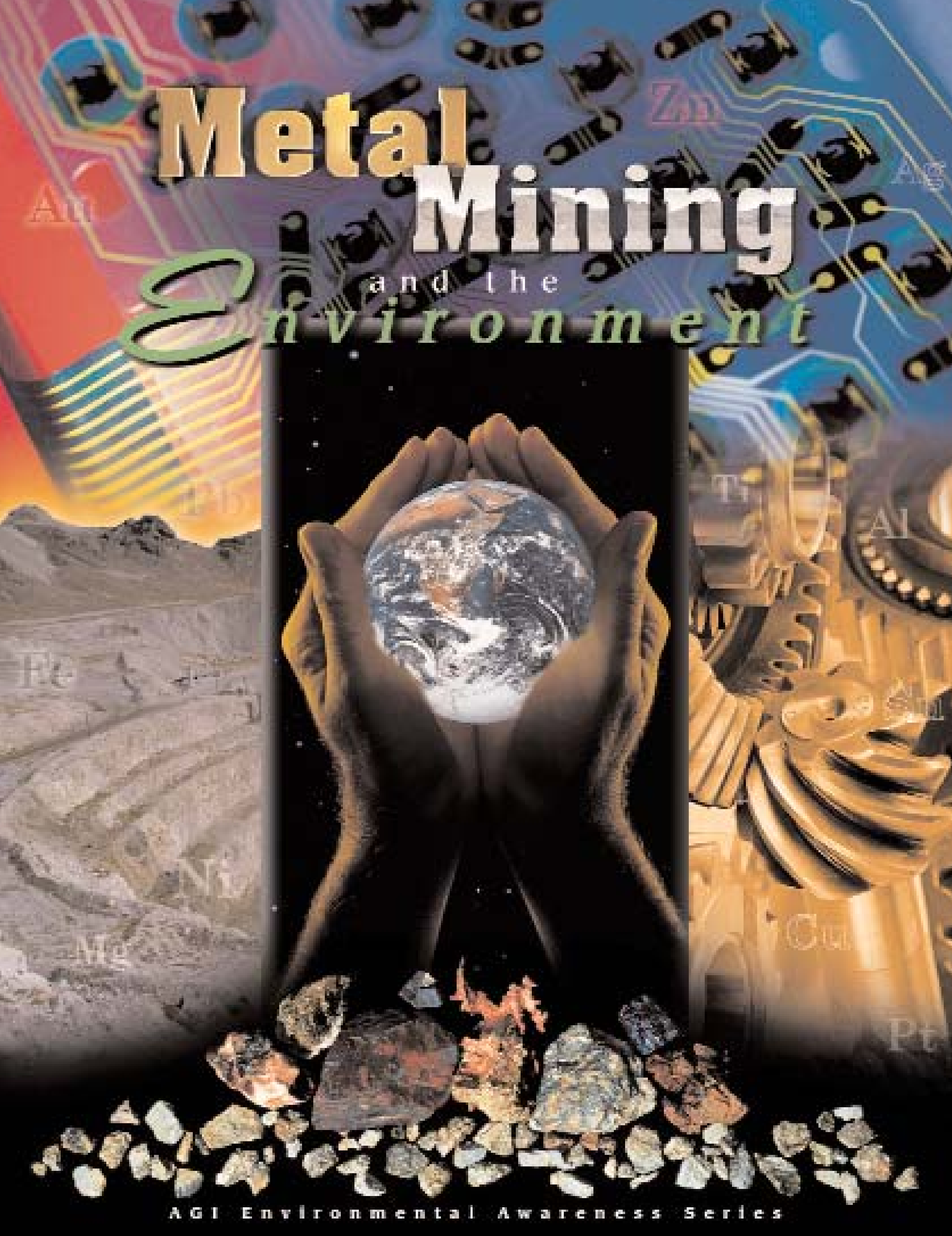
Metal Mining
and the
Environment
AGI Environmental Awareness Series

A better scientific understanding of the environmental impacts of mining, coupled with great advances in mining and environmental technologies, have enabled modern miners to better predict, plan for, and prevent or minimize potential adverse environmental impacts.

About the Authors

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Metal Mining and the Environment

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American Geological Institute
Alexandria, Virginia

In cooperation with

Society of Economic Geologists

Society for Mining, Metallurgy, and Exploration, Inc.

U.S. Department of the Interior
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The American Geological Institute (AGI) is a nonprofit federation of 34 geoscientific and professional organizations, including the Society of Economic Geologists and the Society for Mining, Metallurgy, and Exploration. The AGI member societies represent more than 130,000 geologists, geophysicists, and other Earth and environmental scientists. Since its founding in 1948, AGI has worked with its members to facilitate intersociety affairs and to serve as a focused voice for shared concerns in the geoscience profession; to provide leadership for improving Earth-science education; and to increase public awareness and understanding of the vital role the geosciences play in society's use of resources and its interaction with the environment.

Society of Economic Geologists
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The Society of Economic Geologists (SEG), established in 1920, advances the science of geology, especially the scientific investigation of mineral deposits and their applications to mineral resources appraisal, exploration, mining, and other mineral extractive endeavors; disseminates information about these topics; and encourages advancement of the profession and maintenance of high professional and ethical standards among its 3,400 members.

Society for Mining, Metallurgy, and Exploration, Inc.
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www.smenet.org/

The Society for Mining, Metallurgy, and Exploration (SME), which traces its origins back to 1871, advances the worldwide mining and minerals community through information exchange and professional development. This international society of more than 15,000 members has five divisions: coal, environmental, industrial minerals, mineral and metallurgical processing, and mining and exploration.

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As the nation's largest water, Earth and biological science and civilian mapping agency, the U.S. Geological Survey (USGS) works in cooperation with more than 2000 organizations across the country to provide reliable, impartial scientific information to resource managers, planners, and other customers. This information is gathered in every state by USGS scientists to minimize the loss of life and property from natural disasters, to contribute to the conservation and the sound economic and physical development of the nation's natural resources, and to enhance the quality of life by monitoring water, biological, energy, and mineral resources.

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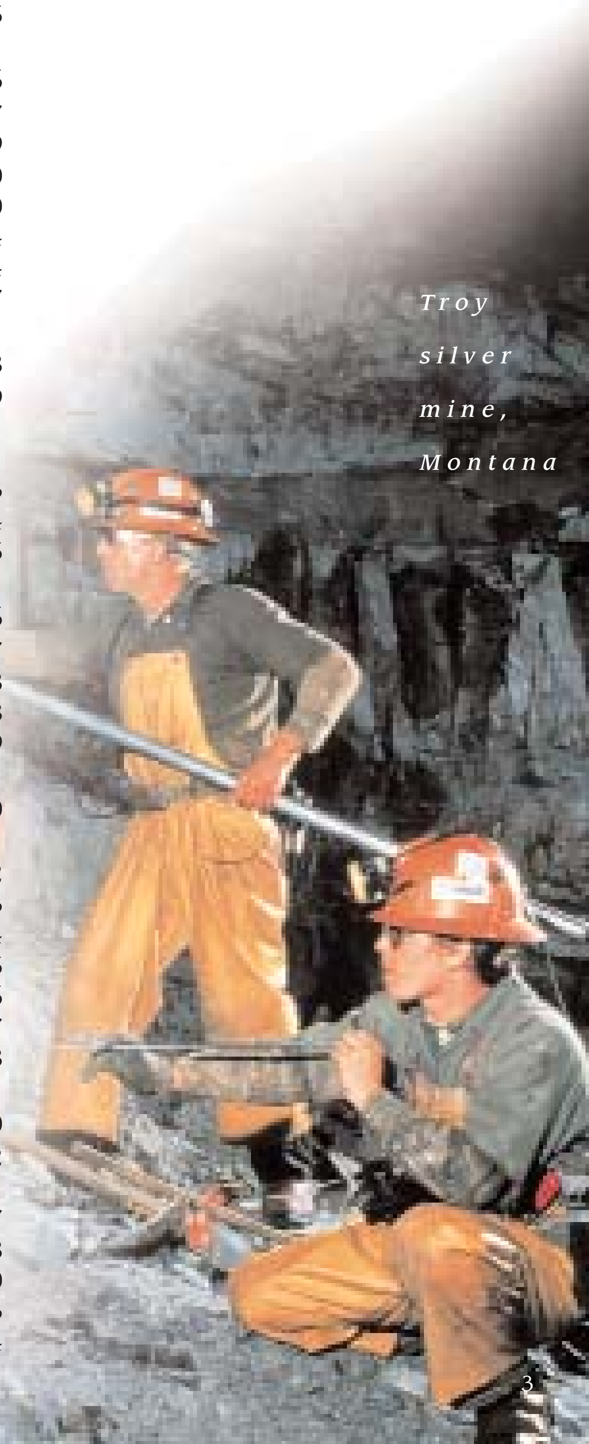

Troy silver mine, Montana

Foreword

Metal Mining and the Environment is part of the AGI Environmental Awareness Series. The American Geological Institute produces the series in cooperation with its member societies and others to provide a nontechnical framework for understanding environmental geoscience concerns. This book was prepared under the sponsorship of the AGI Environmental Geoscience Advisory Committee with support from the AGI Foundation. Since its appointment in 1993, the Committee has assisted AGI by identifying projects and activities that will help the Institute achieve the following goals:

- Increase public awareness and understanding of environmental issues and the controls of Earth systems on the environment;

- Communicate societal needs for better management of Earth resources, protection from natural hazards, and assessment of risks associated with human impacts on the environment;

- Promote appropriate science in public policy through improved communication within and beyond the geoscience community related to environmental policy issues and proposed legislation;

- Increase dissemination of information related to environmental programs, research, and professional activities in the geoscience community.

The objective of the Environmental Awareness Series is to promote better understanding of the role of the geosciences in all aspects of environmental issues. Although metal production is of critical importance to the future of society, the very nature of mining and mineral processing activities raise many environmental questions. We hope that *Metal Mining and the Environment* will help you identify and consider those questions. Through improved science and technology, environmental concerns associated with metal mining can be better assessed and significantly reduced.

David A. Stephenson
AGI President, 1999

Philip E. LaMoreaux
Chair, AGI Environmental Geoscience Advisory Committee 1993-

Stephen H. Stow
Co-Chair, AGI Environmental Geoscience Advisory Committee 1993-

Preface

The process of extracting natural resources, such as metals, from the Earth commonly raises public concerns about potential environmental impacts. *Metal Mining and the Environment* provides basic information about the mining cycle, from exploration for economic mineral deposits to mine closure. The booklet discusses the environmental aspects of metal mining and illustrates the ways science and technology assist in preventing or reducing environmental impacts.

Society's requirement for metals establishes a strong link between our standard of living, the Earth, and science. Understanding the highly technical process of metal mining can help prepare citizens for the necessary discussions and decisions concerning society's increasing need for metals and the related environmental tradeoffs. Decisions about the development and use of Earth's metallic resources affect the economic, social, and environmental fabric of societies worldwide. Our challenge is to balance these important attributes. *Metal Mining and the Environment* helps answer the following questions:

- Why does society need metals?
- What are the principal sources of metals?
- How are metals recovered from the Earth?
- What are the major environmental concerns related to producing metals?
- How can these environmental concerns be managed and mitigated?
- What role can technology play in reducing environmental impacts?
- What is the future need and environmental outlook for metal mining?

The authors are grateful for the technical reviews provided by many colleagues in industry, academia, and federal agencies. Editorial assistance from Alma Paty and Julia Jackson has been invaluable, as the authors' tendency towards technical and scientific discussion necessitated modification of the original manuscript. Our special thanks go to the many individuals and companies who provided illustrations and other forms of support for the project.

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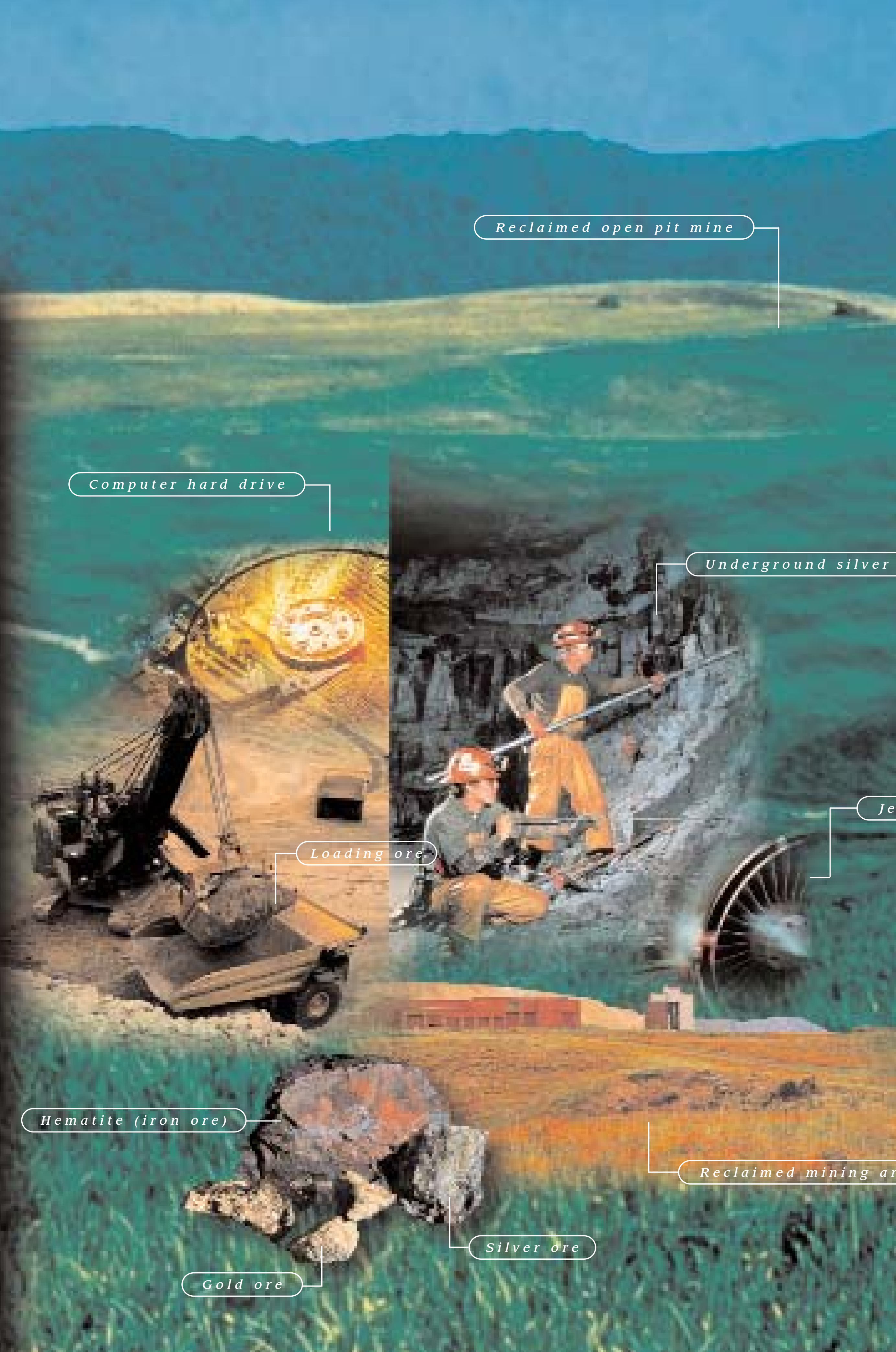
October, 1999

Faint traces of the benches show along the walls of this reclaimed open pit mine. Surface and underground metal-mining operations today plan for and deal with environmental impacts before, during, and after mining.



It Helps to Know...

It is difficult to imagine life without iron, aluminum, copper, zinc, lead, gold, or silver. These and other metallic resources mined from the Earth are vital building blocks of our civilization — and society's need for them is increasing. Metal mining in the United States has evolved from small, simple operations to large, complex production and processing systems. Some historic mining activities that occurred when environmental consequences were poorly understood have left an unfortunate environmental legacy. Today, mining companies must plan for and deal with environmental impacts before, during, and after mining.

Mineral deposits containing metals are mined from the surface in open pit mines, or from underground. Later chapters describe the mining process, which separates metals from the rocks and minerals in which they occur, as well as potential environmental impacts and solutions. Included in this chapter is basic information about metal mining: what the environmental concerns are, how science and technology can help, why metals are important, and the steps in the mining cycle.

What the Environmental Concerns Are

Operations and waste products associated with metal extraction and processing are the principal causes of environmental concerns about metal mining, which may

- Physically disturb landscapes as a result of mine workings, waste rock and tailings disposal areas, and facility development.
- Increase the acidity of soils; such soils can be toxic to vegetation and a source of metals released to the environment.
- Degrade surface and groundwater quality as a result of the oxidation and dissolution of metal-bearing minerals.
- Increase air-borne dust and other emissions, such as sulfur dioxide and nitrogen oxides from smelters, that could contaminate the atmosphere and surrounding areas.

Modern mining operations actively strive to mitigate these potential environmental consequences of extracting metals. The key to effective mitigation lies in implementing scientific and technological advances that prevent or control undesired environmental impacts.

How Science and Technology Can Help

As scientific and technological advances increase the understanding of the physical and chemical processes that cause undesired environmental consequences, metal mines and related beneficiation or smelting facilities apply this understanding to prevent and resolve environmental problems. Ongoing mining operations and mine closure activities employ several different mitigation approaches including

- Reclamation of disturbed lands,
- Treatments and stabilization of metal-bearing soils,
- Prevention and treatment of contaminated water,
- Controls on the amount and character of emissions to the atmosphere,
- Minimizing waste and recycling raw materials and byproducts.

Better, more cost-effective approaches are needed for dealing with the environmental impacts of mining, beneficiation, and smelting, especially measures that prevent undesired environmental impacts. Scientific and technological research, focused on understanding the underlying processes important to these problems, can provide the foundation for new, cost-effective solutions. The challenge for future metal production is to develop environmentally sound mining and processing techniques that can also contribute to more widespread mitigation of historical environmental problems.

Why Metals Are Important

Metals are a class of chemical elements with very useful properties, such as strength, malleability, and conductivity of heat and electricity. Most metals can be pressed into shapes or drawn into thin wire without breaking, and they can be melted or fused. Some metals have magnetic properties, while others are very good conductors of

Metals Empower Us

Aluminum

Chromium

Cobalt

Columbium

Copper

Gold

Iron

Lead

Manganese

Mercury

Molybdenum

Nickel

Platinum

Silver

Tantalum

Tin

Titanium

Tungsten

Zinc

Zirconium

electricity. For example, gold is used in electronic equipment because it is an exceptional conductor of electricity and heat and it does not tarnish or corrode.

Metals and other minerals are essential components in such everyday necessities as our homes, cars, appliances, and tools. Indeed, we find ourselves becoming increasingly dependent on a vast array of new technologies — computer information systems and global communications networks — all of which need metals. Metals are also integral to the basic infrastructure of our society: transportation systems (highways, bridges, railroads, airports, and vehicles), electrical utilities for consumer power, and food production and distribution.

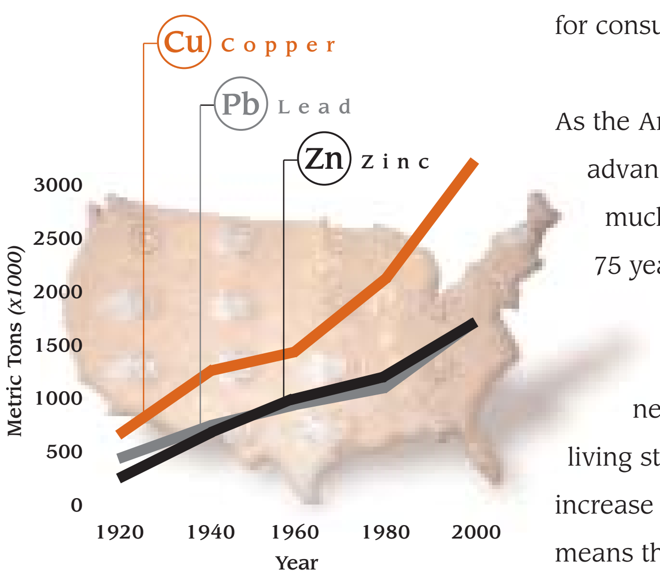


Fig.1. U.S. consumption of copper, lead, and zinc.

As the American population increases and our standard of living advances, so does our need for metals. We now use three times as much copper and four times as much lead and zinc as we did 75 years ago (Fig. 1).

The increasing need for metals in the United States is a need shared throughout the world. The desire to raise global living standards, coupled with a growing world population, will increase worldwide demand for metals in the future. This demand means that metal mining — the industry responsible for extracting metals from the Earth for use in our daily lives — will continue to be vital and necessary.

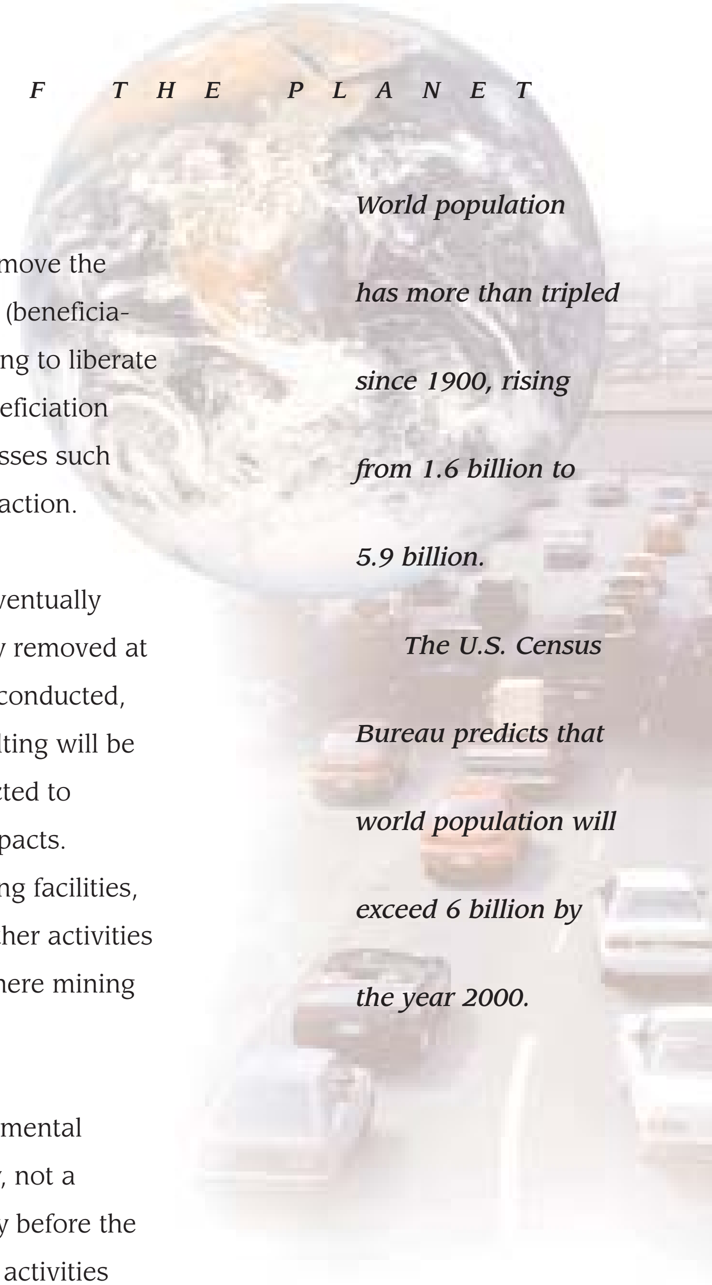
The Metal Mining Cycle

The geologic evolution of the Earth controls the quantity and the very uneven distribution of metal resources in the Earth's crust. Discovering metal-rich deposits commonly requires extensive searching, and exploration is the the first step in the mining cycle. Once exploration geologists find an area with metals, they determine whether it is of sufficient size and richness to be mined profitably. If the deposit is rich enough, activities to extract the metals from the Earth begin.

Extraction, the next part of the cycle, involves mining to remove the metal-bearing minerals from the Earth, mineral processing (beneficiation) to concentrate the metal bearing minerals, and smelting to liberate metals from the minerals that contain them. Although beneficiation and smelting are the most common processes, other processes such as chemical leaching are used for some types of metal extraction.

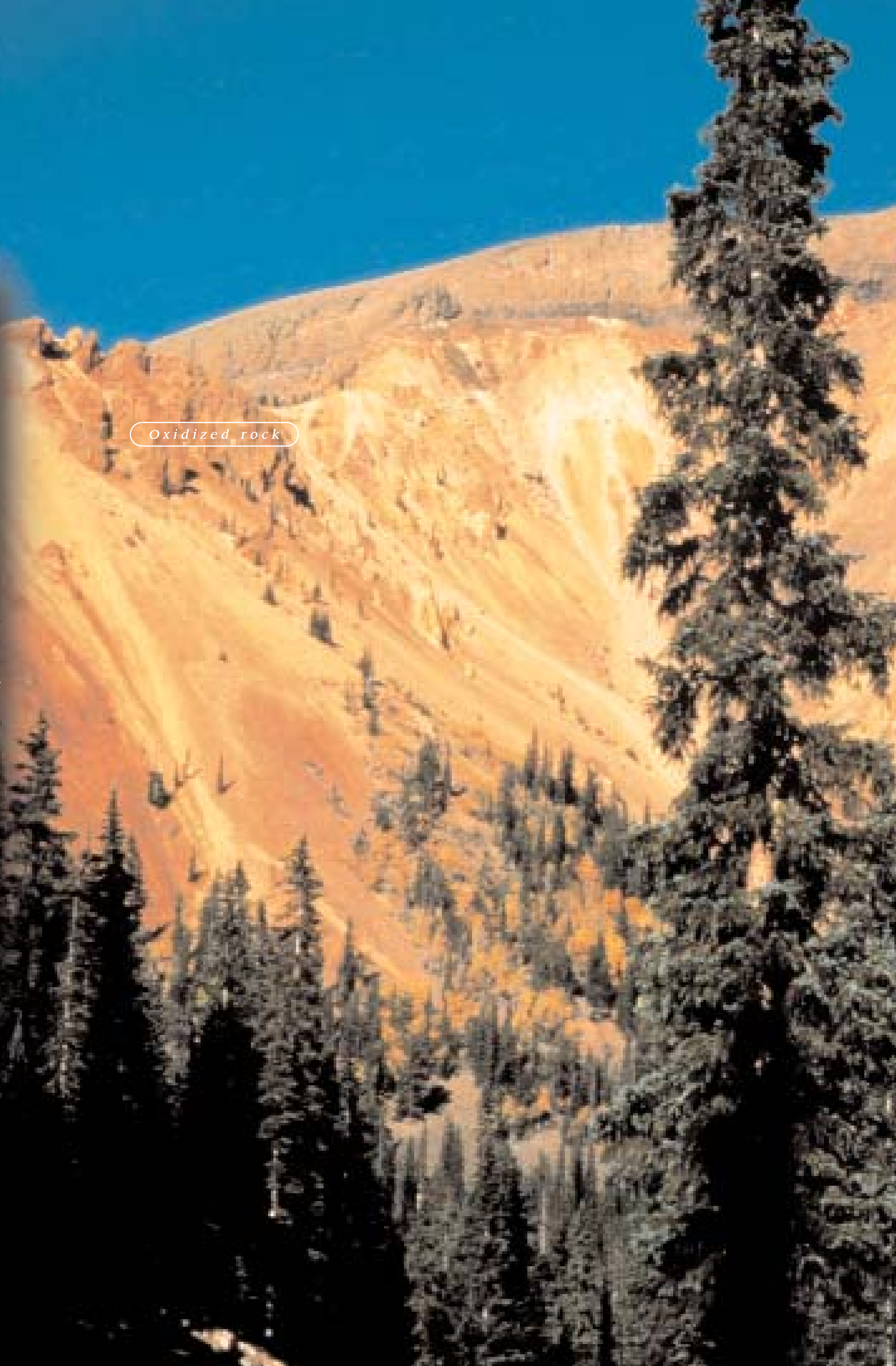
Mine closure is the final step in the mining cycle. Mining eventually depletes the metal-rich material that could be economically removed at a specific mine. When mining can no longer be profitably conducted, the mine and related facilities used in beneficiation or smelting will be closed. Closure involves many activities specifically conducted to prevent or mitigate undesired environmental and social impacts. These activities involve reclaiming disturbed areas, removing facilities, mitigating safety hazards, cross-training employees, and other activities that lead to environmentally benign and safe conditions where mining once took place.

Mining in the early days took place at a time when environmental impacts were not as well understood and most importantly, not a matter of significant concern. During these times, primarily before the 1970s, the mining cycle did not necessarily include closure activities specifically designed to mitigate environmental or social impacts. As a result, historical mine sites may still have unreclaimed areas, remnants of facilities, and untreated water. This inherited legacy of environmental damage from mining is not indicative of the mining cycle today. Now, mine closure and a number of activities to mitigate the social and environmental impacts of mining are an integral part of all metal mine planning and mineral development from the discovery phase through to closure.



World population has more than tripled since 1900, rising from 1.6 billion to 5.9 billion.

The U.S. Census Bureau predicts that world population will exceed 6 billion by the year 2000.



Natural weathering and erosion of these unmined mineral deposits in Colorado release acidic waters and metal-bearing sediments into local streams.

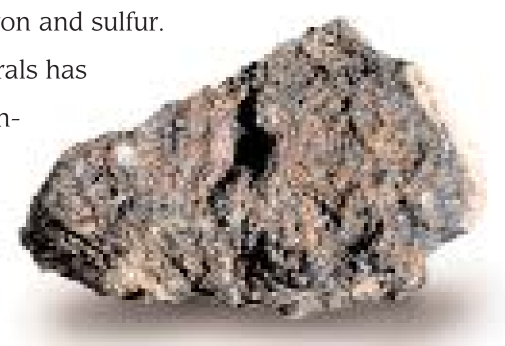
Exploring for Metals

The recovery of metals from the Earth starts with exploration. Mining companies expend tremendous amounts of time, effort, and money in the search for metallic resources. Metallic orebodies are rare; to find new ones, exploration geologists must understand how metals naturally occur, the special geologic processes that control orebody development, and how orebodies are physically and chemically expressed in the Earth.

The Geologic Foundation

Metals come from rocks and minerals in the Earth's crust. Minerals are naturally-formed chemical elements or combinations of elements that have specific chemical compositions and physical properties. Metallic and nonmetallic minerals occur in ordinary rocks throughout the Earth's crust, but only a few minerals contain high enough concentrations of metals to be mined profitably.

Certain metals, such as copper, lead, and zinc have a strong natural affinity for the element sulfur, and they combine with it to form minerals called sulfides. Probably the most familiar sulfide mineral is fool's gold (pyrite), which is composed of iron and sulfur. The mining and processing of sulfide minerals has historically been the source of most environmental concerns with metals extraction.



Ore rich in sulfide minerals

Mineral Deposits

Identifying deposits where geologic processes have concentrated sulfide minerals is a continuing challenge for exploration geologists. They search for mineral deposits that contain rich enough concentrations of metal-bearing minerals to economically justify mining. Metallic mineral deposits can be dispersed through entire mountains and can cause environmental impacts naturally — whether or not they are mined. For example, the mineralized deposits on the facing page are a natural source of acidic and metal-bearing water that enters the watershed.

Fig. 2. Galena (lead sulfide) is the principal ore mineral of lead. Crystals of this bright metallic gray mineral characteristically show right-angle surfaces. Mining operations where lead is the primary metal typically require ores that contain a minimum of 8 percent lead.

Special geologic processes lead to the development of mineral deposits having high concentrations of metal-bearing minerals. These types of mineral deposits are rare, and they occur in very diverse locations. Large mineral deposits are being mined today from various environmental and geographic settings, such as high mountainous rain forests located in Indonesia, arid deserts in Arizona, and the treeless Arctic tundra of Alaska.

The settings where mineral deposits occur can play a significant role in determining the nature and the extent of environmental concerns at specific mine locations. The potential environmental impacts of mining the same type of mineral deposit can be very different in different locations and settings. For example, mining in arid parts of Arizona has different potential impacts on surface water and groundwater quality than if the same mining had occurred in areas of temperate climates, such as the Rocky Mountains or the midwest. Although many metallic mineral deposits have been identified through exploration, only a few deposits are large enough and have a metal content great enough to support commercial operations. The economically important part of a mineral deposit is known as the "ore" or "orebody" (Fig. 2).

Once an orebody is identified within a mineral deposit, geologists determine its form. The form of the orebody is important for two reasons: the shape of an orebody helps determine the best way to mine it, and the orebody form influences the potential environmental impacts associated with mining. Although every mineral deposit has distinctive features, they generally exist in two common forms. In one form, the orebody can have dimensions (length, width, and depth) measured in miles (kilometers) and can include a large volume of rock at or near the surface. These ore deposits are most efficiently mined from surface excavations called open pits.

The other general orebody form is one characterized by tabular shapes in which either the vertical or horizontal dimension is much greater than the other — at the most one or two miles (1 to 3 km) in depth or length. These types of deposits can extend to considerable depth and are most commonly mined by underground mining techniques. Large massive orebodies occurring at depths greater than about 1000 feet (350 meters) also must be extracted by expensive underground mining techniques.

The Exploration Process

Mineral exploration is a challenging enterprise that takes geologists to remote regions throughout the world and requires a variety of scientific and technical skills. Exploration geologists need exceptional perseverance, for they may examine dozens and dozens of mineral deposits without finding one ore body that is rich enough to support mining. On a worldwide scale, however, geologists find a few new orebodies each year.

Mineral exploration

The exploration process begins with a geologist examining satellite images, geologic maps, and reports to identify areas favorable for mineral deposits. Once these areas are defined, the geologist conducts field examinations to create more detailed maps and rock descriptions. Geologists commonly augment their field examinations with geochemical and geophysical exploration techniques that help them identify specific mineral deposits. Geochemical techniques are used to analyze samples of rocks, soils, water, vegetation, or stream sediments which may contain elements that are important clues to possible nearby metal deposits. Geophysical techniques, such as magnetic surveys, can help characterize rocks beneath the surface. Very detailed studies are done to determine if a mineral deposit contains an orebody. The geologist carries out these studies by making detailed maps of the surface geology and combining these with detailed characterizations of rocks extracted from the mineral deposit. Drilling into a mineral deposit commonly recovers cores or chips of the subsurface rocks that geologists then examine and analyze chemically. Verifying the subsurface character and form of an orebody requires extensive drilling.

In general, the exploration process — from initial office compilation to extensive drilling — is expensive and time-consuming. It may take years of work and millions of dollars of expense to reach a development decision for a specific mineral deposit. In most cases, this work and expense will be incurred only to determine that an orebody is not present. In that case, the disturbed sites will be reclaimed and the exploration process starts over and the search for another favorable area begins. Perseverance and insightful geologic analysis are the keys to success — eventually they can lead to the excitement of an orebody discovery, the ultimate reward for an exploration geologist. Discovery of an orebody is the first step toward making the metals available.