Mineral Raw Materials in the National Economy

Increases in world population and living standards call for a reevaluation of the domestic potential.

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The human species is innately provincial, for each individual is raised in his own peculiar environment, from which all others differ. Not too far back in history, when travel and communication were much more limited and pedestrian than they are at the present time, people from other communities were commonly called "outlanders," and by any reasonable local standard their habits, speech, and mores were clearly "outlandish."

The world is still rife with geographic, racial, and religious provincialism, but education and rigorous training have raised members of the professions to a higher, cosmopolitan plane on which the common brand of provincialism is supposed not to exist. Actually, it is present, but under the disguise of professionalism. In this lecture I shall, of course, address you with the complete objectivity that only the geologist can attain! Without his earth, there would be no life, hence no biology. Without his rocks and minerals and life, the chemist would have no raw materials. Without his sphere, the physicist and the astronomer would have no base from which to observe the laws of nature and the universe, and the mathematician's formulas and abstractions would be meaningless.

Unlike Knickerbocker, however, who could not write his history of New York without harking back to creation, I shall take the origin of the earth for granted and will also spare my scientific colleagues in other fields from the charge of provincialism. But I cannot embark upon my theme without pointing an accusing finger at historians, who have shown little or no appreciation of the role this country's mineral history has played in our economic and social development, and even in our military chronicles. The most recent history of the United States (*1*, *2*) manages to get through two volumes, totaling 1076 pages, without indexing coal, oil, steel, or copper. The forty-niners, Andrew Carnegie, and John D. Rockefeller each rate one and a half pages; gold in Colorado is allotted one page; and in the generous two and a third pages given to "resources and their exploitation," the place of minerals is encompassed in a single sentence (*2*, p. 54): "Just as the Western mines have been made to disgorge their gold, silver, and copper to build up the fortunes of the individual investors and speculators . . . so were other sources of wealth drained in a fierce first come, first served rush. . . ."

Whatever label we may attach to the ethics of men called by many names, from "robber barons" to "empire builders," the winning of the West, with its raw material wealth, deserves far more thoughtful treatment at the hands of so-called historians than it is receiving. It required imagination and courage; it called for the spirit and nerve of the gambler; and even though these men played for table stakes, as winners they did not take all—they established viable communities into which a more stable and permanent population could move. It is high time the geologist and the geographer imparted perspective to this significant, even vital, phase of American history, so slighted in the contemporary view.

Prelude to Mineral Exploration

The period of discovery, exploration, and settlement in the Americas offers illuminating contrasts of the Latin and Anglo-Saxon temperaments and objectives. The Spaniards had visions of wealth, which were realized in the highlands of Mexico and in the Altiplano of Peru. The pious efforts of the church to save the heathen souls of the native Indians from hell in the hereafter did not spare their bodies from the hell of despoilment, enslavement, and rape. Few Spaniards came to the New World intending to stay. Their aim was to strike it rich and head for home. But they were intuitive prospectors. From the *tierra fría* of the Sierra Madre in Mexico to the very summits of the Andes, latter-day prospectors can locate few deposits of metallic ores without finding evidence that the conquistadores were there first. In the territory the Spaniards traversed, their only major oversight was the gold in California.

The French came to the New World also to exploit it and to expand their empire. They lacked a mining tradition at home, and the fluvial routes they used to penetrate the continent were singularly devoid of precious metals. They displayed a lively but passing interest in the native copper of the Lake Superior country. There is no evidence that they were aware of the iron, or of the gold and silver, in Ontario, but they were not slow to find the galena of the Driftless Area in Illinois and Wisconsin and of southeastern Missouri. Ammunition was vital in the fur trade that they established. Bullets were being manufactured from the lead ores of southwestern Wisconsin and northwestern Illinois as early as 1687, and large-scale mining was undertaken in the Saint Francois Mountains of Missouri in 1719 (*3*, p. 153). In that year, Philippe Renault transported 200 miners and technicians from France and 500 Negro slaves from Santo Domingo to mine and smelt galena. Although Renault was disappointed to find that the galena contained no silver, he established a successful operation that remained in business until 1742, when trouble with the Indians terminated the venture.

The Northern Europeans crossed the Atlantic less in the spirit of adventure than in the grimness of martyrdom. Their objectives may not have been altruistic, but they were free of any intent to despoil the new country or exploit the natives. They were migrants

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in search, not of wealth but of economic opportunity, not of converts but of religious freedom. Adventurers were few. The English, Dutch, and Swedes came to settle—to live on the land by the fruits of their labor and to establish some sort of coexistence with the Indians.

There was an abortive search for gold in the English colonies, for the charters granted by James I to the London and Plymouth companies in 1606 stipulated that one-fifth of the precious metals and one-fifteenth of the copper found by the settlers would accrue to the Crown. But mining was not the primary business of these colonists, as it was of the Spaniards. Cynically it has been claimed that it was the lack of mineral wealth that made the difference, but this is not so. The English, Dutch, and Swedes did not scour the continent for gold. They stayed put where they landed, whereas the Spaniards roamed the two continents and established fortified settlements only where they could command native wealth and manpower, or control travel routes to and from the Spanish Main.

Historically, then, Spanish America has a past of which mining is an integral part, even though the mining was concerned almost entirely with gold and silver. To this day, mining is a major activity in what were once the Aztec and Inca empires. The fact that interest has shifted from silver and gold to copper, lead, zinc, iron, and tin reflects both the Spanish heritage and a superimposed Anglo-Saxon concern for supplies of the ferrous and base metals to support modern industrial growth.

Mining in the English colonies began inauspiciously in response to local needs that were not being adequately or promptly met by the mother country. Because of the Crown's preoccupation with supplies of copper, there was a desultory search for this metal, and some was found in Massachusetts Bay Colony as early as 1632. It was not until 1709, however, that the first company was chartered to exploit a copper deposit; the site of operations was East Granby, Connecticut. Mining at this location continued until 1773, and the ore was shipped direct to England because smelting in the colonies was prohibited. Later, other copper deposits were exploited, in New Jersey and Vermont, but the objective was to supply the mother country with raw material and not to take care of the colonists' growing needs for metal products.

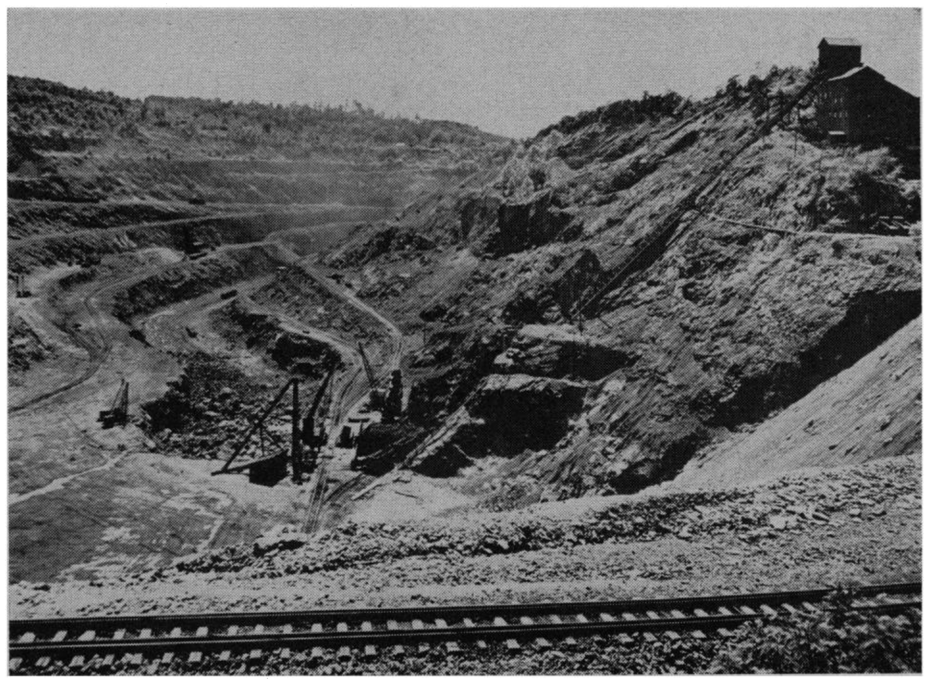
Night scene of a trainload of glowing ingots just removed from their molds. [Bethlehem Steel Co.]

Aerial view of Grace Iron Ore Mine surface buildings during shaft sinking operations near Morgantown, Pa. [Bethlehem Steel Co.]

Further back in colonial history, Ralph Lane and Thomas Heriot, who commanded an expedition sent by Sir Walter Raleigh to North Carolina, found a deposit of iron ore, which was mined as early as 1608 both for local use and for shipment to Bristol, England (*3*, p. 8). In 1619 the London Company sent 153 technicians "skilled in the manufacture of iron" to Virginia, to establish three iron works in the colony. The first plant was started near Jamestown in 1620, but in 1622 the settlement was attacked by Indians, 347 people were massacred, and the plant was completely destroyed. No further attempt was made to recover iron ore or to manufacture iron products until 1646, when a furnace was erected at Saugus Mill, near Lynn, Massachusetts, to utilize the bog iron ore that had been found in nearby glacial swamps. The urgent need for tools and hardware stimulated the establishment of iron works in other colonies, ultimately to the discomfiture of manufacturers in the mother country, who were instrumental in having Parliament pass an act that encouraged the exportation of iron ore to England but discouraged iron manufacturing in America.

The only other known mining undertaken by the English colonists was forced upon them by the environment from which they were trying to wrest a living. Bullets were necessary to kill game and, at certain times and in certain places, to kill Indians. Small deposits of galena were discovered at many points, the first in 1621 on Falling Creek, near Jamestown, Virginia. Mining was usually done when, as, and if needed, and there is no indication from the meager records that lead mining and smelting ever reached the proportions of an industry in any of the original colonies.

Except for liberation from the mother country's restrictions, the mining pattern remained unchanged when the colonies won their independence. The need for domestic manufactures stimulated the growth of local enterprises, and when Washington took office as President, there were forges and bloomeries in all 13 original states. In the glaciated country, bog iron ore was the main source of raw material. In the interior, the Clinton iron ore became a favorite, and by 1810 many of the young nation's 500 blooming mills and forges were located along its line of outcrop, from the Mohawk Valley to Virginia, and even into the territory that, in 1819, was to become the state of Alabama.



Mining ore by the open-pit method at the Cornwall, Pa., mine of the Bethlehem Steel Co.

Charcoal was the fuel used to make iron and steel. Although coal had been discovered and mined in the Richmond basin as early as 1750, furnace men were slow to substitute coke for charcoal. Its ultimate acceptance, about 1835, coincided with the explosive development of the West and the transformation of the mining industry from an aggregate of inconsequential and essentially local operations to big business.

Mineral Empire

During the quarter century between 1835 and 1860 a transformation took place. Discontent with agriculture's diminishing returns in the Piedmont and in New England prompted a younger generation to take a new look at the expanded American domain. Initially its gaze focused upon the wide open spaces of the prairie, and a new concept of farming soon emerged. As settlers spread from western Ohio into Indiana and Illinois, stronger lines of communication with the eastern seaboard became imperative. Clinton's "ditch" connecting Lake Erie with the tidewater of the Hudson River was a vital link, but the construction of canals in the rugged Appalachian Mountain country to the south cannot be rated a financial or engineering success. It was not until a spreading rail network conquered the mountain barrier that Americans turned their attention from the clipper ship and foreign commerce to a lucrative domestic trade with the rapidly multiplying settlements in the interior.

Homesteading was the principal concern of the early arrivals, but it was not long before the other resources the West contained came in for their share of attention. In the early 1840's the lead industry that was started by the French in the Mississippi Valley, with centers of activity at Galena, Illinois, and at Bonne Terre, Missouri, was revived. In 1845 the Galena district alone had a recorded output of 27,250 tons, a substantial part of which was shipped overland to Chicago and thence down the Great Lakes to eastern markets. Soon thereafter came the discovery of the Lake Superior iron ores and the establishment of a commercial copper mining industry on the Keweenaw Peninsula of Upper Michigan. Belatedly, but still within this critical quarter century, oil was discovered back in the mountain country at Titusville, Pennsylvania. And long before the prairie and lake country were tamed, the finding of gold at Sutter's Mill in California lured the adventurous still farther west, across the Plains and the western mountains and deserts.

From 1850 until 1900, the "winning of the West" was a three-fold conquest of Indians, land, and minerals. The early gold camps of Deadwood, Cripple Creek, and the Mother Lode were longer lived than most. Many of the other mining localities that yielded gold when first prospected were richer in copper, lead, and zinc, and except for the more fabulous finds of silver, notably in Nevada, metals other than gold had to await exploitation until the railroads arrived. A few, such as the porphyry coppers of the Great Basin, waited still longer, until technology caught up with the physical and chemical peculiarities and limitations of the ores. Discovery followed upon discovery, from Titusville to Tonopah, and from Butte to Bisbee.

The West soon became the nation's —and the world's—metal warehouse. Lake Superior became its iron-ore bin. The Allegheny Plateau and the Eastern Interior basin developed into its coal bin. The Appalachians, the Mid-Continent, and the Gulf Coast were like so many spigots tapping its limitless oil reservoirs. For nearly half a century the United States furnished roughly two-thirds of the world's mineral wealth and consumed well over half of it (*4*). It was an exporter of ore, concentrates, refined metal, and metal products; of crude oil and refined oil products; of coal; and of a few industrial minerals such as sulfur.

American know-how, capital, and daring then moved into Mexico, Chile, Peru, and Venezuela, thus extending the mineral empire—if one may use that discredited word in its original, creditable meaning. Domestic reserves outlasted World War I and were stretched out by the Depression. But subtle changes were taking place—virtually unnoticed, for we were preoccupied with surpluses; shortages were unthinkable.

The Specter of Dependence

World War II brought home the sobering fact that mineral resources are exhaustible and nonrenewable. Mining companies that engaged in all-out production were aware of the rapid rate of depletion of our known domestic reserves, and even before the war, several corporations had moved into the international field to assure themselves of adequate supplies. Bethlehem Steel Company, which had long since outgrown its century-old deposit at Cornwall, Pennsylvania, was active in Cuba and Chile. To supply its expanding tidewater facilities at Sparrows Point, Maryland, it was developing the first of the vast iron ore bodies in Venezuela, at El Pao, when war came.

The threatened exhaustion of the Mesabi started a frantic postwar search that has been, if anything, too successful in uncovering iron ore. The woods are full of it—south of the Orinoco in Venezuela; in Minas Gerais in interior Brazil; in the jungles and savannas of Liberia, Ghana, and French Guinea; in Chile and Peru; in the Ungava Peninsula of Quebec and Labrador. During the past decade iron ore imports have risen from a negligible fraction to one-third of the industry's requirements.

Recognizing the limitations of the Arkansas bauxite deposits, the Aluminum Company of America moved into Surinam. Then came the war and the entry of Reynolds, Kaiser, Harvey, and Olin Mathieson into the aluminum field. Following identification of the high-iron bauxite of Jamaica, a competitive struggle among companies for reserves ensued—in the Antilles, in Panama and Costa Rica, and as far afield as West Africa.

The major oil companies, engaged in supplying the European market, chiefly from Venezuelan sources after the Mexican government expropriated foreign holdings in 1938, had long eyed the Middle East, where Britain had enjoyed favored status in Iran and Iraq. Exploration and development were risky and expensive, even for the so-called major companies, but the problem was solved by the evolution of the "consortium." Britain's troubles in Iran pointed up the advantages of the international consortium, in which American, British, Dutch, and French interests are pooled in "vertical" companies that cover the field from exploration to distribution of refined products. Here again the effort to find more reserves and get more production was, if anything, too successful. When the Iranian supply was cut off during the brief career of Mossadegh, Arabia, Bahrein, Kuwait, Qatar, and Iraq filled the gap so effectively that it was difficult to fit Iranian oil back into the marketing picture.

Despite the evident surplus, the avid search for oil continued—in the reaches of the upper Amazon basin, in Bolivia, in Guatemala, in the prairie provinces of Canada, in Cuba, and in North Africa. And again successes far overshadowed failures. At the moment the French Sahara and neighboring Libya are about to deliver a million barrels of oil apiece to the glutted markets of the world.

Success stories abroad are without end. Copper, lead, zinc, sulfur, and a host of lesser metals and industrial minerals have come to light—and to the American market. In many of the new foreign developments, American capital is involved, but the proportion is diminishing. Venture capital is playing out faster than mineral wealth elsewhere in the world, and the role of the United States has changed from that of supplier to that of buyer.

Initially, the public and its representatives in government hoped that the scarcity of domestic mineral supplies was merely a war phenomenon, but the Korean crisis dispelled that illusion. This land of plenty was threatened with famine, and, in a spirit of alarm that bordered upon panic, the Administration and the Congress appointed committees and commissions to take inventory of our dwindling domestic supplies of mineral raw materials. Stockpiling was initiated, and strategic minerals were the beneficiaries of support programs. The immediate objective of the programs adopted was to assure the nation of critical supplies of scarce materials. The idea is excellent in theory, but the methods pursued have left everything to be desired. Long-range contracts for specific mineral commodities had the desired effect of stimulating production both at home and abroad. But the contracts were let at peak prices, and the Office of Civil and Defense Mobilization and the General Services Administration insisted on regular deliveries during the period of acute shortages, thereby forcing domestic and foreign prices to fantastic levels. Overproduction and collapse were the inevitable outcome of this policy, and collapse was hastened and intensified by cutbacks or by the fulfillment of stockpiling goals when the commercial market was weakest.

The catastrophic effects of government vacillation on the domestic mining industry are too numerous to catalog, but a few examples are in order. Literally overnight, 84 domestic tungsten mines went out of business on 31 December 1957 because the House of Representatives refused to continue the support program. Marginal lead and zinc mines were permitted to close, many of them never to reopen although their reserves are by no means exhausted. Uranium exploration came to an abrupt stop when the Atomic Energy Commission—apparently to its own surprise—realized that planned production exceeded its requirements. It therefore placed a deadline on the acceptability of newly discovered ore. Canadian, as well as domestic, producers suffered from this blow. The ore in some mines was never brought to the surface, and the new mine-and-mill town of Elliot Lake in Ontario died a-booming. Yet proven domestic reserves (*5*) assure us only of a skimpy 15-year supply. The nation's only cobalt mine and refinery were allowed to go out of production—and out of business—at a time when supplies from the Congo and from the new prospective source at Moa Bay, Cuba, were seriously threatened.

Accustomed as the mining industry has become to the fickleness of the commercial market, at no previous time in its long history has it been confronted with such public apathy, misunderstanding, and even hostility as it now faces—attitudes that are inimical not so much to the industry as to the interest and security of the nation.

Illusion of Plenty

The public attitude toward mineral raw materials seems to have gone full cycle—from the belief in abundance to the fear of scarcity and now to the illusion of plenty. Were this One World, there might be plenty, but only for the immediate future. The long-range outlook is less reassuring. Moreover, this is not One World, nor is it two—West and East. Politically it is undergoing rapid fragmentation. Prior to World War I we could depend upon domestic abundance, with certain seemingly unimportant exceptions. In 1961 abundance is world-wide, not domestic. The difference between 1914 and 1961 is so significant that it should guide national policy.

There is every reason to believe that routine exploration by private and public agencies will continue to disclose new reserves of virtually every mineral raw material, but probably without correcting the geographic inequities of distribution that currently exist. A comparison of the explored areas of the earth with areas only partially explored leads to the conclusion that additions to reserves will exceed withdrawals for some time to come, without resort to the technical methods of exploration that are becoming available. But even with this optimistic assumption, it is clear that the nonrenewable resources will be depleted at an increasingly rapid rate as standards of living rise throughout the world. When the curves for consumption and for new additions to reserves will cross defies prediction. Technology will extend the inevitable date, which hinges upon the rate of population growth and social advance in both the developed and the underdeveloped countries. The claim that 100 times as much iron ore would have been needed in 1961 if the per capita production of steel had been as high in the rest of the world as it was in the United States provides a gauge of potential future demand.

Logarithmic projection of gross mineral consumption is likely to prove reasonably accurate for the world as a whole, but not for individual nations. It may also apply to categories of minerals but not to individual raw materials. For this reason the popular sport of comparing annual gains in production, say between the United States and the Soviet Union, is pointless—witness the latest Russian claim that its iron ore production surpassed that of this country in 1960. The true measure of the stage of progress is per capita consumption of all materials employed for equivalent uses. And even here there is an optimum amount beyond which additional consumption constitutes sheer waste.

Any attempt to fix that optimum limit would be authoritarian, and even to define it would be arbitrary. Suffice it to say that the United States approaches it more closely than any other nation, and that the ambition of other countries is ultimately to equal it.

The achievement of this ambition will be fraught with thought-provoking consequences, chief of which is the nationalization of mineral raw materials to preserve them for domestic use. We need merely follow the news to see this trend in its varied but unmistakable forms. Mexico led the way when she laid claim to her oil reserves by expropriation in 1938. Argentina, Brazil, and Bolivia followed suit, only to discover that possession is meaningless without the capital and technological competence to develop their latent resources. In 1960 we witnessed the extreme form of nationalization in Cuba's "intervention" of foreign and even nationals' holdings of mineral properties. Thereby the world lost—at least temporarily—18 percent of its prospective nickel supply and a substantial addition to its supply of cobalt.

The right of nations to conserve their natural resources cannot be challenged, even though the motives may, in many cases, be questioned. When the purpose is primarily that of holding the national wealth for national benefit, the aim is laudable, especially if there will be a domestic need for the resources within the foreseeable future. If the purpose is to forestall ruthless or wasteful exploitation by foreigners, or to curb exploitation for which there is not adequate compensation, there can be no quarrel. But there is a growing number of instances of nations using specific mineral resources for political purposes, either internal or external. In such instances, the civilized world has a grievance against the nation that withholds its resource or charges exorbitantly for its use, because only by sharing the inequitably distributed mineral wealth in fair exchange can even the best endowed countries evolve a well-rounded, adequately supplied industrial economy.

Insurance for the Future

The current trend toward nationalism and nationalization abroad is disturbing. If it continues, money may not buy what we need. Are we to suffer slow and progressive strangulation for want of strategic raw materials? The answer to this question is not at hand, but it behooves us to take a critical look at our own reserves. The claim of the alarmists that the United States has become a have-not nation is correct only in the sense that we *have not* looked for hidden resources with the equipment now at our command.

Four years ago a panel of experts called together by the National Science Foundation (*6*) reached this conclusion and proposed that industry and government formulate and carry out a program of fundamental geologic, geophysical, and geochemical research, to probe for recoverable mineral wealth that cannot be detected by the crude and empirical methods of the obsolete prospector. The federal government was hesitant about trespassing upon the prerogatives of private industry, and private industry, in turn, would have nothing to do with government. The result fitted Will Rogers' oft-quoted definition of a commission as a group of important people who individually can do nothing but who, collectively, can decide that nothing can be done.

Although nothing has been done collectively since the report of the National Science Foundation was issued in 1956, individual companies, aware of the competitive search for new reserves, have by no means been idle. Indeed, at the time of the study several of them were already engaged in activities paralleling, within limits, some of those recommended in the report. And these activities have been rewarding. Within the past decade new discoveries and developments of native mineral raw materials have been numerous—among them, zinc in Tennessee, iron and copper in Missouri, uranium in Wyoming, copper in Arizona and Washington, molybdenum in New Mexico, rare earths in California, beryllium and potash in Utah, sulfur and oil beneath the waters of the Gulf of Mexico off the coast of Louisiana and Texas.

Nor have the government agencies been idle. In the words of Thomas B. Nolan (*7*), director of the United States Geological Survey, "resources are literally created by man through research that develops new uses for raw materials, research that permits the recovery of ores of lower quality than were previously minable, and research that makes it possible to discover concealed deposits of usable raw materials." The Bureau of Mines has focused a substantial amount of its attention and limited financial appropriations on methods of recovering ores "of lower quality than were previously minable." Its efforts have been furthered and supplemented by the activities of research laboratories, university departments, and private companies. The commercialization of taconite, which brought approximately 20 billion tons of iron ore within the sphere of economic utilization, is but one example of the results of this kind of research. Robert Brison, of Battelle Memorial Institute, and A. M. Gaudin, of Massachusetts Institute of Technology, have made substantial contributions toward the commercial recovery of metals from mineral deposits which, only a few years ago, would have received scant attention from the mining profession. Radioisotopes are being used to advantage in the analysis of ore deposits and in designing improvements in techniques for the physical and chemical concentration and refining of commercially important minerals.

Mining operations being carried on at Cerro Bolivar, Venezuela. [United States Steel Corp.]

Heavily as the ingenuity of the metallurgist and chemist has been taxed, it has risen to the occasion and has extended our reserves of mineral raw materials by methods that can be appropriately described as the conquest of economics by science. But attention has been concentrated almost entirely upon known deposits. The unknown lie outside the fields of metallurgy and chemistry.

It remains for the geologist to uncover unknown deposits, upon which the chemist and metallurgist can work, and in this field the United States Geological Survey has been active. In the past, economic geologists have been content to describe and explain individual mineral deposits in the context of their local geologic environment. Nolan, however, was led to a much broader point of view in a study of a portion of the Basin and Range Province, embracing an area of approximately 125,000 square miles (*8*). The area contains 285 known mineral districts that have produced more than a billion dollars' worth of gold, silver, copper, lead, and zinc. In analyzing the geologic environments of these deposits, he reached the conclusion that "the areal distribution of the nearly 300 districts revealed no recognizable correlation with major geological features within the province."

The statistical significance of Nolan's discovery has been analyzed by Louis B. Slichter (*9*), who opens up a new scientific vista of geophysical research as applied to the discovery of new ore deposits. Although Slichter sees promise in the geophysical equipment and instrumentation already available, he recognizes the need for more sophisticated developments, for geophysics has not reached the degree of sophistication in mining that it has attained in exploration for oil and gas.

Admittedly, the geophysical principles that can be applied in locating oil, natural gas, and other nonmetallic deposits of sedimentary origin, have limited applicability to metallic deposits; and without question mining geophysics will not only find it expedient to improve and develop currently known techniques and instruments but will also find it necessary to move into virgin fields. For example, the magnetic method is the oldest of the geophysical prospecting techniques, and the magnetometer has become a basic instrument in exploration. Yet there is urgent need for more definitive studies of the magnetic properties of common and mineralized rocks, as well as the phenomenon of remanent magnetization. Whether the comparatively new subject of plasma physics has any application to the emplacement of ore bodies has not been determined, but this possibility certainly deserves a casual investigation at the very least. In fact, exploration geophysics is still more an art than a science. Its practitioners are too dependent upon the general principles of physics and not sufficiently dependent upon a more solid background of factual data in geophysics. In the report of the Advisory Committee on Minerals Research to the National Science Foundation, the subcommittee on fundamental geophysical research stressed the inadequacies of our knowledge, not only in magnetics but also in gravitation, seismology, geoelectrical phenomena, nuclear geology, tectonics, and the geothermal characteristics of significant parts of the earth.

The chemistry of ore deposits has long been a subject of intensive investigation. Petrologists have displayed ingenuity in unraveling time and space sequences in the mineralization that has taken place in specific mining localities, districts, and provinces. Metallurgists and chemists, who must find ways to process ores once they are mined, have added materially to our knowledge of mineral chemistry. But in this orthodox, or classical, field of geochemistry the information is largely descriptive and empirical. To explore the unknown, geochemistry must be transformed into a genetic science.

A start has been made in this direction, but it is only a beginning. European—and notably Russian—scientists have made more progress than our own specialists, but many individuals are now engaged in geochemical research, and the United States Geological Survey is contributing substantially to the progress of the young science. A new Geochemical Society has been formed and has shown phenomenal growth. Subscriptions and technical contributions to the principal journal that serves the field have increased rapidly. There is every reason to believe that geochemistry's new adherents will make it a dynamic science—as dynamic as the chemical reactions with which it must deal to become an adjunct to mineral exploration.

One problem demands early attention: The emplacement of primary ore bodies stimulates a spate of chemical reactions within the geologic environment that is host to the intrusion. Immediate contact phenomena are well known, because they are characteristically exposed in the mining of the ore body, hence are readily accessible for study and analysis. For the discovery of hidden mineral deposits, however, the remote or distant chemical effects of emplacement must be genetically identified so that they may furnish clues by which unseen mineral wealth may be tracked to its lair. This is no easy task, because the mineralizing or mineralized agents are differentially affected by the gradual changes in temperature and the drastic changes in lithology that may take place as these agents move farther and farther from their source.

A second field for investigation is postemplacement processes, which must be the subject of separate studies that will supplement what is already known about leaching, enrichment, and other reactions that take place in direct contact with an ore body. Ancient mineral-bearing rocks have been buried by many different kinds of covers—unconformable sediments, glacial moraines, lava flows, and pyroclastic debris. Geochemical sampling has demonstrated that there is selective invasion of the overburden by certain of the ingredients of the mineral deposit, the presence of which may be determined by the degree of concentration of these trace elements over and above normal background. Harry V. Warren, of the University of British Columbia, has found that some plants are especially effective selective agents, and he has proposed the name biogeochemistry for the budding science that joins botany with chemistry to interpret geology.

Until these hybrid sciences of geophysics, geochemistry, and biogeochemistry have been nurtured into purer strains and have been repetitively applied to the discovery of unseen and unknown deposits, such discoveries as have been made during the past 10 years in Tennessee, Missouri, Arizona, Washington, New Mexico, California, and Utah are likely to become fewer in number. It may be anticipated that more refined instrumentation will aid these new sciences; but until the new techniques are further developed and used systematically, on a large scale, in the search for hidden ore bodies, it would be premature to conclude that we have exhausted the mineral-raw-material potential of our country, especially as all the metals that have been mined in the course of our history have been extracted from 1 million acres or less of our terrain.

There need be little worry about the ability of ore-dressing technology to solve the many problems connected with the use of chemically complex or low-grade ores. The monetary reward for success in the milling and refining fields is immediate, hence men, equipment, and money are readily made available for activities of this kind. The conversion of exploration geophysics and geochemistry into usable, applied sciences offers no such attraction or lure. It involves long-range research, the practical outcome of which can never be predicted. This kind of scientific activity is not likely to be undertaken by private companies, and yet it is of obvious importance to the welfare of the nation.

Our access to sources of mineral raw materials is not seriously threatened for the immediate future. We can only make a guess as to when the competition for raw materials will become so keen among nations that we may find ourselves in dire want unless new domestic resources are discovered. This interval, whatever its length may prove to be, should be used for minerals research, and there is no time like the present to start. The manpower is available, and since the shape of the future is clearly defined, the course of action should be equally clear. The day when we will need to turn to newly discovered domestic resources may be years away, but the lead time for discovery is likely to be long, too.

Just as the United States led the world in the 19th-century epoch of mineral discovery and utilization, so now—as insurance against shortages of the strategic raw materials that are the basis of economic growth—it will display wisdom and foresight if it embarks on a new epoch of discovery rooted in 20th-century technology. In the national interest, planning must be made a matter of national policy. It is no longer the prerogative of private industry to decide whether, or when, such planning will be done, and, by the same token, it would be presumptuous to expect private industry to embark upon a program of this kind, where the resulting rewards are likely to prove remote.

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