encouraging mining enterprise and judiciously managing mineral rents for long-term national goals.

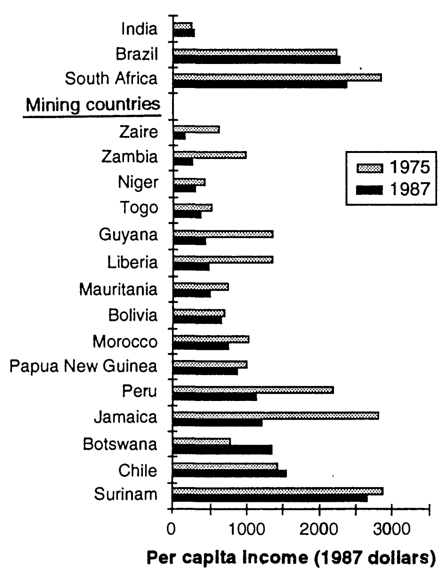

Fig. 11. Per capita income for selected countries. [Data from the World Bank; figure adapted from (*66*) with permission from Resources for the Future, Washington, D.C.]

Multinational mining companies are eager to explore in favorable country wherever geological, political, and social conditions are conducive to investment (*61*). Neither environmental regulation nor lack of sufficient infrastructure is a major deterrent if other factors are optimum, but without government stability, security of tenure, and legal assurance of fair return, investment by multinational corporations in either exploration or development is unlikely.

In the final analysis, it may very well be in the best interests of the industrialized world for mining firms to generate jobs and income in resource-rich developing countries. Transfer of technology, training, education, and environmental stewardship are major steps toward mitigation of both poverty and pollution, the downstream effects of which may include eventual reduction in fertility—albeit these countries constitute but a small fraction of the world population problem.

Conflicts and trade-offs in resource development. If resource exhaustion is not likely to be of serious concern globally for the foreseeable future, then established land-use priorities may need revisiting. Can the United States, and the world, afford to assign higher priority to environmental concerns? Should a decision to develop an ore body now take into account the global context of both minerals availability and ecological resources?

To illustrate the conflicts and trade-offs that can arise between resource development and environmental protection, consider the iron deposit in the Nimba Mountains of Guinea, where a large ore body has long been known. Reserves of high-grade ore (66.5% iron) are estimated at 350 million metric tons (*84*). A consortium of Western mining companies is eager to develop the deposit; the government of Guinea is eager for new mining rents and jobs. However, Mount Nimba, highest point (1760 meters) in the Nimba Range of West Africa, is in rain forest that harbors a number of unique species, and in 1981, the area was designated a World Heritage Site, an ecological preserve, by the United Nations (Yellowstone National Park in the United States is similarly designated). A Guinean nongovernmental organization has mounted a campaign against the project and enlisted the support of a major U.S. environmental group.

It might be asked if the world's need for iron ore is so great that mining should take precedence over ecological value. Proposed production of Mount Nimba iron ore at about 9 million metric tons per year is 1% of annual world production; China and the former Soviet Union each produce 200 million tons annually; Brazil alone produces about 150 million tons (*25*). The resource sought is not in short supply nor likely to be in the next century. Guinea is not bereft of other resources (*84*); it is the world's second largest producer of bauxite (after Australia), having almost unlimited reserves, and with significant production of gem diamonds and gold, Guinea is thought to have major geological potential for new discoveries of these minerals. Iron ore is not the country's only hope for hard currency exports.

Currently, the Mount Nimba project is on hold; the World Bank has withheld financial support, and civil war in neighboring Liberia has prevented linkage with the existing rail line to the coast. Negotiations are continuing, however, "and environmental objections to mining in Nimba National Park . . . are expected to be resolved to the satisfaction of UNESCO" (*85*). Indeed, the government of Guinea was successful in its appeal to the World Heritage Committee to exclude the proposed mine area from the World Heritage Site in a revised (1993) delimitation of its boundaries. The human impact on the ecological resources of the mountainous rain forest environment that would result from the project's implementation and attendant influx of population, however, would be difficult to mitigate (*86*). There are numerous economic, social, and environmental issues yet to be resolved, and appeals to block development are still pending.

Perhaps the potential conflict over mineral deposits and environmental resources is a matter for arbitration, if not by the United Nations, then perhaps by a corporate, multinational organization such as the International Council on Metals and the Environment. Such a self-policing role would seem to fall squarely within the Environmental Charter agreed to by members of that group. The Mount Nimba project represents the sort of dilemma the mining industry and developing nations are likely to confront with increasing frequency as hinterlands continue to disappear around the world.

Summary

Minerals essential to industrial economies are not now in short supply, nor are they likely to be for the next several generations. Accordingly, given the lack of pending crises in raw materials availability, mining can no longer presume de facto acclaim as the best of all possible uses for land; it must compete with compelling demands for alternative uses. Current debate regarding the disposition of U.S. public lands exemplifies this point, as do conflicts elsewhere. Environmental protection and rehabilitation are fast becoming high priorities throughout the world, no longer confined to industrialized nations. Human population growth is the most critical environmental problem facing the entire planet, and 95% of that growth is occurring in the developing world. Investment in mineral deposits of developing nations offers some hope of improving economic and social conditions in those countries that rely on mineral rents for hard currency, but realization hinges on reform and the implementation of long-range government policies for applying those rents to domestic welfare and ensuring environmental sustainability.

As world tensions among major powers diminish and trade expands in the aftermath of the Cold War, concerns about self-sufficiency and minerals security of the United States are no longer overriding. Of greater importance may be the contribution of mineral resource development to the economic rescue of emerging nations, and the consequent hope for an eventual reduction in population growth, without which environmental concerns in these nations are ultimately irrelevant.

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RESEARCH ARTICLE

Mutagenesis and Laue Structures of Enzyme Intermediates: Isocitrate Dehydrogenase

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Site-directed mutagenesis and Laue diffraction data to 2.5 Å resolution were used to solve the structures of two sequential intermediates formed during the catalytic actions of isocitrate dehydrogenase. Both intermediates are distinct from the enzyme-substrate and enzyme-product complexes. Mutation of key catalytic residues changed the rate determining steps so that protein and substrate intermediates within the overall reaction pathway could be visualized.

Standard x-ray crystallography is usually performed on inactivated enzymes or inhibited enzyme complexes in order to prevent the rapid reaction of substrate and time-dependent averaging of electron density. However, polychromatic Laue crystallography, a technique whereby the x-ray source is a synchrotron, provides an increased rate for data collection so that the structural details of intermediate complexes can be visualized (*1–5*). Such Laue studies demonstrate the possibility of visualizing rate-limited enzyme-substrate complexes with very long lifetimes, but do not address the problem of transient intermediate species that normally are not rate-limited.

Determination of the structure of an enzyme-bound intermediate on a path of several intermediates requires a method of inducing the homogeneous synchronized accumulation of that particular species throughout the crystal, during which time diffraction data may be collected. One successful strategy has consisted of triggering an initial, synchronized turnover cycle in the crystal with a caged-type compound (usually a chemically modified substrate molecule that can be released by flash photolysis). During the first round of catalysis after photolysis, rate-limited intermediates accumulate and then decay, provided that the rate of all steps between the initial absorption of photons and the formation of the rate-limited intermediate complex are sufficiently fast. As an alternative strategy we now present the use of site-directed mutagenesis of key catalytic residues to create kinetic bottlenecks at specific catalytic steps in the overall reaction pathway that may then be used to determine the structure of distinct intermediates. Such complexes represent steady-state species that accumulate and persist in the crystal in vast excess of other catalytic states during the course of slow turnover and data collection.