Mineral Resource Perspectives 1975

GEOLOGICAL SURVEY PROFESSIONAL PAPER 940

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PREFACE

The Mining and Minerals Policy Act of 1970, the Club of Rome's report "The Limits of Growth" (Meadows and others, 1972), and the U.S. National Commission on Materials Policy (1973) focused public attention on the Nation's dependence on mineral resources, and reports such as "United States Mineral Resources" (U.S. Geological Survey Professional Paper 820) and "Mineral Resources and the environment" (National Academy of Sciences, 1975) have broadened that concern. The problems of access to raw materials, though often minimized, are complex issues requiring factual data and careful analysis. This report, which supplements the annual report of the Secretary of the Interior under the Mining and Minerals Policy Act of 1970 (P.L. 91–631), provides current Geological Survey perspectives on the status of mineral resources research on other than energy materials, which will be considered elsewhere, and discusses progress toward a better understanding of the problems of minerals availability. The U.S. Bureau of Mines (1974b) has prepared a companion appraisal of mineral reserves, "Commodity Data Summaries 1974."

The task of evaluating mineral resources is a continuing one. Although mineral *resources* are not renewable—that is, they cannot be regenerated or replaced at rates comparable with their extraction—mineral *reserves* can be created from subeconomic resources or new discoveries, but the creation process is possible only through a concerted, well-planned, time-consuming effort by industry, academia, and Government. This report considers some of these problems and describes some current research by the U.S. Geological Survey that is directed toward understanding the problems of access to mineral resources and the methods of their appraisal and exploration

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INTRODUCTION

Energy materials are so much in the limelight today that little attention has been focused on the equally important but less obvious problem of availability of other minerals for an expanding world industrial complex, or indeed for the increased production of energy. **This report summarizes the status of mineral resources and mineral exploration in the United States and mineral resources research in the U.S. Geological Survey in 1974.** It is intended for concerned citizens, scientists, planners, and policymakers, whether in industry, Government, or private life, who want to know more about current and potential mineral resource problems and what steps are being taken, or might be taken, to solve them. Bold-face type is used in the text to emphasize ideas which the authors consider to be especially significant. References are cited in parentheses by the author's name and the date of publication; full citations are given at the end of the report.

WHAT IS OUR MINERALS PROBLEM?

Our society is dependent on minerals, and without a steady supply of them it could not survive. Consider a few of the mineral products in a typical American home:

Building materials: sand, gravel, stone, brick (clay), cement, steel, aluminum, asphalt, glass.

Plumbing and wiring materials: iron and steel, copper, brass, lead, cement, asbestos, glass, tile, plastic.

Insulating materials: rock wool, fiberglass, gypsum (plaster and wallboard).

Paint and wallpaper: mineral pigments (such as iron, zinc, and titanium) and fillers (such as talc and asbestos).

Plastic floor tiles, other plastics: mineral fillers and pigments, petroleum products.

Appliances: iron, copper, and many rare metals.

Furniture: synthetic fibers made from minerals (principally coal and petroleum products); steel springs; wood finished with rotten-stone polish and mineral varnish.

Clothing: natural fibers grown with mineral fertilizers; synthetic fibers made from minerals (principally coal and petroleum products).

Food: grown with mineral fertilizers; processed and packaged by machines made of metals.

Drugs and cosmetics: mineral chemicals.

Other items, such as windows, screens, light bulbs, porcelain fixtures, china, utensils, jewelry: all made from mineral products.

In our homes, our offices, our industries—in almost every facet of our daily life—we use minerals without knowing it, so hidden are many of their uses among the technical complexities of modern industrial processes and products.

The entire U.S. economy is based on minerals. In 1972, the last full year prior to the pinch of the oil embargo, domestic raw materials valued at $32 billion were converted into energy and processed materials, the value of which exceeded $150 billion and formed the basis of the Gross National Product of $1.1 trillion (Mining and Minerals Policy, 1973).

Our problem is simply that **the United States does not have an adequate known domestic supply of all the minerals needed to maintain our society** for the foreseeable future. We never have had all we needed, but in the past we could easily obtain materials from abroad. Today we meet a smaller percentage of our needs from domestic supplies (table 1), and minerals from overseas are increasingly costly and, in some cases, of uncertain availability. Nationalization of mines in some countries discourages participation by American mining companies; cartel agreements among the major producing nations can suddenly and dramatically raise prices or even halt supply, as has happened recently with petroleum; and "developing" nations are now competing in the world market for the purchase of mineral raw materials.

The many facets of our problem become apparent when we consider the ways we might try to alleviate it:

By reducing the demand for scarce minerals, through substitution of others, reduction of waste, or elimination of some uses.

TABLE 1.—*United States' dependence on foreign sources for some of its minerals*
[Mining and Minerals Policy, 1973]

a. Less than half imported from foreign sources:	
Copper	Tellurium
Iron	Stone
Titanium (ilmenite)	Cement
Lead	Salt
Silicon	Gypsum
Magnesium	Barite
Molybdenum	Rare earths
Vanadium	Pumice
Antimony	
b. One-half to three-fourths imported from foreign sources:	
Zinc	Nickel
Gold	Cadmium
Silver	Selenium
Tungsten	Potassium
c. More than three-fourths imported from foreign sources:	
Aluminum	Tantalum
*Manganese	Bismuth
Platinum	Fluorine
Tin	*Strontium
*Cobalt	Asbestos
*Chromium	*Sheet mica
*Titanium (rutile)	Mercury
*Niobium	

* Commodities more than 90 percent imported.

By **supplementing the raw mineral supply**, through recovery and recycling of scrap and used materials. Recycling of scrap (from junk) already provides significant amounts of some metals—over half of our annual needs for antimony and one-quarter to one-third of that for iron, lead, nickel, mercury, silver, and gold (Mining and Minerals Policy, 1973, p. 20). Research on recycling of domestic and industrial waste is developing new processes for use by industry.

By **increasing our domestic supply**, through discovery of new mineral deposits and through development of technology for the feasible recovery of low-grade deposits.

From the perspective of the 1970's, increasing our domestic supply of minerals seems imperative. A **widespread misconception**, however, allows that this is simply a matter of economics and technology—**that the Earth's crust is an infinite storehouse that can readily be tapped** for new supplies of all kinds of mineral raw materials by either raising the price or developing new technology (which in turn may raise the price). The economic and technologic factors governing mineral supply cannot be ignored, but neither can another more fundamental factor: **geologic availability**. A mineral resource is a concentration of elements or compounds in certain rocks, or in certain geologic environments, in a form that can yield a useable mineral commodity, but such **concentrations are geologic rarities**, and even low-grade deposits are anomalous concentrations. **If a mineral is not geologically available, favorable economics and technology are not pertinent.**

Nor is "raising the price" as simple as it sounds. **Raising the price may actually reduce the supply of a mineral commodity** brought from existing facilities to market per unit of time, because the higher price enables the company to mine a lower grade ore, thereby reducing the amount of concentrate derived from the same mill per unit of time. The mining and milling capacity of a property is almost never increased to accommodate what are believed to be short-term price fluctuations.

The use of increasingly lower grades of ore poses two other problems. First, more energy must be spent, both to dig the ore from the ground and to extract the mineral from it. **Second, the environmental impact is greater**, not only as a result of mining larger volumes of rock and discarding larger volumes of waste, but also because of the increased energy and water requirements.

Realistic appraisals of the quantities of mineral resources remaining to be developed and yet to be discovered are a matter of concern for many policymakers in both industry and Government, but mineral resources cannot be inventoried like cans on a shelf. Reserves, or mineral resources that have been found, sampled, and measured and that can be legally and profitably mined under present conditions, can be inventoried (although on a national scale the inventory is only accurate to the extent that mining companies are willing to release data). But in addition to these reserves, there are: known, low-grade deposits not profitable to mine now; new deposits of reserve quality that can be logically inferred to exist but are as yet undiscovered; and even new types of deposits not yet recognized. These are all mineral resources, and appraising them accurately is perhaps as difficult as appraising the 1985 wheat crop. **Resources can be estimated only by successive approximations, subject to constant change** as known deposits are worked out, as new deposits are found, and as new techniques of exploration, mining, and processing are developed, literally creating reserves from material that was previously unuseable. And so an important facet of the minerals problem is the need to improve methods for appraising resources and to have the successive estimates come closer and closer to being coincident with the amount of material actually occurring.

CLASSIFYING MINERAL RESOURCES

Through the years geologists, mining engineers, and economists have used many terms to describe and classify mineral reserves and resources. Some of these terms have gained wide use and acceptance, although their use by different authors commonly has been marked by a vagueness that makes precise comparison of data difficult. More **uniform use of reserve and resource terminology is critical** to better communication on this vital subject.

Modern attempts to establish a standard terminology of mineral resources began during World War II when the U.S. Bureau of Mines and the U.S. Geological Survey (1947) were assessing the Nation's mineral position. That terminology was reviewed and revised later by a committee of the Society of Economic Geologists (Blondel and Lasky, 1956). More recently McKelvey (1972) and Brobst and Pratt (1973) have discussed concepts of mineral resources and their terminology and emphasized the need for understanding the broader implications of the difference between reserves and several categories of mineral resources.

In anticipation of increased activity in the assessment of mineral resources during the coming years, the staffs of the U.S. Bureau of Mines and the U.S. Geological Survey have collaborated in a joint statement on the classification of mineral resources. The classification (summarized here) is intended to be useful for all mineral commodities, including the energy materials, although supplementary essays dealing with classification problems peculiar to certain commodities may be required.

The distinction between resources and reserves is based on current geologic and economic factors. A *resource* is a concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible. A *reserve* is that portion of the identified resource from which a useable mineral or energy commodity can be economically and legally extracted at the time of determination. The term *ore* is used for reserves of some minerals. Resources thus include, in addition to reserves, other mineral deposits that may eventually become available—known deposits that cannot be profitably mined at present, because of economics, technology, or legal restraints, and also unknown deposits, rich and lean, that may be inferred to exist on the basis of geological evaluation but have not yet been discovered. An analogy from the field of personal finance may help to clarify the distinction: reserves are represented by the funds in one's bank account and by other liquid assets; resources include, in addition, all other assets and all anticipated future income, from whatever source.

Public attention usually is focused on reserves of mineral or energy materials. **Long-term public and commercial planning, however, must be based on** the probability of geologic discovery of new deposits and technologic development of economic extraction processes for currently unworkable deposits. Thus, **all components of total resources** must be continuously reassessed in the light of new geologic knowledge, of progress in technology, and of shifts in economic and political conditions.

Another requirement of long-term planning is the weighing of multicommodity or total resource availability against a particular need. The general classification system must therefore be uniformly applicable to all commodities so that data for alternate or substitute commodities can be compared.

To serve these planning purposes, total resources are classified in terms of both economic feasibility and the degree of geologic assurance of their occurrence (fig. 1).

As shown in figure 1, total resources are divided into two major fields, identified and undiscovered resources; they in turn are subdivided. The resource terms that will be most useful to readers are:

Identified resources: Specific bodies of mineral-bearing material, the location, quality, and quantity of which are known from geologic evidence and, if they are in the demonstrated category, are supported by engineering measurements.

- *Reserves* (already defined).
- *Identified subeconomic resources:* Resources that may become reserves as a result of changes in economic, technologic, and legal conditions.

Undiscovered resources: Bodies of mineral-bearing material surmised to exist on the basis of broad geologic knowledge and theory. Exploration that confirms their existence and reveals quantity and quality will permit their reclassification as reserves or as identified subeconomic resources.

- *Hypothetical resources:* Undiscovered resources that may reasonably be expected to exist in a known mining district under known geologic conditions.
- *Speculative resources:* Undiscovered resources that may exist either as known types of deposits in a favorable geologic setting where no discoveries have been made or as unknown types of deposits that remain to be recognized.

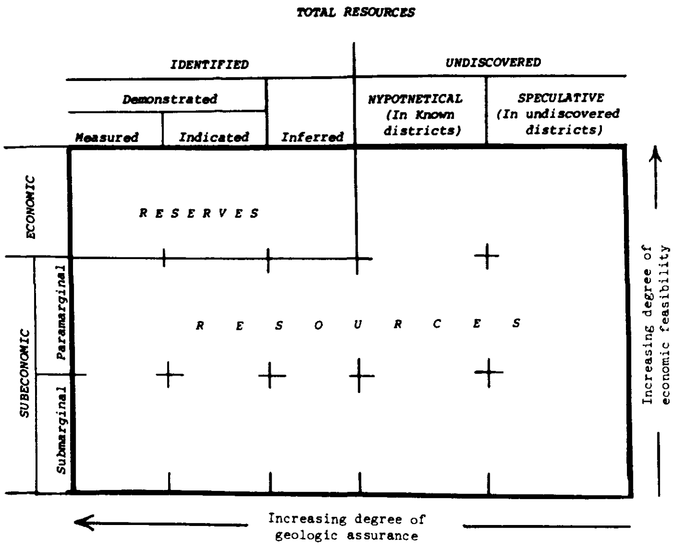

FIGURE 1.—Classification of mineral resources.

Measured, indicated, and inferred are terms applicable to both reserves and identified subeconomic resources.

Measured.—Identified resources for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to be different from the computed tonnage or grade by more than 20 percent.

Indicated.—Identified resources for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on the basis of geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade to be established throughout.

Inferred.—Identified resources for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. Continuity or repetition is assumed on the basis of geologic evidence, which may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred reserves or resources should include a statement of the specific limits within which the inferred material may lie.

The terms *proved, probable,* and *possible* (used by industry for economic evaluations of ore in specific deposits or districts) commonly have been used loosely and interchangeably with the terms *measured, indicated,* or *inferred* (used by the Department of the Interior mainly for regional or national estimates). "Proved" and "measured" are essentially synonymous. "Probable" and "possible," however, are not synonymous with "indicated" and "inferred." "Probable" and "possible" describe estimates of partly sampled deposits—in some definitions, for example, "probable" is used to describe deposits sampled on two or three sides, and "possible" for deposits sampled only on one side; in the Bureau/Survey definitions, both would be described by the term "indicated."

Long-range estimates of resources are little affected by increases of reserves brought about by new discoveries or new technologic or economic developments. What such developments do, in effect, is simply add tons or ounces to the reserve category by taking them away from one of the resource categories shown in figure 1. Such developments are the life blood of the mineral industry because they replenish the dwindling reserves. But they do not alter the *total* resource picture substantially. **A significant increase in the total resources is brought about only by a major scientific or technologic breakthrough.**

Consider, for example, recent estimates of gold resources. In 1967, when the price of gold was $35 per ounce, the U.S. Bureau of Mines estimated 244 million ounces of gold as identified subeconomic resources, potentially recoverable at prices as high as $145 per ounce. With the price in the $160–190 range, as it was late in 1974, those formerly subeconomic resources can be regarded as reserves—but the total resources remain unchanged. On the other hand, gold in seawater is not now considered a resource because of its low concentration—only as much as 0.05 parts per billion, or about 1 ounce of gold per million cubic metres of seawater. Discovery of a method for recovering this gold economically on a commercial scale would add spectacularly to the world's total resources of gold, on the order of 1,000 ounces per cubic kilometre of seawater. In the 1960's, recognition of a new type of resource (the so-called disseminated gold, or Carlin type) was a scientific milestone that added millions of ounces of gold to the categories of identified, hypothetical, and speculative resources.

APPRAISING MINERAL RESOURCES

Mineral reserves and resources are dynamic quantities and must be constantly appraised as known deposits are worked out, new deposits are found, new extractive technologies and uses are developed, and new geologic knowledge indicates new areas and environments favorable for exploration. A final, once-and-for-all "inventory" of any mineral resource is nonsense. Indeed, appraising the national resources of any mineral commodity is at this time an emerging science, and a universally accepted appraisal method has yet to be found.

METHODS

Resource appraisals made in the past have differed greatly because they were made by different methods to fill different needs. Many are of limited use as appraisals of total resource potential because of limitations imposed by the purpose for which they were made. In general, **two types of approaches** have been taken. One utilizes **extrapolations based on production and economic information;** the other utilizes **extrapolations based on information about geologic occurrence.** More recently, geomathematical techniques have been applied to help quantify both types.

Approaches that extrapolate from production and economic data consider such variables as improvements in discovery and recovery techniques and changes in the economics of exploration, production, and marketing (for example, Hubbert, 1962, 1967, 1969; Moore, 1966, 1970). Some incorporate the declining efficiency in exploration, the growth of reserves by additions, and (or) the effects of price changes on resource potential (Arps and others, 1970; Brinck, 1972; Bieniewski and others, 1971). Such approaches tend to allow neither for possible breakthroughs that might make subeconomic occurrences recoverable, nor for possible new discoveries in unexplored areas, and so they have limitations for appraising total resource potential.

Approaches that emphasize geologic occurrence extrapolate data about mineral deposits from explored to unexplored areas. Such geologic evaluation has been used to estimate the number of undiscovered porphyry copper deposits in the Southwestern United States, British Columbia, Chile, and Peru (Lowell, 1970) and to estimate the quantity of several mineral commodities remaining to be discovered in the area north of 60° latitude in Canada (Derry, 1973). This concept of basing mineral resource appraisals on geological extrapolations has been extended by the use of such geomathematical techniques as statistical treatment of opinion polls (Harris and others, 1970) and construction of decision models (Allais, 1957, based on Nolan, 1950; Slichter and others, 1962).

Ideally, resource appraisals should be made by dividing the total unmined resources of each commodity into specific geologic, technologic, and economic subsets, each with its own estimate and each explicitly defined so that its validity can be tested. The procedure by which these estimates are made should be flexible so that new information can be readily incorporated. The precision of an estimate should be stated as explicitly as possible and expressed within prescribed limits of confidence; in practice, however, such confidence intervals are difficult to construct because the assumptions used in making geologic extrapolations about occurrences of mineral commodities are likely to vary, and variability of this sort is not easily reduced to numbers. The assumptions used to construct an estimate should therefore also be stated explicitly. Bias should be avoided; the analyst should not alter an estimate in order to be conservative or optimistic.

The most recent comprehensive mineral resource appraisal by commodity for the United States (and, for some commodities, for the world) was published by the U.S. Geological Survey (Brobst and Pratt, 1973). The methods used to appraise 65 commodities are diverse, but most of them are variants of geologic extrapolation. The appraisals span a broad range, from qualitative to quantitative, and none of the authors would claim that his evaluation is a definitive resource appraisal.

In "Project Appalachia" the Geological Survey of Canada currently is combining expertise in regional geology, mineral-deposit geology, and mathematical processing to provide three approaches to evaluation—(1) a traditional metallogenic (geologic extrapolation) appraisal, (2) a metallogenic-based geomathematical evaluation, and (3) an opinion-poll appraisal. The Canadian Appalachian region was selected for this pilot study because its size is convenient, its geology is relatively well known, and it contains a variety of mineral deposits. Results of the three appraisals will be compared and will be followed up with an opportunity for a second round of opinions based on comments from the first.

On July 1, 1974, the U.S. Geological Survey began a new multidisciplinary program of field and laboratory studies designed to assess the metal and selected nonmetal resources of Alaska. Because mineral appraisals of such large, remote, and little-known regions as Alaska are still largely experimental, a two-year program called the Prototype Alaskan Mineral Resource Assessment Program (PAMRAP) will develop guidelines, techniques, and products as a model for a future statewide mineral assessment program. For each 1:250,000-scale (1°-by-3°) quadrangle studied, geologic, geochemical, and geophysical maps, and computer-enhanced data from satellites (multispectral ERTS imagery) will be interpreted to produce a mineral-potential map. This will be accompanied by a tabular summary of known mines, prospects, and occurrences, and by resource-assessment diagrams showing estimates of identified, hypothetical, and speculative resources.

ORGANIZING DATA

Increasing attention to both geologic and economic evaluation of mineral resources will inevitably generate great masses of numerical data and information which will require skillful organization if it is to be effectively utilized. Because the subject of mineral resources is broad in scope and complexity, involving principally the fields of geology, mining engineering, and economics but also many other closely related, highly technical subjects, and because of the great variety of basic raw materials and the wide range of needs and use patterns, data on mineral resources are difficult to organize, gain access to, and use effectively. **Computerized processing now offers the best available means of improving the usefulness of data.** The computer can separate a whole file into its parts, perform operations on parts, and then reorganize the file. Moreover, a computerized file can be constantly updated, thus eliminating a major problem with the old manual systems. A computer can accomplish in seconds many operations of data which would never even be attempted by manual methods; thus all important relationships of available data can be determined.

Computerized files of resource data now in use within the U.S. Geological Survey and U.S. Bureau of Mines include:

1. CRIB—Computerized Resources Information Bank (for mineral resource data), U.S. Geological Survey.
2. MAS—Minerals Availability System, U.S. Bureau of Mines.
3. Oil and gas file of the Office of Oil and Gas and U.S. Geological Survey.
4. Production/Consumption surveys of the U.S. Bureau of Mines.

THE RESOURCE OUTLOOK

To try to summarize the "status of resources" in a simple numerical table, showing tons of this or that commodity, would be like trying to sketch a sunset in black and white. Describing the full spectrum of resources, like painting a sunset, requires the skillful blending of a full palette of hues—the geologic, technologic, economic, and legal factors that make the appraisal of resources so complex. To disregard these factors and **to tabulate resource estimates as raw numbers removed from their context inevitably lead to misinterpretation.**

The essentials of the resource situation can be expressed by grouping the important commodities according to the general domestic outlook for reserves and resources for the remainder of the twentieth century. These groupings are listed in table 2. An indication of our dependence on foreign sources for some commodities was given in table 1.

TABLE 2.—*General outlook for domestic reserves and resources through 2000 A.D.*

[Within each group, commodities are listed in order of relative importance as determined by dollar value of U.S. primary demand in 1971. An asterisk marks those commodities which may be in much greater demand than is now projected because of known or potential new applications in the production of energy]

Group 1: RESERVES in quantities adequate to fulfill projected needs well beyond 25 years.

Coal	Phosphorus
Construction stone	Silicon
Sand and gravel	Molybdenum
Nitrogen	Gypsum
Chlorine	Bromine
Hydrogen	Boron
Titanium (except rutile)	Argon
	Diatomite
Soda	*Barite
Calcium	Lightweight aggregates
Clays	Helium
Potash	Peat
Magnesium	*Rare earths
Oxygen	*Lithium

Group 2: IDENTIFIED SUBECONOMIC RESOURCES in quantities adequate to fulfill projected needs beyond 25 years and in quantities significantly or slightly greater than estimated UNDISCOVERED RESOURCES.

Aluminum	Vanadium
*Nickel	*Zircon
Uranium	Thorium
Manganese	

Group 3: Estimated UNDISCOVERED (hypothetical and speculative) RESOURCES in quantities adequate to fulfill projected needs beyond 25 years and in quantities significantly greater than IDENTIFIED SUBECONOMIC RESOURCES; research efforts for these commodities should concentrate on geologic theory and exploration methods aimed at discovering new resources.

Iron	Platinum
*Copper	Tungsten
*Zinc	*Beryllium
Gold	*Cobalt
*Lead	*Cadmium
Sulfur	*Bismuth
*Silver	Selenium
*Fluorine	*Niobium

Group 4: IDENTIFIED-SUBECONOMIC and UNDISCOVERED RESOURCES together in quantities probably not adequate to fulfill projected needs beyond the end of the century; research on possible new exploration targets, new types of deposits, and substitutes is necessary to relieve ultimate dependence on imports.

Tin	*Antimony
Asbestos	*Mercury
Chromium	*Tantalum

Known U.S. reserves of many minerals represent only a few years' supply. The outlook for resources is somewhat better, but to bring them into the category of available reserves **will require enormous and costly efforts of exploration and research.** Details on the technologic and geologic problems of utilizing resources of specific commodities are in U.S. Bureau of Mines (1970, Bulletin 650); Brobst and Pratt (1973, U.S. Geological Survey Professional Paper 820); and a shorter report by Pratt and Brobst (1974) that summarizes the principal findings of Professional Paper 820 with regard to the resources of 27 major mineral commodities.

EXPLORATION FOR MINERAL RESOURCES

According to a U.S. Geological Survey compilation from the literature, the world's mineral-reserve wealth was increased in 1973 by nearly 100 million tons of copper; 40 million tons of nickel; several billion tons of iron ore and bauxite; about 38 million tons of zinc; and about 21 million tons of lead. These developments and increased productive capacities are the result of many years of concerted effort by governments and industry.

To maintain the forward thrust of such activities, extensive research and increased exploration activities for new deposits in unexplored but geologically favorable areas are essential. New or improved exploration techniques and geological concepts must be devised. The technology to develop mineral deposits and to increase the recovery of metal from low-grade ores must be improved. New policies and guidelines must be established so that long-range programs of research, discovery, and development may be conducted and investment capital attracted to support the mineral industry. **Closer cooperation between government agencies, universities, and private industry is essential** for a better understanding of geological and technical problems.

TECHNIQUES FOR MINERAL EXPLORATION

Most of the mineral deposits discovered before the twentieth century were found because they were exposed at the Earth's surface and contained high concentrations of the minerals sought. Commonly these minerals were fairly obvious; they occurred as brightly colored stains or as shiny grains on outcrops or in stream sediments.

In many parts of the world today, **most of these obvious mineral deposits have already been discovered.** The emphasis in the search for new resources is therefore on finding low-grade deposits that would not have been profitable to mine in the past, deposits that are poorly exposed or not exposed at all, and deposits of previously unknown types that exhibit no obvious visual surface expression.

Mineral exploration today is a highly sophisticated, expensive and involved science that includes regional appraisal, reconnaissance geological studies, and physical exploration. The role of the traditional mineral prospector who searched for and sampled outcrops continues to decline in importance as the most obviously mineralized areas become thoroughly explored. The equipment used today is more sophisticated and the techniques are costlier than the early prospector could have imagined. At the same time, domestic lands available for prospecting are becoming more restricted with the establishment of primitive and wilderness areas, parks, monuments, and wildlife refuges. In some areas, urban expansion and environmental-protection measures limit access and restrict operations.

Modern exploration activities include geologic, geochemical, and geophysical investigations; three-dimensional sampling by core drilling or other methods; laboratory analyses including ore treatment, concentration, and recovery tests; economic appraisal; and evaluation of transportation, water, and energy requirements. Favorable results must be obtained from these studies before a property or a mineral deposit can be considered for development.

Geology is the principal discipline used in mineral exploration; a thorough understanding of the physical and chemical characteristics of mineral deposits is essential. In regional geologic appraisals an exploration geologist may use such concepts as global tectonics, metallogenic provinces; metallotects (geologic features believed to have influenced the localization or concentration of elements in the Earth's crust); the relationships between geochemical abundance and mineral resources; the relationship between crustal abundance and the size of resources; and multivariate geostatistical analysis.

Geochemical exploration uses the systematic measurement of one or more chemical properties of a naturally occurring material to discover and delineate abnormal chemical patterns that may be related to potentially economic mineral deposits. The chemical property most commonly measured is the concentration of an element, or of a group of elements, in rock, soil, or streambed sediments, in vegetation, in well, stream, lake, or ocean water, in glacial debris, or in airborne volatile materials.

Exploration geophysics applies the principles of physics to the search for mineral deposits that occur in the Earth's subsurface. Most geophysical work is done with sophisticated electronic equipment that can detect subtle contrasts in such physical properties as specific gravity, electrical conductivity, heat conductivity, seismic velocity, and magnetic susceptibility. The common techniques used, either singly or in combination, are gravity, magnetic, electrical, electromagnetic, seismic, and radioactivity methods. Measurements may be made from aircraft, at the Earth's surface, or in boreholes.

In recent years, a variety of "telegeologic" or "remote sensing" techniques—measurements of various geologic or related properties from aircraft or satellites—have provided insights into complex structures of some regions where much of the bedrock is concealed. Side-looking radar imagery or photography has provided useful base maps in areas where conventional photographic methods had failed because of adverse weather and atmospheric conditions. LANDSAT, formerly Earth Resources Technology Satellite, imagery of many areas provides information on potential mineral and mineral-fuel deposits and is proving to be valuable for a better understanding of ground-water conditions and water-management problems. Preliminary results in Alaska and elsewhere suggest that LANDSAT data may have significant value in monitoring environmental effects of mineral and fuel production activities.

Modern laboratory techniques are applied in exploration projects. Electron-probe X-ray microanalysis, new rapid chemical analysis, visual color-comparison techniques, and neutron-activation analysis have been found particularly useful.

In addition to exploration on land and in the air, government and industry are engaged in designing and testing exploration and mining equipment for undersea exploration operations.

LEAD TIME

Following a preliminary regional appraisal and assuming that jurisdictional and land acquisition problems in selected areas are resolved, reconnaissance geological mapping and studies, detailed geological mapping, geochemical and geophysical investigations, physical exploration, bulk sampling, ore testing, reserve calculations, and **economic evaluations commonly require many years of concerted effort and large amounts of capital investment before a mineral deposit may be considered for development. Lead time of 20 years or more** may be necessary from the beginning of the exploration project to the delineation of an economic mineral deposit. Mine development and plant construction activities require several additional years and more capital expenditure before a mineral commodity is produced and marketed. For example:

In 1929, officals of the Copper Range Company recognized that a large deposit of copper ore existed in the White Pine areas of the Michigan Upper Peninsula, but it was not until 1955 that production started at the mine following completion of exploration and development projects at a cost of 61.7 million dollars.

For a period of 10 years, the Bear Creek Mining Company has been exploring a copper-silver prospect in the Spar Lake district of western Sander County, Montana. The American Smelting and Refining Company, which has entered into an agreement to develop the property, indicates that the feasibility study and mine development will require 13 to 18 years.

The Amax's Henderson molybdenum mine in Colorado, which is expected to start production in 1975, required 8 years of development at an estimated cost of about 250 million dollars.

At the Granduc mine, British Columbia, geological investigations, surface exploration drilling, and ore testing required nearly 12 years, and 5 additional years were needed for development work before production began in 1970. Total cost of these activities was nearly 115 million dollars.

The Michiquillay copper ore deposit in Peru was investigated initially in the 1950's, but production is not scheduled to start before 1980 or later.

None of these examples takes into account the time and expenses involved in the initial stages of regional appraisal. Because the mineral industry is so competitive, little information, published or unpublished, is made available in the early stages of regional appraisal and land-acquisition activities.

Factors such as location, size of area under study, availability of base and geological maps, aerial photographs, and geologic reports all affect the time needed and expenses involved at this early stage. In the period 1955–69, nearly one billion dollars was spent in exploration ventures in the Western United States. In 1972, more than 32 million dollars was spent in worldwide geophysical and geochemical studies, 4.3 million of which was spent in the United States.

CHANCES OF SUCCESS

An exploration project that leads to discovery, development, and production is exceptional, and **the odds against making a significant discovery are high:**

Under the Strategic Mineral Development program in the period 1939–1949, about 10,000 prospects were examined; of these 1,342 deposits were investigated in detail, but only 1,053 contained enough tonnage to be of interest. The outstanding development resulting from this program was the San Manuel copper mine in Arizona.

The Defense Minerals Exploration unit (established by the DME Act) in the period 1951–1958 received 3,888 applications for Federal financial assistance to explore deposits of strategic and critical minerals. Of 1,159 contracts granted, 399 resulted in the certification of discovery of some valuable minerals, and by 1959, 45 of the deposits were in production. The outstanding discoveries of this program included zinc ore deposits in Tennessee and lead deposits in the Viburnum district of Missouri.

RECENT EXPLORATION ACTIVITY

In recent years, worldwide exploration for nonfuel minerals has focused principally on copper, iron, bauxite, lead-zinc, nickel-copper, uranium, and fertilizer materials. Improved prices for gold and silver have stimulated search for precious metals. Offshore exploration is receiving more attention than heretofore.

Exploration activities are gaining momentum in the United States and in Brazil, Europe, South Africa, and the Southwest Pacific. Governmental constraints, however, and new investment and mining policies in Australia, British Columbia, Zambia, and Peru have discouraged exploration efforts in these areas.

Major exploration targets in the United States have been disseminated copper, gold, molybdenum, and uranium deposits, stratiform copper deposits, stratabound lead-zinc deposits, and mineral deposits in volcanic sedimentary sequences. The Precambrian Belt series (extending from Libby, Montana, to the Coeur d'Alene district of Idaho); certain districts in Wisconsin, Minnesota, and Tennessee; and some unexplored areas in Alaska have received more than usual attention. Exploration for copper porphyries, massive sulfides, and Mississippi Valley-type lead-zinc deposits has continued in the Appalachian region. Interim results were reported on nickel-copper investigations in Minnesota where, within a large, low-grade mineralized area, some deposits are estimated to contain as much as 100 million tons of rock that is 0.8 percent combined copper-nickel. Other projects include exploration for zinc in central Tennessee; for molybdenum in Idaho and Colorado; for copper in Arizona, Montana, Utah, Nevada, Wyoming, and Washington; and for platinum in Montana.

Also in the United States, known base-metal ore bodies have been extended in the Coeur d'Alene area of Idaho, and large deposits have been developed at Buick, Mo., and Gainsboro, Tenn. Preliminary reports have been made of exploration, development, and reactivation of old precious metal mining districts in Nome, Alaska; Silverton and Cripple Creek, Colo.; Pinson, Nev.; Mocassin, Mont.; and Wenatchee, Wash. The Homestake Mining Company announced the expenditure of several million dollars at the Homestake gold mine, South Dakota, to develop about 13 million tons of ore hitherto considered subeconomic. Exploration for uranium deposits has continued principally in Wyoming, Utah, Colorado, and New Mexico. No significant discoveries have been announced, but some earlier discoveries are being developed.

Recent developments in Canada include lead-zinc-silver deposits of the Strathcona mine in Baffin Islands, the Arvik mine in the Northwest Territories, and the extension of the Kidd Creek ore body, Ontario, Bathhurst district in New Brunswick and the Gays River area, Nova Scotia. Significant discoveries of copper were also reported in Sonora, Mexico.

Elsewhere in the world, exploration for aluminum ore (bauxite) is focused principally on Australia, Brazil, and West Africa; for iron, on Brazil, West Africa, Australia, North Korea, and India; for copper, on Panama, Peru, Chile, Argentina, Australia, Philippines, Indonesia, Pakistan, Iran, India, Yugoslavia, Sweden, U.S.S.R., Zaire, Zambia, Ethiopia, and Southwest Africa; and for nickel, on Africa, Australia, Indonesia, Philippines, India, and Brazil.

Trade journals regularly report new developments in the mineral industry. A comprehensive survey, for example, of international mining activities was published in the British journal *Mining Magazine* (1974).

Results of exploration efforts outside the United States, measured by additions to the world's reserves of the major metals, are summarized by continent in table 3. Impressive as these data are for tons of reserves reported, explored and(or) developed, and expenditures noted, the reader must keep in mind at least three facts:

1. Lead time to reach production levels may be 15 or more years for many of the individual Projects.
2. The products from the foreign developments will for the most part be available to the world market and are not automatically destined for United States consumption.
3. Expenditures yet to be made may be many times those already reported.

TABLE 3.—*Foreign exploration-development data reported in 1973*

Location and mineral	Indicated reserve (ore in millions of tons)	Grade (percent) [1] From	Grade (percent) [1] To	Reported investment (millions of dollars)	Ore in development (millions of tons)
		Africa			
Bauxite	1,490	42	55	470	900
Copper	250	0.8	5.5	200	230
Iron ore	8,880	35	68	600	7,000
Lead-zinc	8	8	18		
Nickel	225	0.7	1.5	291	50
Gold [2]	130	0.5	0.9	150	
Total				1,711	
		Asia			
Bauxite	95	45	59	100	55
Copper	970	0.9	1.5	400	475
Iron ore	2,420				
Lead-zinc	95	17.7			
Nickel	35	0.8	2.0		
Total				500+	
		Australia			
Bauxite	3,735	45	60	900	1,020
Copper	230	0.7	3.0	145	205
Iron ore	1,900	60	64		
Lead-zinc	245	9	24.7		
Nickel	230	1.3	3.3	471	70
Gold [3]	6	0.2	0.4		
Total				1,516+	
		Canada			
Copper	1,600	0.4	1.7	90	190
Iron ore	3,300	23	50	327	700
Lead-zinc [4]	255	7	20	96	10
Nickel	540	0.33	1.6		
Total				513	
		Europe			
Bauxite	60	54	60		
Copper	775	0.7	1.6	175	610
Iron ore	800	50	60		
Lead-zinc	150	9	11.6	18	7
Nickel	820	1.2	1.3	72	110
Total				265+	
		Latin America			
Bauxite	4,000	High grade		1,200	
Copper	8,690	0.4	1.0	1,842	3,300
Iron ore	24,475	46	67	1,230	24,000
Nickel	190	1.0	2.6	430	100
Gold [5]	50	0.15			
Total				4,702+	
		Oceania			
Bauxite	80	50			
Copper	2,470	0.45	2.5	1,397	1,870
Lead-zinc	5	5.2			
Nickel	1,590	1.2	1.65	1,398	1,065
Total				2,795+	

[1] For bauxite, percent Al_2O_3; for gold, oz/ton.
[2] Some low-grade gold ores contain uranium.
[3] Also contains silver values.
[4] Includes Greenland.
[5] Includes complex ores that contain silver, lead, zinc, and copper.

RECENT RESEARCH ON MINING AND EXTRACTION

Research into various aspects of solution mining, or leaching, has advanced from laboratory and field tests to commercial operations, and in the future solution mining will be an alternative to conventional mining in some areas. This technology has made possible the recovery of copper from some deposits hitherto considered uneconomic, and it is being used successfully in treating gold ore. A principal disadvantage of the method is that it does not recover such important byproducts from copper ores as gold, silver, selenium, and tellurium.

The technical and economic feasibility of deriving aluminum from large domestic alunite deposits in the Western States and from high-alumina clays in Georgia is under serious study. Domestic aluminous laterites from deposits in Oregon have been used successfully instead of bauxite in a conventional alumina refinery.

Offshore exploration for deposits of manganese nodules, which also contain appreciable quantities of copper, nickel, and cobalt, has attracted worldwide attention, particularly by interests in the United States, Germany, Japan, and the U.S.S.R. These nodules have great potential value, and the technology to gather them from the deep seabed (4,000–6,000 metres) is rapidly being developed. If a satisfactory legal regime can be forged that will protect the miner's investment, commercial manganese nodule production will likely be operable before 1980.

Other significant results of scientific and engineering investigations in developing technology for extracting, processing, and recycling minerals, metals, and fossil fuels are summarized in U.S. Bureau of Mines (1974a).

ROLES OF INDUSTRY AND GOVERNMENT IN RESEARCH

For many reasons the ultimate objectives of industry's and Government's research in mineral resources lie at the ends of diverging paths. The mineral industry is composed of specialized units focused on individual or small groups of commodities, each of which has different search and development problems. The industry is so highly competitive and independent in operation, even for the same commodities, that no national focus has been possible beyond those imposed by supply and demand. **The primary purpose of a private company is to find ore and provide a marketable product at a profit.** A large part of industry's exploration activity is therefore directed toward developing reserves, generally from identified subeconomic resources and only to a much more limited extent from hypothetical and speculative resources. A company is understandably most concerned with its position in the short-term marketplace, **whereas Government is deeply concerned with developing knowledge about the Nation's long-term total resource potential and its options for access to resources in the short term.** The overall balance in treatment and understanding needed for public-policy decisions cannot be achieved by industry alone, as industry concentrates its efforts on specific commodities and possibly overlooks others.

In recent years **the cost in time and money of exploring for ore and developing reserves has increased markedly; at the same time the rate of discovery has decreased markedly.** These factors have contributed materially to a reduction in domestic supplies and to price fluctuations which have resulted in overall reduction in funds available to industry for activities in mineral exploration. Some of these difficulties stem from Government actions. Even if industry funds were available, the costs are becoming too great to tolerate continued duplication of uncoordinated effort. Thus Government has the option to nurture the supply system through incentives to industry as a whole for increasing exploration activity and efficiency through mineral research and development.

A responsibility of Government is to collect, synthesize, and analyze basic data about mineral resources and **to make the information available** to those who need and want such information for making both public and private decisions. A broad base of data is needed by large and small mining companies for development of new target areas for exploration and new exploration and production methods. Planners also require it for determining quantitative analysis of the geologic and economic availability of national and international mineral supplies. In the years ahead, it will be increasingly necessary for Government to have a reservoir of information for planning purposes and to be able to monitor supplies and sources of supply, as well as uses of minerals at home and abroad, in order to help the Nation and its mineral industry across the inevitable economic highs and lows.

MINERAL RESOURCES RESEARCH PROGRAMS IN THE U.S. GEOLOGICAL SURVEY

The U.S. Geological Survey conducts mineral resources research programs in several of the organizational units shown in figure 2. The focus of this report is on those nonenergy programs that include the development and testing of resource theory and its application to improved appraisal and discovery technology; the development of resource information systems; and the analysis of these data to locate new resource targets and to provide forecasting and monitoring capabilities. These activities are supported by analytical laboratory facilities and by programs in geophysical and geochemical laboratory and field research, mineralogic and petrologic research on ore-forming environments, and development of new techniques for geochemical and geophysical exploration. Other very important resource programs which are not discussed within the scope of this report include: (1) those for energy materials such as oil and gas, coal, uranium, thorium, and oil shale; (2) studies directed specifically toward environmental impacts of mining; (3) detailed mining engineering studies of leasable mineral commodities on Federal lands; and (4) hydrologic studies that support resource appraisal and development.

U.S. Geological Survey mineral resource research programs collect and interpret Earth-science data in order to define the origin and occurrence of useful materials and to appraise the current and future availability of mineral resources in the United States. These programs **lead to the definition of regions that seem likely to contain ore deposits, but not to their exploration or development as ore bodies which is the responsibility of the private sector.** Incentives, however, to increase domestic exploration for selected minerals are provided to private companies through an exploration loan program and through research to improve exploration technology.

Knowledge about the geologic availability of domestic and overseas mineral resources is the first link of a chain leading to discovery of ore deposits; this knowledge is basic to the development of sound Government policy decisions, and it fosters timely production of minerals by industry. U.S. Geological Survey programs aim to provide this kind of knowledge through four concurrent and continuing types of research:

Investigations of the geologic environment of mineral occurrence.—These studies are aimed at obtaining basic information about known mineral occurrences that will help in identifying new exploration targets and accelerating the conversion of undiscovered mineral resources into reserves. They include (a) geologic, geochemical, and geophysical field investigations in known mining districts as well as in broad regions and mineral belts, and (b) geochemical laboratory research on the ore-forming environment and the processes of ore deposition. Clues to the location of a deposit can be established from the characteristics of occurrence and mode of formation of similar deposits. Geologic research involves documenting type examples of metal-mining districts and the detailed examination of mineralized rocks and the processes that form them. Research that synthesizes geochemical, mineralogic, and petro-

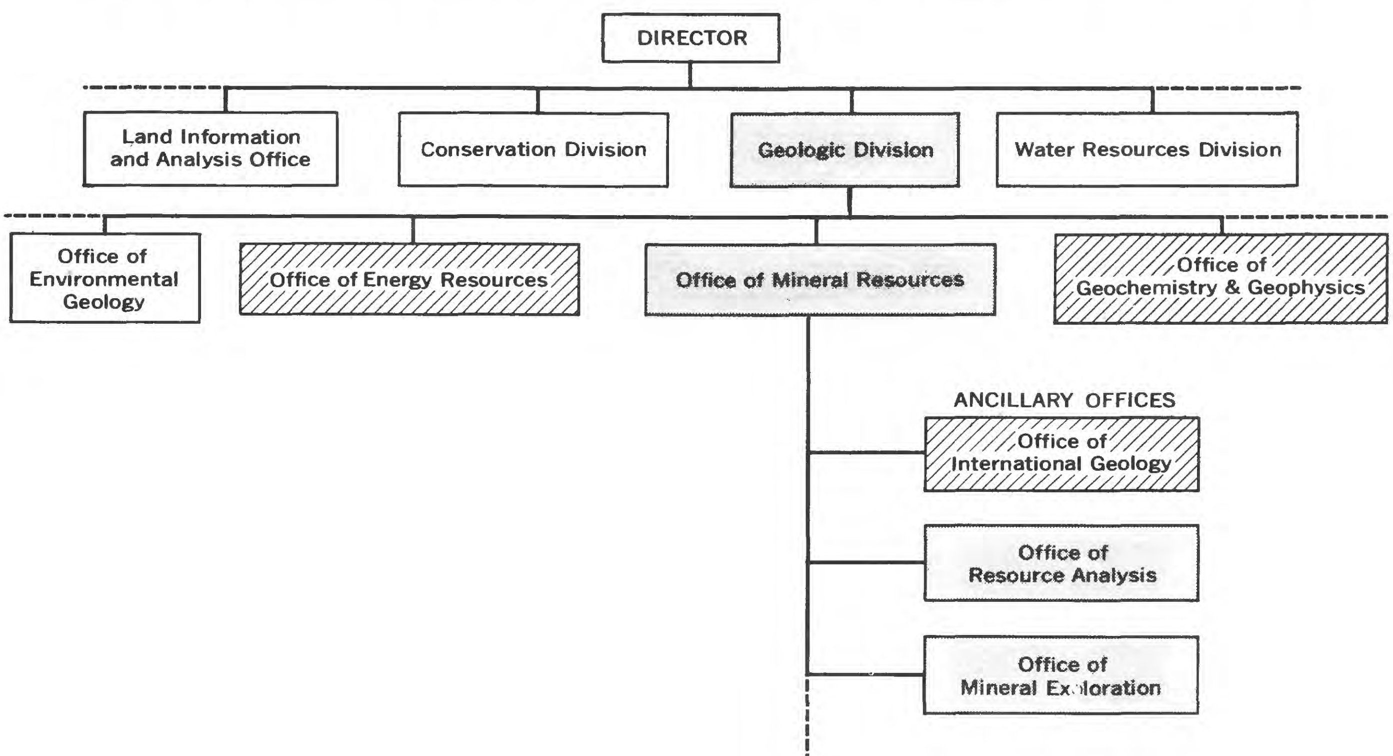

FIGURE 2.—Organizations in the Geological Survey having program responsibilities for mineral resources research. Primary responsibility for programs described in the report are indicated by stipple patterns, shared and supporting program responsibility indicated by line pattern.

logic field and laboratory work aims at evaluating sources of ore-forming solutions, how the solutions move, and establishing the conditions favorable for ore deposition.

Geologic studies in potentially mineralized areas.—These studies are aimed at applying basic resource information and multidisciplinary field techniques to the appraisal and discovery of resources in potentially mineralized areas. The objectives are to develop greater competence in rapid and accurate resource appraisal, to provide information needed for decisions about using potentially mineralized land, to identify new geologic targets to explore for conventional as well as new types of ore deposits, and to make quantitative studies of the resources of critically short commodities. Reports on this work are increasingly sought where Federal, State, and private lands are available for exploration by industry or involve Government management of leases; they are also needed when land-use and environmental impact decisions are being made prior to urban development of areas that may contain minerals of potential commercial value. Programs of this sort are also conducted by the U.S. Geological Survey in other countries under the auspices of USAID or contracts negotiated by the Department of State with other national governments, and have three benefits: (a) They assist foreign governments in on-the-job training of geologists and in development of mineral exploration programs, thereby speeding discovery and appraisal of the country's resources; (b) they add to basic knowledge of mineral deposits that can then be applied to the search for similar deposits in the United States; and (c) they provide opportunities for the evaluation of foreign resources and their potential impact on domestic supply.

Research in mineral exploration technology.—These programs integrate geologic, geochemical, and geophysical concepts and data gathered both in the laboratory and in the field to develop and field-test new methods for assessing mineral resource potential as well as those for finding minerals, especially in new deposits and districts. Computer technology is used to process and aid in interpreting field and laboratory data.

Resource analysis.—Programs of analysis using computerized data systems permit storage and categorized retrieval of information obtained from Government and industry. Analysis includes testing and evaluating computer programs for specific application to improving resource appraisals; to designing, developing, and testing predictive models of resource occurrence for use in economic studies of the conversion of resources into reserves; and to continual updating of resource-data banks.

Results of all these programs are published as reports and maps that provide the public with a continuously expanding base of resource-related information. The principal publications of the U.S. Geological Survey are **Professional Papers, Bulletins, Circulars, and various series of maps.** Information is also made available in open-file reports or published in professional scientific journals. Reports and maps released by the Government are described in a monthly listing, New Publications of the Geological Survey, which is free upon application to the U.S. Geological Survey, National Center 329, Reston, Va. 22092.

In addition to the four types of continuing research, and the extensive technical support required by that research, the U.S. Geological Survey is committed to certain prescribed objectives based on statutory acts (such as giving advice to the Government and response to Congressional mandates) and on contractual agreements between the various parts of the Survey itself or with outside agencies (such as projects financed jointly with the National Science Foundation or with State agencies). The prescribed objectives are annually becoming a larger part of the Survey's mineral resource research program, and their fulfillment is possible only because of a substantial past investment in continuing scientific research backed by effective technical support.

Work at the operating level is organized into individual projects that may be concerned with one or more of the four major types of research. Some projects are regional in scope; others are more localized, intensive topical studies. These projects are described individually in the Science Information Exchange of the Smithsonian Institution, Washington, D. C. The current status or noteworthy achievements of projects are reported in *Geological Survey Research 1974*, U.S. Geological Survey Professional Paper 900. A brief summary of current mineral resource programs follows.

REGIONAL APPRAISAL

Regional resource mapping programs in geology, geophysics, and geochemistry are conducted in the United States as well as overseas. Increasingly, the successful and productive programs are multidisciplinary efforts. Characterization of resource potential depends on a geologic map framework that in turn is based on factors such as isotopic geochronology, geochemical distribution, and aeromagnetic map features. These programs are designed

to broaden the base of resource-appraisal theory and to provide answers about resource potential of large areas.

Regional resource appraisal is receiving new emphasis now because of the Wilderness Program on Forest Service lands and studies of Indian and Bureau of Land Management Interior lands (see p. 17). The Alaska Native Claims Act of 1974, for example, requires resource availability decisions for 80 million acres to be made within a 5-year period. In the Tucson area of Arizona, where mining and urban development interests are competing for the same lands, an assessment of potential copper resources has been made. Several mineral belts or regions in Nevada, Oregon, Colorado, and New Mexico are being examined at the 1:250,000 scale (2° quadrangle). The potential for developing new exploration targets of critical commodities such as platinum, nickel, copper, and chromium associated in ultramafic terranes is the basis for regional 2°-quadrangle appraisal mapping in California, Oregon, Minnesota, and Michigan. Gold- and silver-bearing volcanic rocks of Nevada are also being examined in detail.

Aeromagnetic and gravity methods have long been used singly or in combination to analyze the regional framework and to identify major rock types that may contain mineral resources. Under the national aeromagnetic map program, the U.S. Geological Survey, along with cooperating State agencies, added 125,000 square miles of magnetic coverage in 1973. The work was done mainly by private contractors. Aeromagnetic maps are now publicly available, or are in press, for 40 percent of the Nation, including complete coverage of ten states—Arizona, Colorado, Connecticut, Indiana, Iowa, Maryland, Massachusetts, Michigan, Minnesota, and Virginia. The flight-line spacing on these maps ranges from reconnaissance of 5 miles (about 8 kilometres) down to 1 mile (1.6 kilometres), which is well suited for helping to define mineral prospects. The truck-borne magnetometer has been effective as a rapid and economical means of examining the magnetic "signature" of an area, which is used in planning aeromagnetic work, or for detailed evaluation of specific anomalies shown on existing aeromagnetic maps.

AREAL GEOLOGIC STUDIES

Areal geologic studies are aimed at **defining broad mineral belts that contain conventional types of deposits and new types of resource possibilities.** Precambrian shield areas, for example, are sources of many mineral resources elsewhere in the world, but they have not been extensively explored in the United States except for iron; therefore, studies of stratigraphy, structure, and chemical facies of Precambrian iron formations and greenstone terranes in the Great Lakes shield and elsewhere are underway. Similarly, areas containing post-Precambrian crystalline volcanic rocks are being examined for possible massive sulfide deposits; carbonate platform rocks are being examined as stratigraphic traps for base metal deposits of the Mississippi Valley type; coastal plain sedimentary rocks and local placer deposits are being examined for high-alumina clay and titanium deposits; areas containing porphyry-type disseminations are being examined for copper and uranium; and new or extensions of old mineral belts containing hydrothermal vein and manto-type deposits are being examined for base and precious metals.

DETAILED STUDIES IN MINING DISTRICTS

Detailed studies in mining districts have long been a cornerstone of resource research **to define ore-forming environments** and they continue to be a vital part of the program. Data on the geologic characteristics of a new type of low-grade disseminated copper-silver deposits at Spar Lake, Montana, in Precambrian quartzites will provide the basis for future exploration as the need for such deposits develops. Studies of low-grade disseminated gold deposits of the Carlin type continue; discovery of these deposits opened new opportunities for precious-metals exploration in similar geologic terranes elsewhere. Porphyry deposits are the major source of copper in the United States and are producers of important quantities of molybdenum, gold, and some base metals. Extensive studies of this type of deposit in both production and exploration phases are in progress at Ray, Arizona; in Puerto Rico; and in the Cathcart Mountain area, Maine.

Research on natural processes that produce ore deposits continues in the east Tennessee zinc district and the San Juan Mountains of Colorado. Both studies are concerned with understanding spatial relationships, the chemical and thermal nature of solutions, their plumbing systems, and the sources of metals that were concentrated.

Investigations of the geochemistry of ore deposits provide new insights into the processes responsible for anomalous concentrations of minerals. Continuing laboratory studies of mineral-phase equilibria have yielded information regarding physical and chemical conditions at the time of ore deposition. Field and laboratory studies are directed toward understanding the source of metals, the mode of transportation, and the reasons for localization of the metals. For example, mineralogic and sulfur isotopic studies at Homestake, S. Dak., have shown that gold can be related to original sedimentary accumulations, thereby enlarging the area of search for additional deposits.

GEOCHEMICAL EXPLORATION

Geochemical exploration programs are based on **the systematic measurement of one or more chemical properties of naturally occurring materials, and the discovery and delineation of chemical patterns that may be related to potential mineral deposits.** One approach to a better understanding of how geochemical exploration can be more useful in the search for mineral deposits is to evaluate and compare data from various kinds of samples (rock, soil, stream sediment, gases) collected in known mineral districts or from other localities thought to have a high potential for new deposits. Such investigations are under way in a variety of climatic environments (humid-tropical, humid-temperate, arid, and alpine). These studies will help to establish the best type of sample to collect in order to find a particular type of mineral deposit in a particular climatic environment.

Other geochemical investigations are oriented toward model studies of individual mineral deposits or mineral districts. These studies characterize the patterns of major, minor, and trace elements found in rocks in and around known mineralized areas. The characteristic chemical dispersion patterns can then be searched for in other areas to locate new deposits, especially those that are deeply buried under rock, soil, water, and ice.

Other studies deal with the chemical effects of weathering processes on mineral deposits and how these changes can be used to locate new deposits. Studies of the abundances of various trace elements in vegetation, in surface and ground waters, and in specialized types of samples such as chemically precipitated coatings on rock surfaces and gases in the atmosphere and soils should provide a better understanding of how various chemical elements move under natural conditions and, therefore, how geochemists can best use this information in the search for new mineral resources.

Studies are also being conducted in the application of computer technology to geochemical data. Many surveys now involve the analysis of thousands of samples for as many as 30 or 40 separate chemical elements. Such a large set of data can be evaluated adequately only by computer. New statistical and graphic concepts are also being applied to geochemical data sets to evaluate with greater confidence the mineral resource potential of selected areas in the United States. New analytical methods being tested are needed to fulfill the new search specifications. The emphasis is on methods that are cheaper, faster, and more accurate. Many chemical elements that in the past were not routinely sought in samples can now be determined, thereby increasing the possibilities of finding new resources of these elements.

GEOPHYSICAL EXPLORATION

Geophysical exploration is **aimed at the detection of subsurface mineral deposits** where drilling and excavation are prohibitively expensive but where rapid appraisal of the possibilities for the occurrence of mineral resources is required. The capabilities of several geophysical methods are currently being tested and evaluated.

Magnetic anomalies may denote unmapped or blind intrusive bodies that have associated mineralization, such as the porphyry copper deposits at Ruth, Nev., or they may directly reflect iron ore deposits, as at Marmora, Ontario. Negative anomalies also may be significant where the magnetite content of the host rock has been greatly reduced by hydrothermal alteration associated with ore emplacement, as at Cripple Creek, Colo.

Electrical resistivity and electromagnetic surveys provide additional information about target areas delineated with gravity and magnetic surveys, particularly in the identification of buried conductors which are indicative of massive sulfide deposits or in locating buried channels that may control uranium deposits.

Radioactivity surveys are used not only to detect radioactive minerals directly but also for correlation of rock units in geologic mapping. Gamma-ray spectrometers can be used to discriminate between radiation from uranium, thorium, and potassium sources. For example, radioactive potassium associated with hydrothermal alteration that occurred during mineralization can be studied.

Several methods for measurement of natural earth currents are proving to be useful and economical reconnaissance techniques in exploring for conductive anomalies that may be associated with geothermal systems, which are in turn associated with large self-potential anomalies. These methods offer promise for the development of improved mineral resource exploration techniques for the future.

Remote-sensing experiments using a multispectral 4-band camera and thermal infrared scanner are underway over areas of known base-metal and uranium mineralization to study resolution of subtle surface-alteration patterns. In studies of the Goldfield area in Nevada, a combination of digital computer processing and color compositing of LANDSAT multispectral scanner images were used to enhance spectral reflectance differences; hydrothermally altered areas associated with mineral deposits were detected and mapped (Rowan and others, 1974).

The technique of total-field resistivity mapping promises to be a rapid yet good-resolution reconnaissance approach for deep resistivity studies. An improved electromagnetic technique designated ELF (extra low frequency) is being developed which uses a ground transmitter as a multiple-frequency source and an aircraft to carry the receiver. In addition to providing a reliable signal along with rapid, systematic coverage, the depth of penetration for a large target is about 500 metres in areas of resistive country rock.

The application of paleomagnetism to the study of time and sequence of uranium deposition is being investigated. Samples of the ore zones, alteration halos, and host rocks are analyzed to detect significant variations in magnetization relative to varying intensities and directions of magnetic fields in past geologic history.

Progress is being made in interpretation of geophysical data using electronic computers. Highly effective computer programs for automatic interpretation of two- and three-dimensional models from both d.c.-resistivity and electromagnetic data are being developed, such as techniques for making automatic depth determinations and for calculating the pseudogravity field from magnetic data. More rigorous mathematical treatment of filtering is being applied to magnetic data in an attempt to separate superimposed magnetic anomalies, the sources of which are at different depths below the surface. This should aid in detecting buried stocks that may be mineralized in areas where volcanic rocks are at the surface.

RESOURCE ANALYSIS

Research in resource analysis is a relatively new component of the mineral resource appraisal program. The primary emphasis is on **improving data storage and retrieval capability and developing systems for resource estimation and prediction.** The development and expansion of the computerized resource information bank (CRIB), which is the primary storage and retrieval system for mineral resource information in the U.S. Geological Survey (Calkins and others, 1973) is focused on insuring CRIB's compatibility with data systems in other State as well as Federal agencies. Application of computer graphics to geologic-data solutions and displays is also being examined. Geostatistics and computer theory are applied to seeking mathematical models of resource occurrences, the economics of the exploration process, and resource convertability to reserves.

MINERAL RESOURCE STUDIES BY SPECIALISTS

An integral part of the mineral resource appraisal program is an intensified emphasis on **long-term studies of specific critical commodities**—an approach to resource studies that has served the Nation effectively in the past. The comprehensive assessment of resources of each mineral commodity on a nationwide scale, presented in Professional Paper 820 (Brobst and Pratt, 1973), could not have been prepared without the specialized knowledge of several dozen commodity experts, each of whom had devoted a major part of his professional career to field, laboratory, and library research on the economic geology of one or a few mineral commodities.

Understanding of the U.S. resource base now requires global resource knowledge. In addition to establishing priorities for national commodity-study emphasis, the specialist program provides opportunities for field studies at home and abroad, laboratory support, and technical services to broaden the experience and competence of individual specialists.

Mineral resource specialists assigned to all the commodities of national significance must maintain up-to-date mineral information for program planning as well as for advisory purposes. Commodities currently covered by the mineral-resources-specialist program are listed in table 4.

STATE REPORTS REQUESTED BY THE U.S. SENATE

The first of the modern Federal documents on the mineral and water resources of various States, prepared at the request of the Interior and Insular Affairs Committee of the U.S. Senate, was the U.S. Geological Survey report on Wyoming submitted to Senator Gale McGee in 1960. **Between 1963 and 1974 the Geological Survey, at Senatorial request, provided reports on Montana, Alaska, Colorado, Idaho, Nevada, South Dakota, Eastern Montana,**

TABLE 4.—*Commodities in the mineral-resources-specialists program*

Aluminum	Niobium
Barite	Nitrates
Beryllium	Peat
Boron	Phosphate
Bromine	Platinum-group
Chromium	Potash
Clays	Rare earths
Copper	Rhenium
Feldspar	Salt
Fluorine	Scandium
Gold	Silver
Graphite	Stone, construction
Iron ore	Sulfur
Kyanite	Talc
Lead	Tantalum
Lightweight aggregates	Tin
Limestone and dolomite	Titanium
Lithium	Tungsten
Mercury	Vermiculite
Mica	Zeolites
Molybdenum	Zinc
Nickel	

New Mexico, Washington, California, Missouri, Oregon, Arizona, Utah, and North Dakota. With the exception of the original Wyoming report, these were prepared by the U.S. Geological Survey in collaboration or cooperation with the respective State geological or mining agencies, and in some cases with State universities or other Federal or State agencies, such as the U.S. Bureau of Mines and Bureau of Reclamation. All were published originally as U.S. Senate Documents or Committee Prints, but some were reprinted separately as reports of the various State agencies. Because of limitations of staff and the short time available for preparation (generally only a few months), these reports have not entailed new field surveys but have relied on the collective experience of numerous professionals in the various agencies.

Early in 1974, the U.S. Geological Survey was requested to revise and update the report on South Dakota, originally published in 1964. These reports are a long-term obligation that has been met as Survey staff, funding, and scientific support from respective State geologic agencies became available.

MINERAL APPRAISAL OF FEDERAL LANDS

Appraisal of the mineral resources of Federal lands is the responsibility of the Government and was a cardinal point in the legislation that created the U.S. Geological Survey. In the past, legislation of two types has directed such appraisal. The Mineral Leasing Acts of 1920 and 1947 provided for the appraisal of identified *leasable minerals*—energy minerals, potash, sodium, phosphate, and sulfur—on Federal lands. The Wilderness Act of 1964 provided for the appraisal of mineral resources of all types on primitive and wilderness-type lands prior to their withdrawal from future mineral entry. Currently, the anticipation of increased monetary returns from mineral leasing under the proposed act to replace the Mining Law of 1872 emphasizes the need for systematic appraisal of mineral resources of all Federal lands.

Federally owned or federally managed lands comprise about 762 million acres, or about one-third of the Nation. Almost half of the federally-owned lands (353 million acres) is in Alaska; almost 90 percent of the remainder (358 million acres) is in 11 western States (table 5), and about 43 million acres of that lie in States east of the Rocky Mountains. The principal agencies responsible for management of Federal lands are shown in table 6. The Bureau of Indian Affairs manages about 50.5 million acres of Indian lands, which are not federally owned.

TABLE 5.—*Federally owned land in 11 western States and Alaska as of June 30, 1971*

[From U.S. Bureau of Land Management, 1972]

State	Federal lands (millions of acres)	Percent of total area of State
Arizona	31.9	44.0
California	44.9	44.8
Colorado	23.9	36.0
Idaho	33.8	63.8
Montana	27.6	29.6
Nevada	60.8	86.5
New Mexico	26.0	33.5
Oregon	32.2	52.3
Utah	34.8	66.0
Washington	12.6	29.6
Wyoming	30.0	48.1
Total in 11 Western States	358.5	
Alaska	353.5	96.7

TABLE 6.—*Major landholding agencies in the Federal Government*

Agency	Millions of acres[1]
Department of the Interior	
Bureau of Land Management	474.
Bureau of Sport Fisheries and Wildlife	27.9
National Park Service	24.5
Bureau of Reclamation	7.6
Bureau of Indian Affairs	[2] 2.2
Department of Agriculture	
Forest Service	186.8
Department of Defense	30.3

[1] As of June 30, 1971 (from U.S. Bureau of Land Management, 1972).
[2] As of June 30, 1973 (from Counselman, 1973); does not include 50.5 million acres of Indian-owned lands managed by B.I.A.

Minerals from the Federal lands have contributed markedly to the industrial and economic development of the Nation and can be expected to continue to do so. According to the U.S. National Commission on Materials Policy (1973, p. 79), "In 1965 the western Public Lands produced over 90 percent of the Nation's domestic copper, 95 percent of the mercury and silver, and 100 percent of the nickel, molybdenum, and potash, and about 50 percent of the lead." Oil and gas production from onshore Federal and Indian lands has supported 5 to 6 percent of the Nation's total domestic energy production in the recent past. During fiscal year 1974, receipts from all energy and mineral leasing activities conducted by the Bureau of Land Management, including rentals, royalties, and bonuses from lands and from the Outer Continental Shelf, totalled about 7 billion dollars.

Not all Federal lands are open to mineral exploration development. As of June 30, 1967, more than 111 million acres had been withdrawn from mining, and more than 103 million acres from mineral leasing. Most of the withdrawn lands are in National Parks, Monuments, Fish and Wildlife Game Refuges, Indian Reservations, reclamation projects, military reservations, and scientific testing areas. The Wilderness Act of 1964 provides that areas designated as Wilderness will be withdrawn from mining laws and mineral leasing activities by December 31, 1983. Other lands not subject to leasing are the Naval Petroleum and Oil Shale Reserves, the National Park System, and a one-mile buffer zone around Naval Petroleum, oil shale, and helium reserves. In total, the Federal lands subject to mineral development aggregate about 822 million acres, including public lands not withdrawn, acquired lands, and lands which have been patented with minerals reserved to the United States. Submerged lands of the Outer Continental Shelf are also subject to mineral development.

Once resources are identified on Federal land, **the Bureau of Land Management and the Forest Service have the main responsibility for administering the laws concerning leasable and locatable minerals.** *Leasable* minerals include energy minerals and potash, sodium, phosphate, and sulfur. *Locatable* minerals include those metallic and nonmetallic minerals that may be located under the Mining Law of 1972. *Mineral materials*, largely sand, stone, gravel, pumice, and clay, are obtainable by competitive sale by contract. **The U.S. Geological Survey is responsible for classification of public lands for their leasable mineral resources** for retention-disposal, exchange, and multiple-use purposes. The U.S. Geological Survey is also responsible for prelease resource evaluation and postlease administration of leasable minerals.

In its statutory role to assess mineral resources on Federal lands **the U.S. Geological Survey currently provides three levels of resource appraisal of specific tracts** of Federal lands, depending on the time, personnel, and funds available (table 7). Level I is a library and record analysis that provides enough data to delineate those areas that are known to have promising mineral potential but is inadequate to form the basis for decisions about the disposition of lands. Level II is a more extensive investigation, including field reconnaissance, which evaluates the mineral potential of areas and designates potential targets for detailed studies or exploration for possible future development. These results are adequate for making land-use decisions with regard to mineral potential but not for leasing purposes. Level III consists of detailed studies required for resource evaluation and lease management decisions and mineral resource research on mining districts. Research at this level not only increases our understanding of the genesis, distribution, and economic potential of metallic and nonmetallic resources, but also contributes to the development of modification of exploration tools and techniques. The cost of these levels of appraisal varies depending on the degree to which an area has already been developed, the amount of available geoscience data, the difficulty and expense of obtaining such data, and the length of time available to make the study.

Much remains to be done before the mineral resources on all Federal lands have been appraised. Table 8 shows the magnitude of the task ahead; much is known, however, about the geology and mineral resources in many as yet unappraised areas because of U.S. Geological Survey, State, industry, university, and other studies. When the status of knowledge on these areas is determined, it will be possible to revise table 8; nevertheless, the task will remain a formidable one. In addition, appraisals will eventually be needed for 50.5 million acres of Indian land. Finally, future planners must also bear in mind that much of the **1,600 million acres of privately owned lands**, mostly in the eastern part of the United States, **has never been adequately appraised.**

Following are summaries of the principal current U.S. Geological Survey programs directed wholly or in part toward mineral resource appraisal of Federal lands, exclusive of the continuing mineral classification program.

Wilderness Program.—The U.S. Geological Survey and the U.S. Bureau of Mines jointly have conducted mineral surveys on wilderness and proposed wilderness areas in National Forests under the Wilderness Act of 1964. The Survey evaluates the

TABLE 7.—*Three levels of resource appraisal used by the U.S. Geological Survey*

Level	Objective	Method of study	Advantages	Limitations
I	General inventory of past production and resource activity. Identify areas needing more detailed study.	Library and records survey; search of all sources for unpublished data on known districts; computer storage of data.	Status report: assessment of all known resource information. Important first step for any assessment.	Superficial; most data will be spotty; inadequate for determination of total resource; often biased; undeveloped areas will be overlooked.
II	Uniform reconnaissance-level appraisal to establish base for total resource estimate.	Level I plus reconnaissance geologic, geochemical, and geophysical mapping; remote sensing; sampling of broad areas that are promising. Computer storage, retrieval, and interpretation of data.	Sufficient detail to present resource evaluation for use of decision makers. New areas identified for classification and development.	Not sufficient to define reserves or to be used by management. Deeply buried deposits missed.
III	Sufficiently detailed geoscience data to determine reserves and to make management decisions regarding leases and environmental consequences.	Detailed geologic mapping, geochemical sampling and assaying, and geophysical surveys in small areas of known potential. Computer storage, retrieval, and interpretation of data.	Development of geologic theory leading to identification of new types of deposits; basis for stockpile decisions.	Time consuming, expensive.

TABLE 8.—*Mineral resource appraisal of Federal lands completed to September 1974*

Federal land area	Millions of acres
Total Federal land areas	762
Federal lands appraised at Level I	
Alaska (Native Claims areas)	80
Desert lands (Bureau of Land Management)	1
Urban areas,[1] San Francisco, California	1
Federal lands appraised at Level II	
Wilderness lands (Forest Service)	15.4
Urban areas,[1] Tucson, Arizona	5
Quadrangle appraisal mapping[1]	2
Federal lands appraised at Level III[2]	undetermined

[1] Includes some Indian and(or) private lands.
[2] The status of extensive U.S. Geological Survey mineral classification programs of the past 70 years, which routinely provided data about the potential mineral resources of Federal lands to Federal land-administering agencies, is not tabulated in this compilation.

mineral potential of the areas on the basis of reconnaissance geologic, geochemical, and geophysical examinations. The Bureau evaluates all previous and existing exploration and mining in the area, including examination of all mining claims. In addition, a minability appraisal is made where appropriate.

As of September 1974, 447 primitive, wilderness, and proposed wilderness areas totaled about 38.7 million acres; 129 areas, about 15.4 million acres, had been evaluated. Studies of the remaining areas are scheduled to be completed by January 1, 1983. In January 1975, 16 new wilderness areas, totalling 212,618 acres of the Eastern United States, were established, and 17 proposed wilderness areas were designated for study.

Desert land studies.—An evaluation of the geology of the Randsburg-Searles Lake area, California, is the first of several studies that will provide information on the known mineral resources and mining activities of the area, which information will be used by the Bureau of Land Management as a basis for classifying these Federal lands for protection of the desert environment. Less than 1 million acres have been appraised in this new program.

Urban studies.—Reconnaissance geologic mapping and compilation of previous geologic work is being conducted in the Tucson area, Arizona, much of which is composed of Federal or Indian lands. Data on the mineral potential are based on past production and unpublished material contributed by the mining industry. The resulting maps will provide State and local planners with factual data for land-use decisions. Southeastern Arizona is one of the world's richest copper provinces, and it currently faces the problems of industrial growth, urbanization, and protection of environmental values. Approximately 5 million acres have been examined in this program.

Quadrangle appraisal mapping.—Reconnaissance mapping and local detailed mapping of selected 2° quadrangles, large segments of which are Federal lands, include extensive geophysical surveys and some geochemical sampling. The studies are designed to test the potential of areas that have known promise as mineral belts and to determine parts of those areas that warrant more detailed studies, as well as to evaluate other geologic environments which elsewhere in the world have produced mineral resources.

Indian land studies.—A new program to summarize existing information on the geology and mineral resources of Indian lands was begun in 1975 in cooperation with the Bureau of Mines and

Bureau of Indian Affairs. Compilation of resources summaries of nearly 10 million acres of Indian lands is in progress. Some of these lands contain large resources of fuels and minerals, and their orderly development is essential to the welfare of Indian people and the Nation's economy.

Alaska land appraisal.—Alaska is almost equal in size to one-fifth of the total area of the conterminous United States. Although a large part of Alaska (353.5 of its 365.5 million acres) was Federally owned land as of June 30, 1971, the land ownership pattern is changing significantly. By 1978, as required by the Alaska Statehood and Alaska Native Claims Settlement Acts, the State will own 103 million acres and Natives will own 40 million acres. Proposals for adding about 80 million acres to the National Park, Wildlife Refuge, Forest, and Wild and Scenic River Systems have been submitted for Congressional consideration under provisions of the Alaska Native Claims Settlement Act. Much of the land included in these proposals may be withdrawn from mining and mineral entry even though some of it includes parts of potential mineral belts.

Because of these pending changes, the U.S. Geological Survey's Alaska mineral resource appraisal program is attempting to increase the rate of appraisal as well as its quality and scope. Started in July 1974, the program describes and evaluates energy, metal, and nonmetal mineral resources and their potential for discovery.

CONCLUSIONS: SOME PRESSING PROBLEMS

Because there are so many minerals, the related problems are even more complex than those for energy. The national and international flow of minerals, for example, and the possibilities for substitution of one mineral for another, are very complex phenomena that are not well understood. Public awareness of the need for many minerals has not yet been aroused because vital mineral uses are not obvious in a complex society, but sudden shortages would affect our personal lives in unforeseen ways. Prior **planning and critical evaluation are as necessary to the development and utilization of nonfuel mineral resources as they are for the energy minerals**, if potentially serious problems are to be avoided or at least minimized.

DETERMINING CRITICALNESS OF MINERAL COMMODITIES

Objective means of evaluating the overall national and international importance of each commodity must be developed so that priorities for research may be assigned to various commodities and to the most productive lines of research for each. Factors to be considered include:

1. Importance of the commodity to industry and commerce,
2. Defense or other needs of overriding importance,
3. Extent to which the commodity can be replaced by others,
4. Extent of domestic reserves,
5. Extent of economic, technologic, and legal use of domestic resources,
6. Dependence on foreign imports, and
7. Political stability (internal or international) of foreign import sources.

Every mineral commodity being mined today is essential to some industrial process or product, but to assume that either government or industry can fully pursue the research needed on all mineral commodities would be far from realistic.

DEPENDING ON IMPORTED MINERALS

Patterns in world mineral supply and demand which had persisted for some four decades **began to change radically after World War II.** In 1940, the United States produced and consumed nearly 50 percent of world mineral supplies, including fossil fuel, but in 1971 the United States' share had dropped to about 27 percent, and it continues to diminish. Between 1945 and 1972, world consumption of 18 basic mineral commodities increased about six times, whereas U.S. consumption less than doubled. Starting from a far lower per capita base, both the developed and the more advanced developing countries are catching up in industrial production. Furthermore, world population is multiplying rapidly, placing increasing demands on limited mineral supply.

The United States continues to be ever more dependent on foreign sources of supply for essential mineral raw materials. In 1972 and 1973, our overall dependence on imports for 15 critical industrial materials other than energy was about 60 percent of our consumption (Council on International Economic Policy, 1974, figs. 2 and 15); the situation for individual materials ranged from total dependence to total independence. In 1974, the Nation was more than 90 percent dependent on imports of primary materials for four commodities, 75 to 90 percent dependent for 8 additional commodities, and 50 to 75 percent dependent for 8 commodities. Seventeen other major commodities are imported. Forecasts for the year 2000 indicate that we shall then be completely dependent on imports for 12 commodities, more than 75 percent dependent for 19 commodities, and more than 50 percent dependent for 26 commodities. Among causes of this increase are (a) the depletion of known domestic ore deposits, and (b) the "free market" economy, whereby it is cheaper to use imported supplies of some raw materials than to process and use our own, even though we may have ample supplies. **The increasing dependence on imports seems inescapable** but by no means approaches the degree of dependency of any other major industrialized country with the exception of the U.S.S.R., which is relatively self-sufficient in most essential commodities and which has, in the last five decades, made enormous investment in geologic research and prospecting in carefully planned programs.

Rapidly evolving complex changes in the attitude of people and nations foreshadow fundamental changes in economic patterns throughout the world. Sparked by rising national consciousness and economic pressures, **the industrially underdeveloped and developing nations are increasingly less willing to export only raw materials** and would prefer to export their mineral materials in at least the semifinished stage. These nations possess many of the world's major mineral deposits, upon which the industrial world will depend during the next quarter century, and they are forming national companies to prospect for and exploit their ore deposits. Many highly industrialized nations, including France, Japan, and Germany, are actively supporting these national companies of the developing nations to insure continued raw material supplies for their own economies. Some industrialized nations, including those already mentioned, negotiate through their own government-supported industrial firms, thereby increasing government-to-government negotiations in this field.

In contrast, United States industry has not entered into comparable joint ventures with the Federal Government. The United States is thereby put into a less competitive position in negotiations abroad for access to available foreign supplies. And at the same time, **environmental constraints on the activities of the mining and manufacturing industries in the United States are forcing a trend toward additional domestic dependence on foreign supplies** of both raw and partly processed mineral products.

Some options available to the United States to insure adequate supplies of mineral raw materials from abroad include:

Diversification of overseas sources of supply.

Government activities to assure access to foreign sources of supply, combined with steps by industry to increase overseas processing of raw materials.

A major economic stockpiling program by industry or Government for those commodities, including energy materials, supplies of which are dependent on a few foreign sources.

Restraint in consumption of the scarcer raw material supplies. Products and processes can be redesigned to use abundant rather than scarce materials.

National and worldwide programs for recycling of metals.

Bilateral technical assistance programs in mineral fields, financed by the United States.

Placement of staff trained in mineral deposit and mineral industry development in United States Missions overseas to insure accurate, up-to-date information on present and potential mineral supplies.

Fostering of close cooperation between Government and industry. The natural short-range view of industry, working toward an impressive balance sheet, must be melded with the natural long-range view of Government, working toward long continued economic and social progress and stability.

STATE OF THE MINING INDUSTRY

Keeping a finger on the pulse of domestic mining activities, an implied responsibility under provisions of the Mining and Minerals Policy Act of 1970, is very difficult because of the complexity of the mining industry. **One possible measure of the state of health of the industry is the amount of resource exploration activity, and present exploration activity can be considered a barometer of the future mining activity.** A systematic quantified method to obtain this information should be developed jointly with the industry. Improved liaison will lead to the development of a more accurate resource data base.

REPORTING RESERVE DATA

The difficulty of making reliable estimates of mineral resources has been compounded by the longstanding, but declining, practice of many mining companies to maintain secrecy about the magnitude of their reserves in the ground. Public release of such data obviously could be disadvantageous to corporations in the competitive business atmosphere. **Reliable reserve and resource estimates, however, are increasingly needed for use in making policy decisions both in corporate board rooms and Govern-**

ment conference rooms. Adequate reporting of such information can be done in strictest confidence so as not to prejudice private interests.

RECOVERING POTENTIAL MINERAL BYPRODUCTS

Potential mineral byproducts or coproducts are being lost while their associated principal mineral products are being mined and recovered (Brobst and Pratt, 1973, p. 7–8). A few of these minerals are lost because of selective mining—the gold, silver, selenium, and tellurium that remain behind during in-place leaching of copper deposits. Most of them are lost in selective processing—vanadium in magnetite deposits; fluorine, vanadium, uranium, scandium, and rare earths in marine phosphorites; cadmium, bismuth, cobalt, and mercury in lead ores; and several metals in coal ash. Industry or public **research and development are needed to identify these escaping resources and determine ways of recovering them.** Other commodities that have potential for recovery as byproducts include aluminum and soda ash from oil shale; vanadium and nickel from crude oils; gold and tungsten from sand and gravel operations; trace metals from brines and mine waters; and several metals from seawater and sea bed deposits.

CONSIDERING SUBSEA MINERAL RESOURCES

As offshore drilling for oil becomes more common, the potential for other mineral resources under the sea will receive more public attention. **Neither the continental margins nor the deep seabed resource potentials can be ignored in future appraisals of the world's mineral resources.** The continental margins, being geologically part of the continents, contain in general the same kinds of resources as the continents and have contributed some mineral production, whereas the deep seabed, being composed largely of basaltic igneous rock covered by clays and other fine-grained sediments, contains a much smaller variety of minerals—chiefly metals occurring in manganese nodules, pavements, and crusts, and deposits that are genetically related to mafic igneous rocks.

Minerals that have been produced from continental margin rocks mainly by means of shafts extending from on-land to beneath the seabed include coal, iron ore, nickel, copper, tin, gold, mercury, barite, and limestone. In recent years only coal, iron ore, and barite were being produced in significant amounts by this method. Barite, although a bedrock deposit, was mined from an open-pit operation beneath the sea.

Surficial deposits on the world's continental shelves include sand and gravel, calcium carbonate in the form of shells, precious coral, iron sands, placer deposits containing tin, diamonds, titanium sands, zircon, monazite, and gold and other heavy minerals, and phosphorite nodules. Sand and gravel is by far the most important by volume.

No minerals have yet been produced commercially from the deep seabed, but commercial manganese-nodule production will likely begin before 1980. Metalliferous brines and muds also have some potential in the deep seabed, but little is known about them, and any possible commercial recovery seems several decades in the future.

STAFFING FOR MINERAL APPRAISAL AND EXPLORATION

Continued appraisal of and exploration for mineral resources require a continuing supply of geologists, geochemists, and geophysicists as well as mineral economists. Student enrollments in these disciplines have decreased steadily in recent years, and at the same time employment demands have increased sharply.

Since the National Science Foundation's Register of Scientific and Technical Personnel was discontinued in 1970, **no system exists for monitoring employment demands and predicting trends.** Informal observations made to the American Geological Institute by university department heads, who are probably in the best position to observe where hiring emphasis is being placed from year to year, indicate a recent large upsurge in demand for Earth scientists, particularly at the Batchelor's and Master's levels, although the number of Master's candidates decreased by 4 percent and the number of Doctoral candidates decreased by 5 percent in 1974 (Henderson, 1974). Timely availability of adequate numbers of university graduates at various academic levels requires that employment needs be anticipated 2 to 7 years in advance, but the mineral industry generally has not been able to anticipate its need for Earth scientists by more than a few years.

The level of exploration activity seems to be the index by which to measure the need for Earth scientists. Long-term increases in exploration activity can be anticipated reasonably because of the vast increase in mineral production that must occur during the next decade or so. Over the past 7 years, student enrollment evidently has conformed quite closely to demand or kept ahead of demand in a marketplace in which no mineral crises and no sudden large upsurges in mineral exploration activity have occurred. Now, with the existing crisis in energy and impending crises for several metals, the educational process may not be able to keep abreast of demand. It seems likely that **anticipated increases in mineral-exploration activity may result in a near-term shortage of geologists and a chronic shortage of geophysicists and geochemists.** The identification of new employment requirements and support for short-term retraining programs are probably areas in which Government, alone or jointly with industry, can assist in meeting changing needs.

INCREASING PUBLIC AWARENESS

Finally, the popular misconception that a steady supply of minerals from the crust of the Earth is simply a matter of favorable economics and technology has induced widespread public complacency. This notion ignores that fundamental factor governing mineral supply: geologic availability. Neither technologic magic nor astronomical dollar value can make it possible to extract iron, aluminum, gold, sulfur, or phosphorus from rocks in which they are not present.

Our total resources in 1975 are vast, but they cannot be mined, much less used, until they have been identified, appraised, and finally moved into the category of reserves. We must begin now, in both industry and Government, to inform the public about the real nature of our minerals problem, and to stimulate the research that will make our mineral resources available.

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