THE WASTING ORES OF A SMALL PLANET.

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ABSTRACT. Idealists rightly urge an improved standard of living over the world. Realists recognize that the greatest tangible advances toward that end have come through utilization of mineral resources, particularly metals and fuels. Of these, the present single generation has consumed more than all the world throughout its prior history. None of these rare and non-replaceable special concentrations below a skin-deep layer of the crust will ever benefit man. Areally, there remain no great new domains of mineral resource to conquer. The ultimate amount available is shrinking at an alarming rate under man’s mounting needs. Only by utmost wisdom may he continue mastery of his environment.

Plainly, the world’s mineral stores must henceforth be dealt with as the precious heritage that they are. Efficiency in discovery and exploitation, economy in use, and, equally, wise and just international procedures for optimum distribution of the benefits they confer, must receive far more consideration from scientific specialists, political economists, and governments than ever before.

Steps that seem desirable in a program of enlightened self-interest for the greatest creditor nation are examined as part of a world-wide attitude toward this critical and profoundly important problem.

A figure of speech which one hears fairly often these days is that the world is becoming smaller. This is, however, merely a fanciful way of recognizing that man’s expanding activities are beginning to feel the restrictions imposed by the scale of the planet to which he is confined. The rapidity and ease of modern communication and the speed of travel bring this situation most dramatically to the attention of everyone, when a speaker’s voice can be reproduced on the far side of the world before it is heard in the rear of an auditorium, and when planes in flocks are crossing the widest oceans as part of routine operations. These are, of course, merely details of the immense development of scientific and technical ideas and skills that have transformed the world in the past century and that are pushing us ahead, at least in material ways, at a breath-taking rate.

Such achievements, however, have not been accomplished without cost. To bring them about has required the expenditure of such a vast amount of our planetary capital of fuels and metallic ores that the adequacy not only of national supplies of these vital raw materials but of the world’s potential supply is beginning to be questioned.
For all practical purposes, only a thin superficial layer of the earth is accessible to man. He has made excursions of a few tens of thousands of feet into the atmosphere, and has reached below the surface for 9,000 feet or so in mines or 15,000 feet in drill holes. These distances are so extremely small in comparison with the earth's diameter that man's range for all practical purposes is hardly more than a film on the rocky crust. Within these narrow limits, there is indeed a fairly generous accumulation of geological wealth, but only those portions of it that are in deposits truncated by the present surface or are not too blindly concealed beneath it are actually available for his use.

To be sure, much of the land area of the planet still remains to be explored with the completeness necessary to exhaust its possibilities. An extraordinarily large percentage of it, however, has already been examined in a preliminary way, and the obvious and easily exploited riches have been gathered. Already the returns from exploration, as measured by discoveries of new sources of ores and fuels, are declining in relation to the efforts being made. With few uncharted places left, it is all too clear that there are no "new worlds" to be found, to use the somewhat extravagant term applied to the relatively empty continents that were overrun by Europeans a few centuries ago. Even with generous allowance for average returns as the remaining untested areas are opened up, we cannot fail to recognize that the ratio of the world's resources to man's expanding needs is becoming steadily smaller and that the utmost wisdom will be required if the human species is to continue to prosper in its restricted habitat.

Throughout his history man has prized metals, and his ability to obtain and to use them has afforded a fair index of his cultural growth. Our generation, however, with its ever expanding technical developments, has consumed more metal than all the generations of men that have preceded it; and today the insistent demands of the war, which rudely override all considerations of economy or conservation, have pushed the output of all metals to limits that strain the capacity of mines and plants.

Compared with the eruptions of volcanoes or the erosion of great rivers, these activities on the part of man may seem puny among geological processes, but they are so remarkably selective in their attack on metallic ores and fuels that in a gen-
eration or so the bulk of these deposits, which represent the accumulation of geologic ages, will have been destroyed and their metals and energy dissipated.

The utilization of metals with the development of ways of obtaining them from the earth's crust has indeed been one of man's major achievements. Without this skill, his recent and sudden advancement in mastering the material world would have been impossible. This growth, however, has been in a real sense at the expense of our geological capital—or planetary capital. At times, it is obviously wise to dip into capital and the expenditures to date have been amazingly fruitful. But, it must also be recognized that the reserves of this sort are not unlimited, and once spent they cannot be replaced in kind.

A geologist, of course, is used to dealing with time in generous blocks and an event may seem immediately impending to him that to others is far enough in the future to be of little immediate interest. Before the war, the possibility of shortages of metals and of metal bearing ores was regarded at least by most Americans as a matter of academic rather than practical concern. But these days, when we are searching for metals with the eagerness of a deer seeking a salt lick, sober appraisals are being made, not only of the nation's own potential ores, but of those of the world as a whole.

The focus is still further sharpened for a geologist by his appreciation of the nature of ore bodies and his recognition that they are the result of processes of concentration that have functioned extraordinarily well under certain special conditions usually far beyond our power to reproduce. Even if the temperatures and pressures involved in the formation of an ore were within easy range (as they are in the case of deposits of certain types), the time requirements must still be taken into account—and geologic time is a dimension that is difficult to reduce to the scale of a laboratory or factory. Consequently, a geologist rightly regards the ores as a heritage, accumulated throughout long periods of time, which once used up, cannot possibly be restored.

Probably at this stage of the discussion it might be helpful to define just what we mean by the term ore. Technically, an ore is regarded as an aggregate of minerals from which a metal or a metallic product can be extracted with profit or with hope of profit. If the term profit is understood in a properly broad
sense, the definition is valid for any economy, and not merely for one, such as our present age, when profit can be most conveniently measured in dollars won under competitive conditions.

A better definition, however, from a geological standpoint, is that an ore is a natural concentrate from which a metal or metallic product can be obtained, with profit or hope of profit, by further concentration employing artificial means. In this definition, geologic processes of concentration, essential in the formation of ores, are given particular emphasis. Only where such processes have functioned effectively in the course of geologic history are ores formed; and only where such deposits have been preserved and left on or near enough to the surface of the earth to be within our limited range, are they to be included in the reserves of ore upon which we can draw for the metals that are now so vital for our existence.

For every metal, there is a grade or degree of natural concentration that must exist in deposits of its minerals before the material can be regarded as an ore. That grade is the content in metals at which the ore can be mined and the metal extracted at a cost that is less than the value of the metal. Under ordinary conditions, this can be measured easily and practically in terms of the price the metal commands in the market and the expense in the same currency of obtaining it. In more general terms that perhaps are more significant under war conditions, the limiting grade of a commercial ore is determined by the need for the metal balanced against the expenditure in materials (including machinery, fuel, and supplies of all sorts) and labor required to obtain it from the given deposit. (For example, we need tin these days. A few extensive low grade deposits, in addition to the ores being worked in Bolivia, are available and accessible. The question to be answered in each case is whether or not the tin in such low grade ores, critically needed as it is, is worth the expenditure of other war necessities such as steel that is required to win it.)

The metals may be divided into two categories, (1) those sufficiently abundant in ordinary rocks to supply all possible needs, provided they could be recovered in the quantities desired with expenditure of other materials, energy, and labor not out of line with the value of the product, and (2) those too scarce to offer any hope of recovery on an industrial scale from ordinary rocks but which must be obtained from relatively
small deposits where natural concentrations of the desired element have occurred.

Iron, aluminum, and magnesium are the only metals that fall in the first group, but of these magnesium, the latest of the industrial metals, is the only one that is recovered from an ordinary rock (dolomite) or from other abundant sources, such as brines and the ocean. Even in this case, these ores, extensive as they are, are products of a process of concentration, for the element in question was derived originally from lower grade material and accumulated over long periods in saline waters and in precipitates from them. However, it is clearly an exception in a commercial sense, for the availability of magnesium in the future will not be limited by the supplies of raw material.

Aluminum and iron, however, even though they constitute 8 per cent and 5 per cent respectively of the igneous rocks of the earth's outer crust, and are as abundant as 15 per cent or 10 per cent in some special types, are still obtained only from restricted sources where by some means or other an enrichment in these metals has been created and ore deposits accumulated with the grade or other properties necessary for treatment at costs possible under current conditions. The chemist, of course, can easily extract iron from basalt or aluminum from syenite—both of them abundant rocks—but to obtain them in quantity at a low cost is another matter, and at the moment there is certainly no reason to think that the vast store of the two common metallic elements in the unenriched rocks will ever be available for human needs. The ores from which they can be successfully derived today are of much higher grade than the content found in common rocks. Possession of such ores confers tremendous advantages and the lands that contain them are among the most coveted parts of the earth. Enormous tonnages of iron-bearing sediments exist, however, that are now on the edge of being commercial ores. They will be worked in the future to a greater and greater degree; but the iron they yield will be more costly and the nation dependent on it will be in an inferior competitive position to those with high grade resources. The same comment can be made for aluminum. It undoubtedly will be recovered from clay in the future; but not at costs comparable to those at which it is now obtained from bauxite, unless the chemists and metallurgists discover an entirely new bag of tricks.
But even these long range possibilities are lacking for the other metals, including not only the precious and rare elements but such common ones as copper, lead, and zinc. Manganese, chromium, nickel, and tungsten are the most abundant among this group, as far as average content in igneous rock are concerned, but in none of the ordinary deposits of the earth are they present in sufficient quantity to approach ore grade, even remotely. And, as for the others, their presence is usually reported in quantities so small as to be almost meaningless in averages. As far as these metals are concerned, the supplies of the future are surely limited to the ores themselves, and when they are gone, no magic can provide them in the quantities we now use, at least until the physicist finds cheap enough ways to upset the stability of more plentiful atoms.

Consequently, for all practical purposes, we must base our plans for the future on the ores with which the planet is provided; and their possession is necessarily a matter of immense concern to all ambitious nations.

The key to their distribution is to be found in the geologic history of the region in which they occur. If the conditions under which they were formed are understood, and if we can recognize where and when in the geologic past these conditions prevailed, some reason can be seen for ores being where they are and for their geographic habits. Certain regions are richly endowed; others are barren; and no amount of effort or wishful thinking will change this fact. Metalliferous provinces cut across many lines important in human history. Countries, unlike men in our favorite political theory, are not created equal but must be accepted as they are. Men must go to the places where ores exist. The growth of cities or states may be determined by their presence; but when the local supplies are exhausted, new sources of ore must again be sought farther afield, which may lead to excursions across lines established by distribution of races or boundaries established by expeditions of the past that may have little relation to the realities of the present world.

Prior to the last century the demand for metals was so relatively small, even per capita, that it was easily satisfied either from mining and metallurgical operations based on small, local ore bodies, or from trade that could be handled without difficulty in the small vessels of the times. With the industrial revolution came the building of machines of all sorts; and machines are made largely of metal. Iron and the fuels, of
course, were the dominant need, and it is no accident that the major centers of growth of industries and of populations supported by them were in those countries where a people competent to grasp the intricacies of advancing science and technical discoveries had these natural resources at their disposal.

As industries multiplied and grew, as successive scientific discoveries were applied to technical ends, one metal after another was demanded—copper as electricity was put to work, tungsten and chromium for alloy steels as tools had to meet more exacting requirements, aluminum and magnesium as aircraft were designed—and so on, until the consumption of metals reached levels far beyond the geological endowment of most nations. First the countries with limited resources had to obtain their ores from abroad. Belgium, where the famous mines of La Vieille Montagne in the Moesnet district had played an important part in the development of the zinc industry, was able to retain its position as a zinc producer only by obtaining ores from abroad for its smelters. Britain long ago outran its meager resources in copper and tin, though its Swansea smelters continued to struggle along with a fair degree of success by importing their ores. The Empire, of course, helped England maintain its position, but as far as domestic supplies were concerned, Great Britain in the last few decades must be regarded as a land nearly depleted of all ores except iron, and dependent on water-borne supplies even for much of that.

Today, not one of the major industrial nations can obtain all the ores it needs from domestic sources. Even the United States with the best-endowed area of earth within its continental borders, lacks many metals that are vital in its economy; and as war goes on, we are tearing the heart out of our mines at a rate that is bringing the period of scarcity so much nearer that it cannot be safely ignored as a dominant factor in our future life.

For the United States, this change is apt to be especially painful, for the tradition of inexhaustible supplies simply awaiting development is hard to break. Even in these days, its influence is strong in high places, where opinions have been expressed lately that the scarcity of one metal or another is to be attributed to deliberate suppression on the part of large corporations, with naive disregard of the simple fact that the ore deposits, for the desired new production, are inadequate or lacking.

Prior to the war, shortages in the so-called strategic min-
erals, especially those of the alloy metals needed in the steel industry, and a few others such as tin, were the only ones that caused much concern; and as a matter of fact little serious attention was given even to these, in our confidence that the danger of interruption of overseas supplies was slight. Today with expanding tempo of the war effort—intensified by the needs of the entire group of the United Nations as well as our own—there is scarcely a metal that is not a strategic product or that can be regarded as available in adequate quantities.

This means, of course, that the ore reserves of this continent, not only in scarce metals such as manganese, nickel, chromium, tungsten, and mercury, but in iron, copper, lead, and zinc, are being drawn upon for the maximum quantities the mills and smelters can handle. Old districts are being pushed to new records, and scattered new mines are being reopened or equipped for operation, but to the best of my knowledge, not one of these developments is based on a new discovery. More ore is being found in old districts, to be sure, for the quantity of ore in such mines usually goes well beyond conservative engineering measurements; but the bulk of this huge new output is coming from our known reserves. In a very real sense, we are spending our capital, and hastening the coming of the day when our economy must be adjusted to meet an inevitably troublesome situation.

At this stage, it is well to consider what policies might best be followed to meet the shortage of ores that sooner or later will inevitably occur. The steps that to me seem most desirable, at least from a national standpoint, are (1) more intensive effort to improve our methods in the search for ore, in the exploitation of ore bodies, in the extraction and refinement of the metals, and in their economic utilization; (2) the acquisition through mutually beneficial international agreements of sources of metals in accessible foreign lands; and (3) the accumulation of stock piles on an immense scale of ores, concentrates, or other metallic products, by importation or by purchases from domestic mines at prices sufficient to maintain production at certain minimum levels.

The importance of improvement in scientific knowledge of ore bodies and in the technology of working them and using their metallic products scarcely needs argument. The easily found ores have been found. Those still to be discovered—and there may yet be many—are more subtly hidden and will be found only by those who can decipher obscure and indirect signs, and
who have a shrewd understanding of the nature and habits of their quarry. For the most part, these hunters will probably be geologists; but geologists who are prepared to use all the devices that modern chemistry and physics and engineering can give them. But, with all improvements possible, discovery and exploiting of ores and recovery of metals will still eventually approach the limits set by the available natural deposits, and science and technology in these stages will simply postpone the period of scarcity. With good fortune and skill, however, this lean time may be postponed longer than one could safely count on at the moment, but the basic nature of the problem would not be changed.

Most other nations already are dependent for major parts of their essential ores on sources outside their boundaries. Prior to the war, Germany lacked ores of copper, of all the alloy metals, of aluminum, and of many other vital materials and had to import them. (The fact that she was able to build up huge stock piles is a clear refutation of the theory that the markets of the world were closed to her.) An important part of England’s iron ore came from Sweden, from Algiers, from Spain and even from India. Nearly all the other metals needed for its industry came from overseas, but mostly from sources in the Empire. Japan had a fair amount of copper, but inadequate iron ore, manganese, chromium, tungsten, tin, zinc or lead, until their conquests. Now they control practically all these raw materials in abundance, and it is particularly painful to note that they are the temporary beneficiaries of our own skill in the Philippines where many mining enterprises were just getting well under way. With the tin and tungsten of Indo-China and Malaya, the lead and zinc of Burma, the chrome, manganese and iron of the Philippines and the tungsten of southeast China, the Japanese unfortunately are now well provided—though these materials must still be brought overseas to Japan itself, which may prove to be a fatal weakness.

After the victory, I trust that we shall be guided by enlightened self-interest sufficiently to make sure of two things, (1) that we shall have access to these vital supplies of ores and metals to the full extent our future economy and security requires, and (2) that we shall so control the quantities made available to our enemies that the building of a new war machine can be effectively prevented. The nature of our interest in mines in foreign lands needs to be studied in a realistic way
with recognition (1) of their critical importance to us, (2) of the value of the technical contribution we have already made and can make to still greater degree in their development and exploitation, and (3) of the proper security that must be provided for such undertakings involving heavy expenditures and high initial risk. To accomplish these ends by the methods of economic imperialism, however, would not be an attractive solution, and other procedures must surely be sought, whereby our objectives can be attained with mutual benefits to the less industrially minded or technically inclined nations—which by chance happen to control areas of the earth where many urgently needed geologic deposits are situated. With just recognition of national objectives, plans should be worked out in each specific case that would result in just return both to the group that assumes the major financial risk and contributes the technical skill and to those who possess the rights of ownership and the responsibilities and privileges of sovereignty. Whatever form enterprises of this sort take, however, it is clear that we cannot avoid reaching across foreign boundaries for many of our ores and supplies, if our present industries are to prosper and our relatively high level of living is to be maintained. If such actions, even adjusted equitably to modern needs, are too distasteful to idealists or isolationists, then they must be prepared to accept the other alternative—a lower standard of living when our own resources in raw materials are depleted.

In the first world war, we provided a substantial fraction of the materials needed both for the fighting and for the subsequent reconstruction; and accepted paper in return. Later, we shipped large quantities of products abroad that were essential in the rearming of the world for the present war. Our potential enemies and our friends were treated impartially, though the former actually benefited in greater measure. And for this strange service, we accepted gold with the result that we built up our hoard to a total of some 22,000 tons, on which a book value of nearly $23 \times 10^9$ is placed. And then, still later, the United States adopted lend-lease, and now ships its wealth abroad with no restrictions or guarantees whatever. Of course, there is an element of life insurance in this policy which might reasonably be regarded as adequate return; but it would seem more realistic if at this stage some more tangible benefits could be secured for the nation for the immense wealth
in part irreplaceable mineral capital—with which it has parted. Concessions might well be sought as a fair return that in the end would result in mutual benefits, such as the right under reasonable conditions to explore and exploit ore deposits of the metals we lack in some of the extensive empty territories of our friends.

Raw mineral products indeed provide one of the few ways in which the debts owed to us can ever be paid. With high tariffs, preventing or limiting the entry of goods, we must accept paper or tokens such as gold if we insist on maintaining a one-sided foreign trade. With recognition of our serious deficiencies, however—deficiencies that are certain to become more and more acute in the decades not far ahead—the importation of vast quantities of these indestructible materials and their storage in stock piles for the future would undoubtedly be a better policy. If our present stock of gold (or the much less valuable paper promises of the first war) could be transformed into masses of high grade tungsten ore or concentrates, of chromite, of manganese ore or even of blister copper, pig lead or slabs of zinc, even at high prices, how much better off we would be at the moment. Indeed, I believe that such a policy in the postwar period would go far not only in providing the security against shortages but in protecting the value of the gold itself in which we have such a vast commitment.

Stock piles undoubtedly would have their political dangers, but the advantages they would bring, by affording protection against scarcity in a war emergency, by providing a means of obtaining something besides gold and paper in return for our goods, by reducing our unbalanced gold supply, and by providing a depletion reserve against the time of exhaustion of our ores are overwhelming arguments in their favor.

Policies with regard to exploitation of our marginal ores—such as the low grade manganese, chromium and tungsten ores that could not compete in a world market—also need consideration. Many mines have been developed and plants installed with prices guaranteed as a war measure for a period adequate to return the expenditure and a modest profit. Should these plants continue to be operated, under protection of tariffs or should we take advantage after the war of cheaper high grade foreign ores? Probably a small domestic production might well be subsidized, as a means of maintaining the existing plants in working condition for the security that they provide against
blockade; but otherwise, it would be in my judgment nationally advantageous to obtain the major part of such materials from abroad and postpone the depletion of our own deposits.

All these considerations, however, are perhaps narrowly nationalistic. The problems of the whole planet have not been given much consideration; but they are essentially the same, though shortages on a world scale may be a century or more away rather than a few decades ahead. There are still empty places to explore, and there are undoubtedly discoveries of major importance still to come, such as the Rhodesian copper fields that were found twenty-five years ago, though probably these happy events will occur at increasingly long intervals. But, as has been previously emphasized, they merely postpone the time of scarcity and do not remove the threat that the scale of living of the human race—or at least its rate of consuming—will eventually have to be drastically reduced, if metals and the ore deposits from which they are won continue to be essential as they now are for so many vital services.

By then perhaps, the physicists and chemists will have developed processes for utilizing the ordinary rocks and other abundant supplies of the earth that will have made men independent of his geological heritage in ores or will have found some new magic by which to relieve the need. This possibility is far more than idle speculation—indeed it is a thrilling hope. But so far, their achievements have resulted in accelerating the consumption of metals, rather than conserving them, for each new discovery has led to so many applications that even though smaller and more efficient machines displace the older, cumbersome engines, the net consumption of metal is actually increased. So, I am sceptical of the relief that will be obtained from them at least in the decades immediately ahead which are of the most personal concern to us, though we must look to these high priests of science and engineering for the means to carry on, after the geologic or terrestrial capital stored in our ore bodies has been depleted.

Our generation, which can still benefit richly by this heritage, should recognize the obligation to spend it well with the minimum of waste, and to restore the capital, not in kind for that is impossible, but by attaining such mastery over the material world in these years of plenty that the exhaustion of the planet’s stock of ore will not make further progress impossible.

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