Future Ore Supply And Geophysical Prospecting

Mineral Properties Now Entering a New Epoch

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IN THE United States in 1929, 55 per cent of all revenue freight hauled by Class I railroads consisted of "products of the mines." This classification included only mineral products before manufacture. If the same products after manufacture had been included, the total would have been approximately 75 per cent. Thus modern high-energy civilizations, as contrasted with all previous ones of a low-energy character, may truly be called mineral civilizations.

Modern industry may therefore be conceived of as one vast flow-line of

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as to the extent of their solubility in such solutions. However, where quartz and quartzose rocks have been replaced, the active solutions were probably alkaline at the place where replacement is going forward.

Conclusion

This outline of the probable physico-chemical processes of ore formation lacks definite support in many places, and is in part only what seems the most probable relationships in the light of our present knowledge. I assume in accordance with the views of probably most geologists and experimental workers that segregation of mineralizing materials is a result of crystallization differentiation, but Fenner* believes that such materials are evolved for most ore deposits as a gas phase immediately after intrusions and before advanced crystallization of the magma. If this is so, mineralization (autometamorphism) of the parent rock will be absent. Evidence for a decision between the two theories can probably be best tested by the field geologist through evidence for the early or late formation of mineral deposits. Autometamorphism has been recognized in many places, but evidence for or against it should be carefully noted. One should remember, however, that ore-forming materials have differentiated by processes that tend to bring about equilibrium with the parent rock, and therefore their alteration is likely to be slight compared with the effect on invaded rocks.

The entire problem of the chemical character of ore-forming solutions is but vaguely understood. Their acid or alkaline character is in dispute. It is difficult to picture a solution that can in a single course of events dissolve and remove material from the parent magma, transport it to the place of deposition, and there drop its load only to dissolve and remove great quantities of replaced rock. We know a little about the solid materials and the acid radicals present through the minerals deposited, but we know next to nothing about the materials that failed to be precipitated and so left no record behind. We know but little about the ranges of stability of large groups of minerals. We talk about high and low temperature deposits but allow a wide range for the actual temperature of our guess.

The field geologist and mining engineer have much to contribute in solving these problems. Perhaps I may here emphasize that gangue minerals, which have at times been neglected in studies of ore deposits, probably are capable of revealing important information about the intermediate stages of differentiation that lie between magma processes and ore deposition. Theories of ore deposition must be rigorously tested in the field, but this demands an understanding of geologic implications of physico-chemical experimental work.

Much of the information required to clear up problems of ore deposition can be supplied only through physico-chemical research. In the past, numerous experiments have been made on the solubility of ore materials in first one possible solvent and then in another. Such haphazard experiments are now completely outmoded and only detailed phase relation studies of minerals and their possible solvents are capable of giving the necessary information. A beginning is being made in the study of systems containing water, and the methods are being worked out. Phase relation studies reveal relationships quite incapable of discovery by any other method. The recent paper by Bowen, Schairer, and Posnjak* on the anhydrous system CaO-FeO-SiO_2, for instance, has revealed relationships that the older methods could not possibly have revealed; and it is evident that phase relation studies of systems containing volatile materials will yield equally unlooked-for results. Evidently our science is in vital need of much more extended research along physico-chemical lines, which applies particularly to ore-deposition problems.

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minerals flowing from the earth by way of the mines into industry, and finally, by wastage and chemical disintegration, returning to earth again. This flow begins at the mineral deposits of relatively high concentration and ends in a dissemination of low concentration, or a scattering, so to speak, to the four corners of the earth. It is, therefore, a unidirectional and non-reversible flow. Minerals, though never destroyed chemically, are mined only once, and, after being wasted, are not likely ever to be collected together again.

The first stage in this mineral flowline is that of prospecting and discovery. For the rate of flow of minerals from known geological reserves into industrial uses to be constant over an extended period of time, the rate of discovery of new reserves must equal the rate of exhaustion of the old ones. Thus one sees that the flow-line involves a whole industrial complex, and that any attempt to discuss prospecting alone without taking into account the factors determining the rate of flow of the whole would be essentially futile.

Mineral Distribution

The practical depth limits of mining and of the production of petroleum up to the present have been of the order of two miles from the earth's surface. Although this will doubtless be increased, discussions involving mineral distribution in the upper two miles of the crust are not likely to be invalidated for greater depths.

The outstanding characteristic of the distribution of any particular mineral, such as iron, is that in by far the greater part of the upper two miles the product occurs in very low concentration. On an average, the surface rocks contain only 8 per cent aluminum, 5 per cent iron, and 2 per cent magnesium. All of the other metals commonly used in industry occur on the average only in small fractions of 1 per cent.

Fortunately for civilization, in a very small per cent of these rocks higher concentrations of the useful minerals occur. To represent this graphically (Fig. 1), one may draw a rectangle the area of which represents all the rock in, say, the upper two miles of the crust. Now, supposing that this rectangle be divided into vertical columns from left to right, arranged in the order of the concentration or percentage by weight of some industrial metal, say, iron, one would find that a very narrow column at the extreme left had the maximum iron content of a little over 72 per cent. This would represent an iron ore of pure magnetite with no gangue mineral. The iron content of the next column to the right would decline to 70 per cent (pure hematite), then to 50, to 30, and to 20. From each of these to the next, the decline would be somewhat more gradual, with a broad plateau in the vicinity of 5 per cent. Finally in the narrow columns at the extreme right it would probably decline sharply towards zero.

Even if exact data were available, it would be difficult to draw such a graph accurately, because of the extremely narrow range of the higher concentrations. Curves similar to Fig. 1 but with different ranges in the concentration would be true for each of the other industrial metals.

The significance of such curves is that the greatest quantity of any metal occurs in very low concentrations, and, although this could possibly be extracted and refined, the physical cost in energy expenditure would be extremely high. In general, the higher the concentration, the smaller the physical cost of extraction per ton of final product. This condition forces the mining industry to begin at the available deposits of highest metallic concentration, and, as these are exhausted, work down gradually to those of lower and lower metallic content.

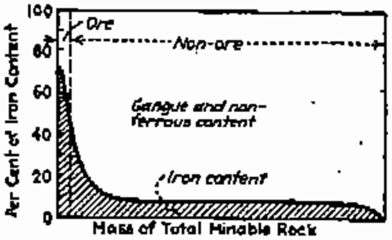


Fig. 1—Graphic representation of the occurrence of the higher concentrations of iron in relation to the volume of total minable rock

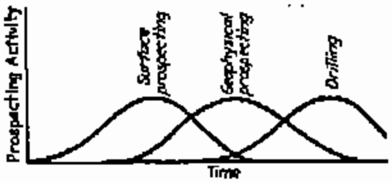


Fig. 2—Sequence of prospecting operations in present-day examination of mineral properties

England, for example, formerly mined iron ore of over 50 per cent iron content, but is now reduced to working 30 per cent ores. In the Lake Superior region, the average grade was formerly 60 per cent. and better, but now is 51 per cent, with reserves of this grade sufficient for only fifteen or twenty years more at the 1929 rate of production.

This mining of lower and lower grades of ore progressively, with the consequent mounting of physical costs of extraction, places a premium upon the discovery of hitherto unknown reserves of higher-grade deposits.

Sequence of Prospecting Methods

In the initial exploration of any large land area for useful minerals a natural sequence of methods is employed, which also depends upon physical costs. The first method is that of reconnaissance exploration, followed later by more detailed study, involving essentially the old-fashioned surface prospecting methods. All of the "easy" discoveries are thus eventually made. In other words, there is a certain time period in which the rate of discovery of minerals increases with increased intensity of surface prospecting. Then the rate of discovery declines in spite of increased intensity of prospecting.

A more refined and systematic form of surface prospecting which usually succeeds the original and more or less haphazard initial form is that of geologic mapping. This may result in a few more discoveries. After that, surface methods are of little further avail. This is borne out in both Western Europe and the United States, the two principal mineral areas of the earth, when one considers that, as Leith has pointed out, there has not been a major mineral discovery, save for oil and potash, in the United States since 1915 or in Europe since 1850.

The decline in the rate of discovery has occurred in the face of the most spectacular growth in the rate of consumption of minerals and a corresponding increase in the intensity of surface prospecting and of geologic mapping the world has ever known. It seems fair to conclude that for these two areas the days of discovery by surface methods are almost over.

Geophysical Work

Most of the possible discoveries in any area having already been made by surface methods, two possibilities remain: (1) other major undiscovered deposits do not exist, or (2) such undiscovered deposits do exist but have not been brought to light by surface methods.

As for the first, if other deposits do not exist, no amount of exploration will yield discoveries. The high-grade deposits will in time be exhausted, and mining operations will fall back upon ores of continuously lower grade, with physical cost of production simultaneously mounting. This process will continue for any given district until the grade of ore becomes so low and the physical cost so high that mining will cease.

As for the second possibility, it is highly probable that in any large area other high-grade ores may exist, but simply are not detectable by surface methods. The problem of discovery remains. Direct methods can be used, involving exploration pits, drill holes, or shafts, and, if enough of such work were done, one could be assured that any hidden ore deposit would be discovered. The restraining factor is physical cost; in this case, the cost per unit discovered. Because of this factor, drilling as a form of prospecting can be indulged in only after data have indicated a high probability of discovery.

Finally, only the last alternative remains: discovery by indirect methods involving a relatively low physical cost per unit discovered. This is the domain of geophysical prospecting. To recapitulate: in any mineral area there is a definite sequence of prospecting methods arranged in the order of their cost per unit discovered. This is: (1) Surface prospecting. (2) Geologic mapping. (3) Geophysical prospecting. (4) Drilling. This sequence is true historically for a region. Since the advent of geophysical prospecting, it is the approximate sequence in the present-day examination of individual properties (Fig. 2).

Inasmuch as geophysical prospecting methods have entered the scene chiefly since 1920, it may be worth while to consider briefly the probable future trends in the design of apparatus and development of technique. The major possible applications of geophysical methods appear to have been already tried sufficiently to indicate that in the future no departure from magnetic, electrical, and seismic fields as the most productive of the domains of geophysical prospecting is likely to occur. Already a pronounced trend is discernible toward limiting apparatus to a few simple kinds having maximum sturdiness and sensitivity, combined with decreasing weight. Apparatus is being evolved toward an automatic instrumental elimination of extraneous factors from the observed data, so that quantities observed are becoming more and more closely related to the unknown sought. At the same time, theory is being improved and computing methods are becoming more simple and graphical.

In reflection work in seismology, reliable reflections are being obtained at progressively greater depths with decreasing quantities of dynamite per shot, until depths of 12,000 ft. are being attained with dynamite charges of the order of 1 lb. per shot.

All of these trends will continue, but the future of apparatus and technique promises to be largely an orderly evolutionary development concerned with the perfection of details rather than abrupt departures of a "mutational" sort, characteristic of the early stages of development in the past decade.

Viewed on any long-time basis, the mineral industries appear to be just now entering what might be termed the "geophysical epoch" of prospecting. By no means is it accidental that surface geological mapping in the oil industry was largely supplanted between 1925 and 1930 by subsurface mapping from well-log data and by geophysical methods. The old surface methods had had their day, and, if more oil were to be found by methods less expensive than by "wildcat" drilling, geophysical methods were the only alternative.

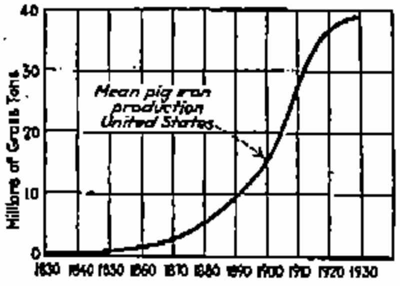


Fig. 3—Curve showing mean production of pig iron in the United States, 1830-1930

Promising Localities

Another question that might well be considered, particularly as regards metallic ores, is that of the geologically probable localities from which discoveries during the "geophysical epoch" of prospecting are most likely to be made. There is always a high probability of other deposits being hidden in the vicinity of known deposits. Many of the future geophysical discoveries will consist essentially therefore in determining the extension of known deposits.

Among the most fertile areas for deposits of metallic minerals thus far known have been the great Pre-Cambrian shields, such as the Canadian and the Baltic. Inasmuch as both of these regions were extensively glaciated during the Pleistocene, large areas are now covered by lakes and glacial drift. That such hidden areas may contain important metallic deposits is highly probable. Recent geophysical discoveries in these areas in both Sweden and in Canada have sustained this supposition.

Besides being covered in parts with glacial drift this same basement complex extends everywhere beneath the younger sediments. In these areas it has remained almost entirely unexplored to date. The geophysical prospecting of the future may quite probably make some of its most important discoveries in such regions, especially where the sedimentary cover is not too thick. The famous Kursk magnetic anomaly in the plains of Russia may be considered a forerunner of future discoveries in such regions.

Mountains and their igneous rocks also afford probable localities for future discovery.

From the foregoing the reader may see that I consider the increasing use of geophysical prospecting methods to be but the natural consequence of the progressive exhaustion of known high-grade mineral deposits in any particular area. Inasmuch as the world is now entering seriously this phase of its evolution, we may confidently expect the immediate future to witness a rapid acceleration in the application of these methods. The proven high-grade reserves of most of the world's minerals will suffice at 1929 rates of production only for some decades, after which they must either be supplemented through new high-grade discoveries or else world production must be derived thereafter from low-grade deposits at great expense. The latter alternative will force the mineral industry to make the widest possible use of geophysical methods.

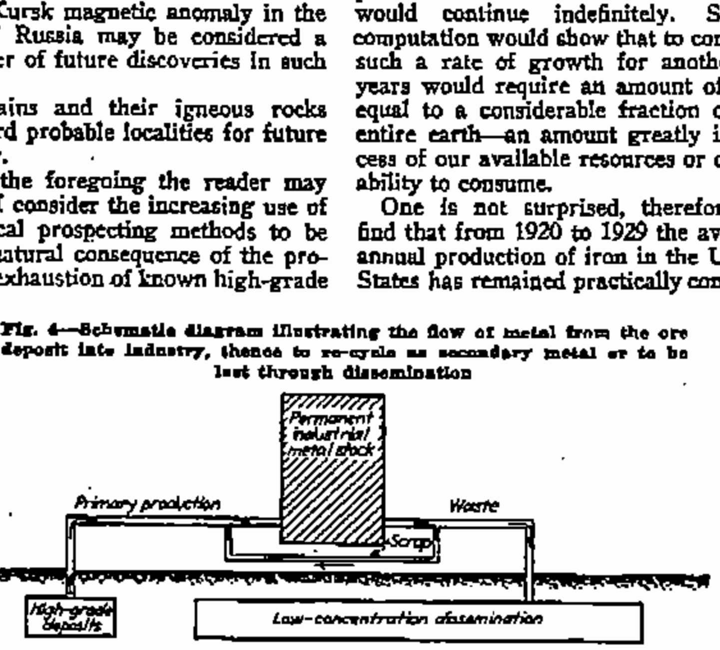
As already pointed out, regardless of how fast or how slow the process may be, the one fundamental trend of all mineral movements is from high-grade deposits to complete scattering in low-concentration dissemination. This is a non-reversible process, so there can be but one ultimate answer: namely, that all high-grade deposits will ultimately be exhausted. As said at the outset, prospecting and discovery constitute the first step in this progression.

During the last 100 years the rate of growth of mineral exploitation has been so spectacular that many have been led to assume that the rate would continue more or less indefinitely. If this were so, the various phases of evolution considered would be much shortened. Certain important restraining influences, which until recently have been comparatively obscured, tend to retard this rate, however, by prolonging the time period of each phase.

From 1870 to 1915 the growth of pig-iron production in the United States was almost a perfect exponential curve at an instantaneous rate of increment of about 5 per cent annum. Most of the operations of the iron and steel industry until recently have been based upon the premise that this rate of increment would continue indefinitely. Simple computation would show that to continue such a rate of growth for another 50 years would require an amount of iron equal to a considerable fraction of the entire earth—an amount greatly in excess of our available resources or of our ability to consume.

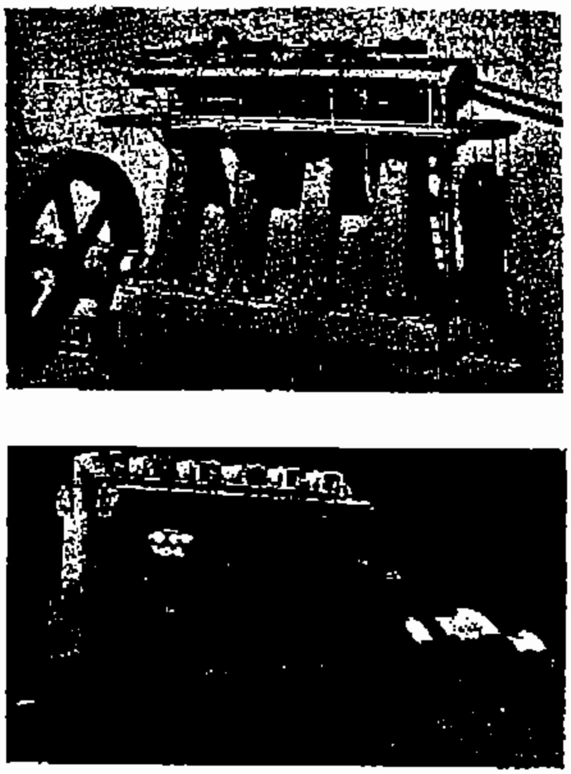
One is not surprised, therefore, to find that from 1920 to 1929 the average annual production of iron in the United States has remained practically constant.

Fig. 4—Schematic diagram illustrating the flow of metal from the ore deposit into industry, thence to re-cycle as secondary metal or to be lost through dissemination



What is thus pointed out with regard to iron is equally true for coal, copper, and most of the other principal mineral resources. After a period of spectacular growth comes a leveling off of production suggesting a saturation of the ability to consume, in cases where the decline cannot be ascribed to the inability to produce.

At the outset, I stated that the mineral flow-line included three essential stages: (1) Mining, or primary production. (2) Industrial use. (3) Wastage. This is exactly analogous to a pipe line into and out of a surge tank (Fig. 4). The primary production corresponds to the input; the stock of metals retained permanently in industrial use represents the fluid stored in the surge tanks; the wastage of minerals after use represents the outflow from the tank. Obviously, the input can be maintained at any given rate only if either the amount in the tank is increasing or the outflow is equal to the input per unit of time.



Less metal per brake horsepower is required in the lower of these two diesel engines than in the one above it. The upper, an old-style unit, develops 500 hp. and weighs 490 lb. per b.hp. The lower, of modern design, develops 450 hp. and weighs only 115 lb. per b.hp.

In the past, the outflow or wastage has been large, and the quantity retained in industrial uses (except in the case of consumables such as fuel) has been continuously increasing. Each of these factors has caused an increased demand upon primary production.

At present, one of the outstanding trends in metals is that of the increasing use of scrap. In the United States in 1929, for instance, primary production of copper was about 1,360,000 short tons, whereas at the same time secondary production was as high as 400,000 short tons, or approximately 30 per cent of the primary. Within the last year secondary production has risen to over 90 per cent of the primary. This trend is also discernible in other metals—iron, zinc, tin, lead, nickel, aluminum, and antimony—and can be expected to become increasingly important in the future. All the secondary metals thus recovered make it unnecessary to draw upon an equal amount of primary metals. This retards primary production by that amount.

The other factor in the flow-line of metals affecting the rate of future primary production, and hence of future discovery, is that of the quantity of metals retained as a permanent circulating stock by industry. In the past, railroads, factories, power systems, and telephone and telegraph systems had to be built, each requiring its quota of metals, mostly primary. Hence the quantity in the surge tank, so to speak, was increasing and the capacity of the tank was large.

Today this is largely over. The one fundamental trend in modern industry is toward speed. Almost every new plant or piece of equipment runs faster than its predecessor. Witness the steam turbine as compared to the Corliss reciprocating engine of the same horsepower rating. In the meantime, the production output of modern industry as a whole is rapidly leveling off and will in all probability continue to do so.

Putting these two things together—a leveling off of industrial production together with an increase in the tempo of industrial processes—one gets a significant result. A physical relationship applies to all physical equipment to the effect that the faster any machine operates with a given output rate, the smaller it needs to be. This is true whether applied to simple individual apparatus, such as power-transmission belts, pipe lines, and individual motors, or to whole factories, to office equipment, or to a whole industrial complex. *Quite generally, for a given productive output rate the faster the apparatus is made to operate, the smaller it will tend to become.*

Granting this, it is entirely possible and not improbable that in North America in the near future the industrial plant may contract to such an extent that the available secondary metals may for some time almost entirely supplant those from primary sources. This will tend to delay the time of exhaustion of known high-grade deposits and will prolong the length of the "epoch of geophysical prospecting."

Foreign Trade

Proposal is not infrequently made that a way of getting rid of present primary minerals be instituted by such practices as raising the Chinese standard of living to that of the United States. If this were seriously attempted it would get rid of the minerals, but not by appreciably raising the level of the Chinese nearly so much as by reducing the level of the American standard. This is true for the simple reason that American resources are not nearly adequate to stand any such form of international philanthropy indulged in for reasons of business expediency.

Another reason why such a course is not likely is that no country can possibly maintain for more than a few years what is known in economics as a "favorable balance of trade." This consists in shipping out more goods than are allowed to be shipped in. A perfect trade balance, following the above logic, would consist in shipping out all and receiving nothing in return!

Both domestically and internationally, auxiliary minerals move to centers of industrial activity—centers of coal and iron. Iron ore moves to coal. Tungsten moves from China to Europe and to North America. Oil moves from Colombia and Venezuela to the United States and to Europe—not automobiles from these latter places to South American oil. This sort of thing, aside from temporary interferences, is likely to continue in the future. If it does, the rate of mineral production in North America is likely to continue to be largely for domestic consumption. This will not so much postpone geophysical prospecting as lengthen the period of time during which it will be found useful.