The Industrial Minerals

They used to be the poor relations of the mining world. Today they look more like the pace-setters.

by Ian Campbell

Industrial minerals, for a long time, were known to economic geologists as "the nonmetallics." These were the minerals sought, not for their content of a metallic element (as we seek galena for its content of lead), but for some industrially useful property that was perhaps inherent in the mineral just as it came from the ground (diamond or native sulphur), or which could be developed by a treatment that did not require reduction to an element (the conversion of limestone and shale in a kiln into Portland cement).

The nonmetallics are a large and diverse category, including such common things as sand and clay, and such relatively rare materials as sheet mica (for dielectric uses) and zircon (for high-grade refractories).

Economic geologists and mining engineers of the past generation looked down on the nonmetals. Some still look down on them – even though, in terms of our national economy, the value of the annual output of the industrial minerals in each year since World War II has exceeded by several millions of dollars the value of the annual output of the metalliferous minerals.

The industrial minerals have been the poor relations of the mining world. They have lacked the glamor of the metals. There have been very few bonanzas among industrial mineral deposits, and there have been few easygoing profits. As a result the industrial mineral industry well deserves to be compared with our packing industry, which has long claimed that in order to make any profit it must utilize "everything but the squeal of the pig." This has been one of the major contributions to mineral development that has stemmed largely from the industrial minerals – the recognition of the importance of by-products and the development of methods to handle them.

Parenthetically, it is of interest to note that in recent years, just as nonmetals have graduated to the more positive and dignified term, "industrial minerals," so have many by-products been graduated to the more dignified term of "co-products"! Let me take an illustration from the USSR, both because it will give credit where credit in this case is surely due, and because it will illustrate some other factors of mineral economics.

Prior to the first world war, Russia had obtained the bulk of the phosphate fertilizer so necessary to her great wheat-growing areas from the rich phosphate deposits of North Africa. During that war, Russia was effectively isolated from Mediterranean shipping, and in the last years of the war considerable portions of the Russian population were virtually on a starvation basis, largely because of the reduced crop yields resulting from the lack of phosphates. Accordingly, one of the early developments in the first Soviet five-year plan was a program to discover domestic sources of phosphate.

At that time no high-grade rock phosphate of the type that we know here, or that was available in North Africa, was known in Russia. But in the Kola Peninsula – that far northern projection into the Arctic lying just west of the White Sea – were large bodies of curious rock composed of two otherwise rather rare minerals: apatite, a calcium phosphate; and nepheline, a high-alumina, potassium aluminum silicate.

"The Industrial Minerals" has been adapted from Dr. Campbell's address as retiring president of the Pacific Division of the American Association for the Advancement of Science at Utah State University on June 16, 1958.

Up until this time neither mineral had been of any industrial importance. But apatite is a phosphate mineral and with proper treatment it can be converted to the super-phosphate desired by agriculture. This the Russians set out to do, and the building of the Leningrad-Murmansk railroad (so important to the Allies during World War II) was one of the elements in that program.

But to mine this rock, utilize the apatite, and allow the nepheline which constituted nearly 50 percent of the rock to pile up as waste would be highly uneconomic. Soviet scientists recognized that nepheline had qualities which for many purposes made it superior to feldspar in ceramic applications. The result: a new industrial mineral was born out of what had been a museum curiosity.

Next let me turn to an illustration much closer to home.

Sand and clay are important and fortunately rather widespread industrial minerals. Unfortunately, in California, despite our richness in many mineral deposits, sands and clays of industrial quality are all too scarce. Such as do occur are mostly confined to one geological horizon, the very early Tertiary. The Ione formation in the foothills of the Sierras is of this age and locally has produced some good clays, but extensive sections of Ione clay have been regarded as worthless by the ceramic industries because of their high sand content.

Just a few years ago the Gladding McBean Company, one of the principal producers of ceramics on the Pacific Coast, and the Pacific Division of the Owens-Illinois Glass Company jointly undertook a study of portions of the Ione formation with the idea that, by developing suitable extraction techniques, material that had been worthless either as a clay or as a sand could be purified sufficiently to yield both a commercial clay and a commercial glass sand. And just within the past year this has become an accomplished fact.

Everybody wins

One company does the mining; the other one does the beneficiation; Gladding McBean gets the clay; Owens-Illinois gets the glass sand; and the state of California, which collects taxes from both, is happy to see what had been worthless ground turned into a valuable industrial mineral asset.

Besides the tangible profits that are accruing to both companies and to the state, there is important intangible value that develops from an *entente cordiale* between two companies which otherwise might have been competitive. Does it take much imagination to extrapolate such a situation to the case of two countries, which to the advantage of both might share mineral resources and mining techniques rather than hoard them or fight over them?

One more illustration I want to take from California, and once again I wish to review a problem that was of great concern to the United States during the first world war. Phosphorus is not the only important "fertilizer mineral." The big three – as they are sometimes referred to – are phosphorus, nitrogen and potassium. The United States has long been well off in phosphate minerals; nitrogen we can get from the air (as well as from mineral deposits in Chile); but up until World War I we had been dependent on mineral imports from Germany for the potash vital to our agricultural industry. When the body politic gets hurt in the stomach, things are apt to happen! Even so, they happened slowly.

We subsisted – barely subsisted – for a number of years on desperate measures. We dredged kelp off the California coast and burned it, to recover its small yield of potash; we installed the first bag filters on cement kiln stacks, in order to get the potash that was going off in the dust. The American Potash and Chemical Corporation undertook to extract potash from the brines of Searles Lake. (Only later came the discoveries in the Carlsbad area of New Mexico which have so greatly increased our potash production and our potash reserves.)

An extraordinary lake

Searles Lake is no lake in the ordinary sense. In the first place, it is a "dry lake," unique, geologically, in that it consists of a thick body of salts of which NaCl is only one, and among which are a number of otherwise extremely rare minerals – various combinations of Na, K, Mg carbonates and sulphates.

This unique salt body has rather high porosity and the pores are everywhere filled with brine. The American Potash and Chemical Company does not mine the solid salts; it mines the brine – by means of wells and pumps. And from this brine it originally extracted potash and, as an important co-product, boron.

For several years potash salts and borax constituted the products. But in the course of evaporating and crystallizing out these salts from the brine, it became apparent that other products could be obtained by going just a little further in the extractive process. Salt cake (sodium sulphate), soda ash (sodium carbonate), and phosphoric acid have now become important co-products. And – surprising to many – Searles Lake emerged during World War II, just when we needed it most, as our principal producer of lithium.

Bromine salts are also being produced, and only recently we have learned that the Searles Lake brines constitute our nation's greatest reserve of tungsten – something we had thought of as exclusively the property of the hard-rock miner! Tungsten is not now being extracted because at present prices and with presently known methods of extraction, it could not be economically produced.

Glauber salt operations of the American Potash and Chemical Corporation at Searles Lake, California. In winter, when temperatures are sufficiently low, fossil brine is pumped from the crystalline salt body below and sprayed into the air, precipitating Glauber salt, which is "harvested" in spring or summer. In the plant in the background the fossil brine is processed for its yield of potassium salts, borax, sodium carbonate, lithium compounds and other valuable mineral materials.

Not only is Searles Lake a unique mineral deposit; the process of extraction is even more unique. The now successful plant process for the Searles Lake brines is the result of a great deal of painstaking research — research which met the discouragements that research into a new and untried field not uncommonly encounters, but research that today has well demonstrated both its scientific and its economic soundness.

Research in the field of the industrial minerals has been responsible not only for turning worthless rock and fossil brines into ore, and for developing unexpected by-products from sources established for other needs, it has led to synthesis — from easily and abundantly available materials — of industrial minerals of which there is far too scant a natural supply. Take, for example, cryolite (sodium aluminum fluoride)— which is found in only two or three localities in the world, and in only one of these localities does it occur in more than pound lots. In this one occurrence, on the southwest coast of Greenland, it fortunately occurred in millions of tons; for this mineral is the foundation of the aluminum industry.

Cryolite provides the bath in which the far more common, but more refractory ores of aluminum are melted and electrolyzed to yield the metal. Although, in this process, only relatively small amounts of cryolite are consumed, the one natural deposit of this mineral has now been virtually exhausted. Fortunately, synthetic cryolite can now be prepared from other much more abundant and widely distributed minerals.

Diamond is today far more important as an industrial mineral (because of its supreme hardness) than it is as a gem-stone. The United States has always been, and probably always will be, dependent on Angola and South Africa for its supply of natural diamonds. But now, after more than a century of abortive attempts by scientists, engineers, philosophers, frauds and magicians, we at last have a practical method for synthesizing diamonds from that very abundant raw material, coal. Mica, one of the trickiest of all minerals to synthesize, can now be made as the result of patient and imaginative research. And we are thus no longer so dependent upon India and Brazil as we once were for this mineral which throughout the war and for some time after stood practically at the top of the list of critical materials.

As a result of the spectacular development in satellites, moonwatching has become a serious avocation and missilery has become an especially engaging field of science. But I cannot help but feel that with the great hue and cry towards outer space we may be neglecting important exploration that needs to be done beneath our very feet!

Should it be any more intriguing to send recording instruments into the relatively unknown areas just beyond the earth's atmosphere than to send recording instruments down beneath the first of the discontinuities in the earth's structure? The so-called Mohorovicic discontinuity (immediately beneath it we know almost nothing of the underlying material) lies only some 20 miles beneath the continental areas, less than 5 miles beneath the oceans.

We are already conducting mining operations at depths of about two miles, and oil wells have been drilled nearly four miles down. Ten years ago the farthest up we had reached (with a V-2) was a little over 100 miles. Now the U.S. Air Force rocket has gone 79,000 miles! Is any more of a scientific and engineering breakthrough required to go from 100 to 79,000 miles up, than to go from 4 to 20 miles down?

Our artificial satellites are sending back information on temperature, density, and radiation. This is exactly the kind of information that we need from these unknown depths in the earth. Such information would be of intense scientific interest, and it could be of great practical value, for out of it we might learn what triggers earthquakes, how granite is formed and whence the lava is generated that causes volcanoes. Here is research that should be done, and I hope will be done soon.

Mineral policy

But, in the meantime, let us look into the vexing problem of mineral policy. In order that, for the moment at least, I may not incur the wrath of my friends in either the nonmetals or metals industries, I shall take my first illustration of mineral policy from the field of petroleum.

A distinguished petroleum geologist told me a few weeks ago that the "extractive cost" of a barrel of oil at the well head in Saudi Arabia is about a nickel. Here in the United States, it is about a dollar. If Americans, as a nation of automobile users, desired to establish a policy by applying the rule of "the greatest good to the greatest number," it would seem that we should bring in all of that nickel-a-barrel oil that we possibly can and thereby lower the cost of living, or at least the cost of driving, to our benefit. Moreover, in doing this, might we not also enjoy the satisfying feeling that we were at the same time contributing to our national defense?

We have only so much oil in the ground and we have already taken a lot of it out. Producing, as we have for many years, more than half of the world's requirements for petroleum, we now have left only about 15 percent of the Free World's reserves. We might have real trouble in fighting another big war with just the oil still available from domestic sources. Why not, therefore, import all the foreign oil we can and save our own oil for the time when we may desperately need it?

Counterargument

These are telling arguments, but before accepting them at face value, look at the other side of the coin. The domestic petroleum industry is one of our largest and most efficiently functioning industries (as the result of heavy emphasis on research all the way from exploration to production and processing). If nickel-a-barrel oil comes here in large quantities, then large segments of our domestic industry may have to go out of business — industry that is employing thousands of Americans, paying millions of dollars in taxes, and millions of dollars in dividends. Would this be good?

And what of national defense? Just knowing that we have reserves of oil in the ground would do us little good for either an immediate military or industrial effort. We must have equipment installed *and* operating in order to get the oil from the ground, and we must have men familiar with operating that equipment. Obviously we cannot accomplish this by having the oil wells and the petroleum engineers all in Saudi Arabia and Venezuela!

If I have pointed up the problem of petroleum policy it is only because petroleum is a more familiar mineral commodity to most of us than are many of the metallic and the industrial minerals. Many of these, even though our tonnage needs are small as compared to petroleum, are equally vital to our economy. And the problem of supply is more acute for many other minerals than is the supply of petroleum, for a good number of vital minerals are not found in minable concentrations within the United States.

I know there is a general feeling that "if we want some mineral badly enough, we need only raise the price high enough, and we'll get it — from domestic sources." For some things this may well be true, as it was true for magnesium during the war, and more recently, for uranium. But for some things this is just not true — tin for example. The price of tin could be raised to dollars a pound, and the amount of domestic tin ore that would result would be insufficient to supply even a tiny fraction of our needs. So what must we do to get tin? *We must be friends* and *keep* friends with the tin-producing nations. We can do this by reasonable and consistent reciprocal trade agreements; we cannot do this by unilateral deals, by making sudden demands and following these with sudden cutbacks, by forcing feast and then famine upon sister nations.

Whether the problem is one of domestic versus foreign production, or of needed imports, it is clear that there are no easy solutions. Mineral policy right now, and probably for years to come, must be a policy of compromise. Intelligent compromise can only be achieved on the basis of thorough knowledge and understanding. Alas! Geologists and mineralogists do not yet know nearly as much as they would like to know about the ultimate origin or the cause of distribution of ore deposits.

This we do know: Ours is a rather assymetric world, geographically. The rocks that immediately underlie the great ocean basins are basically different from those that immediately underlie the continents. And within the continents there are vast differences in the details of the rocks, and associated mineral deposits. Why was almost all of the world's cryolite concentrated in a few acres of ground at Ivigtut, Greenland? Why is perhaps 90 percent of the world's borax concentrated in southern California?

But while the answers are being sought, we must live with the facts: that no nation is self-sufficient in terms of the mineral resources required for 20th century civilization. Therefore when a nation has 99 percent of this, or 75 percent of that, has not nature herself presented that nation with a trust that is certainly the concern of all the world, and which thus should be treated as a trust by the nation that by accident of geology and geography has been presented with such a treasure? Ideally, yes. But, practically, we still live in an age dominated by the principle of "finders keepers," and if we find something first, it's all ours, to do with just as we very well please.

A way out

Must we always live within the horns of these dilemmas? Must we continue to vacillate between the theoretical logic of "one world" and the free trade principles that this implies, and the practical necessities that seemingly call for high tariffs? Nor is this vacillation any free-swinging pendulum; every time it moves, it generates friction, and generates friction in an environment so tinder-dry that a small spark can start war. Too many wars already have been fought for mineral rights. Must we have more?

There is, I think, a way out. It is probably a slow way out; but I think it is a sure way out. It is likely to be slow for in part it depends on basic research that is still to be done; and the time is as unpredictable as it is for any basic research to reach its objective. And there are many objectives. I will mention only one: *Can we geologists learn successfully to synthesize granite in order that we can better learn how to take it apart?*

"What for?", you may well ask. Well, in the course of fractionation of magma to produce granite, that has gone on in our continental areas, many valuable components have become relatively concentrated in granitic rocks. In 100 tons of average granite there are about 8 tons of aluminum, 5 tons of iron, 3 tons of potassium, 1200 pounds of magnesium, 1200 pounds of titanium, 180 pounds of manganese, 70 pounds of chromium, 40 pounds of nickel, 30 pounds of vanadium, 20 pounds of copper, 10 pounds of tungsten, 4 pounds of lead, as well as significant amounts of boron, lithium, etc.

This is all very fine, you will say, but most of these elements are "locked up" in the form of silicate minerals which are difficult chemically and expensive economically to decompose into their constituents. Quite so. But an average granite also contains about 12 parts per million of thorium and 4 ppm of uranium. These 16 ppm of radioactive elements in 100 tons of granite represent the fuel equivalent of 4500 tons of coal.

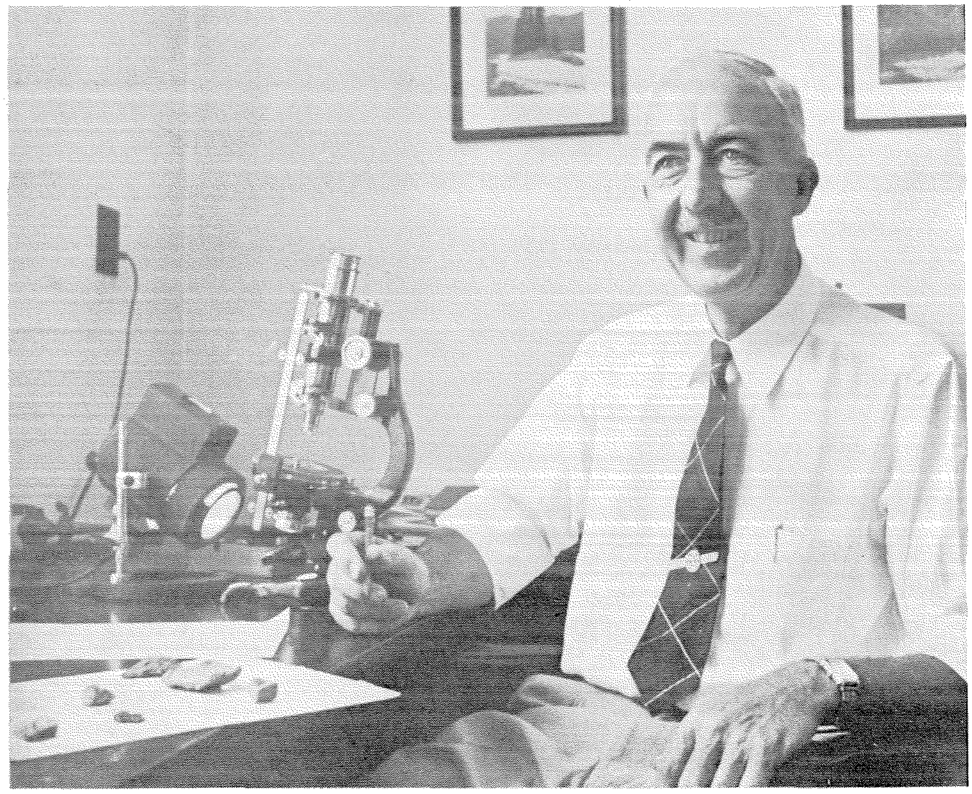
Furthermore, the thorium and uranium, recent research has shown, are not locked up wholly in refractory minerals; a large share is in rather easily extractable form. It seems not unlikely that more than enough nuclear fuel can be obtained from granite to furnish the energy required for its own recovery plus enough surplus to accomplish the extraction of many of the valuable elements cited above.

Inexhaustible mineral resource

When this is done, we may have achieved the nearest approach to perpetual motion that the world has yet seen, *and* we will have a virtually inexhaustible and widely distributed mineral resource, granite, to draw upon. To be sure, this is some distance in the future. We are not yet at the stage of considering nuclear fuel as economically competitive with other sources.

But when the time arrives that nuclear fuel can undercut conventional sources, then we are going to see such demands for thorium and uranium as are rapidly going to exhaust our presently known high-grade ores. Granite will be a next logical source, and the mining of granite for its nuclear fuel thus opens up tremendous vistas for by-products and co-products.

Another virtually inexhaustible resource is already producing minerals for us: the ocean — the "mineral sump" for all of the continents. Long ago, when gold was more sought after than now, we were sometimes dazzled by the figures quoted of the "jillions" of dollars of gold stored in the oceans. And it was true that in a few areas, the concentration of gold in sea



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water was not far below the point where it might be extracted at a profit. If the price of gold should ever go, as once it did on the black market, to $90 an ounce, I daresay someone might start a successful gold mining operation in the seas off the coast of Australia!

Much more important to us today than gold, and a much more realistic example of what is already being done to make the seas productive, mineral-wise, is magnesium. For a number of years the Dow Chemical Company (in Freeport, Texas), and the Northwest Magnesite Company (at Cape May, Virginia), and the Kaiser Aluminum & Chemical Corporation at Moss Landing, California, have successfully been extracting magnesium salts from sea water – so successfully, indeed, that "synthetic" or sea-water magnesia, has now to a considerable extent replaced magnesite mined from our continental deposits.

Many other valuable constituents are present in sea water, and some day will be forthcoming as co-products or by-products of magnesia.

Trends in the industrial mineral field are pointing the way which soon may be followed by the entire mineral industry. In the past, prospector and producer alike sought the rare and high-grade mineral deposit. Today the prospectors and producers of industrial minerals have successfully shown that the most effective mineral supply is best obtained from large, low-grade, and widely distributed deposits. This development has been made possible by research which has developed by-products and co-products from complex low-grade sources and by research which has made possible synthesis of rare minerals from common materials. Mineral policy, meantime, has of necessity been founded on the unhappy fact that the high-grade mineral deposits – the deposits upon which we have largely built our industrial civilization – are distributed according to what might be regarded as accidents of geology, of geography, and of history. With such distribution it is inevitable that mineral policy could never be entirely satisfactory nor wholly consistent.

Now, by prosecuting research with sufficient vigor, we can look forward to the time when virtually all of our mineral needs, including fuels, can be obtained from two virtually inexhaustible resources: granite batholiths and ocean water. Almost all nations have access to the sea; almost all nations have granite cropping out within their borders, or present at no great depth beneath the surface veneer of sediments. Thus almost all nations will have ready at hand those mineral raw materials which, because of scarcity, have been the source of so much conflict and so much unhappy compromise in the field of mineral policy.

To speed this day we must vigorously prosecute mineral research, This is a job not only for the geologist and mineralogist, but for the engineering scientist, the physicist, the chemist and – recognizing that some of our most important mineral deposits are directly or indirectly the results of organic activity – the biologist. As scientists we can give our research no finer goal. For, when successful, we will have eliminated one of the major causes of war. For the present, however, mineral policy must be compounded out of knowledge and tolerance, and a recognition of the need for intelligent compromise.