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THE PRESENT STANDING OF APPLIED GEOLOGY.

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In a strict sense all geology is applied science; it is, indeed, the application of many sciences to the elucidation of the history of the earth. But as a synonym of *economic geology*, or what the Germans call *praktische Geologie*, the term *applied geology* is so obviously convenient to express the application of general geological methods and principles to the study of valuable mineral deposits as to warrant its use with this special meaning.

In Germany, owing doubtless to the long and unbroken association of names illustrious in the annals of geology with the famous mining schools of that country, economic geology has always received notable recognition and its study has flourished in honorable affiliation with the other branches of earth science. In Britain, on the other hand, the great pioneers who in the first half of the last century almost justified the boast that geology was a British science, expounded with such irresistible fascination the principles of stratigraphy, of volcanism and of earth sculpture or erosion, that these branches of the science have continued to be more attractive to most English-speaking geologists than the obscure problems relating to the occurrence of ores. Nor is this very surprising. One who recalls Hugh Miller's descriptions of his excursions in search of ichthyolites along the shore of the Firth of Cromarty, some memorable parts of Geikie's "Ancient Volcanoes of Great Britain," or certain chapters in Gilbert's "Henry Mountains" or in Dutton's "Grand Canyon of the Colorado," can scarcely fail to realize how much stronger in their

instant appeal to the imagination, particularly to the youthful imagination, are studies pursued amidst such attractive surroundings than investigations requiring frequent descent into the gloom and grime of mines and dealing with processes many of which we can never hope to see in operation. Thus it is, that geologists as a class have looked upon the economic branch of their science with rather languid interest or have even regarded it as occupying a somewhat lower plane where the pure light of science is slightly dimmed by the smoke of commercialism. That this attitude on the part of the general geologist is not altogether imaginary is indicated by the fact that papers dealing with economic geology, even when of the highest order of scientific merit, seldom appear in the periodicals devoted to geology, but for want of a more appropriate place, find their most congenial lodgment in the transactions of engineering societies and in the mining journals. To the creation of this anomalous condition, however, other factors have also contributed.

The economic geologist of the present day occupies a domain which cannot be definitely marked off from that of the general geologist on the one hand and that of the mining engineer on the other. His training, methods of work, mode of thought, and aims, are scientific rather than technical. He is primarily a geologist and probably in no branch of geology are knowledge of stratigraphy, petrology, geomorphology, mineralogy, chemistry and physics, as well as the proper use of the imagination and a mastery of the art of lucid expression, so essential to the highest success. But he must also be to some extent an engineer and he cannot ignore the commercial importance of the deposits that are the subjects of his study.

The mutual influence of the mining engineer and the economic geologist upon each other's work and thought has of late years been especially marked. In spite of the charlatans, who have long availed themselves of the cloak of geology and of the glamour of conspicuous mining success to prey upon the credulity, or cupidity of those who seek large returns with small outlay, there can be no question that the aid of geology in large mining enterprises is being more and more appreciated by those who are

quite able to distinguish the assurance and verbiage of the pseudo-scientist from the painstaking effort and moderate statements of the conscientious scientific worker. That this recognition is largely due to the character of the investigations carried out by our federal and state geological surveys is certain, and the work of the government surveys in particular has won for economic geology in this country an importance that seems to fully justify the establishment of a journal devoted exclusively to this branch of geological science.

From the practical standpoint, the installation of a modern mining plant, which may mean an initial outlay of more than a million of dollars, is warranted only when corresponding efforts have been made to ascertain the extent, structural relations and genesis of the ore body that it is proposed to exploit. The construction of railways and pipe-lines, the erection of mills and smelters, and the other costly preliminaries to the successful working of large low-grade deposits, require a more scientific calculation of probabilities than is necessary for the extraction of a superficial pocket of rich ore with bucket and windlass. While too, in many cases, a good mine captain, through his long experience in just such kind of work and his thorough familiarity with the ground, may surpass the geologist in the facility with which he follows the visible clues leading to individual ore shoots, yet it is becoming increasingly apparent to those in charge of extensive mining operations that to disregard geological conditions is to invite loss through misdirection of effort if not to court failure. Accordingly some of the larger mining companies and at least one of our railway companies now retain in their permanent employ geologists of recognized ability and international repute, apparently without any misgivings lest in so doing they should be maintaining an expensive scientific luxury. It is worth noting, moreover, in illustration of this trend of opinion, that a prominent engineer in a recently published paper urges strongly the advantages of this policy and his recommendation is made the text of an appreciative editorial in an issue of one of the mining journals received while this was being written. Intelligent mining men no longer believe that

the geologist lays claim to miraculous prescience, or that his work involves anything more than the concentration of special training, wide experience and common sense, directed by a well-ordered imagination upon the problems in hand. The importance of this indispensable directing faculty, however, one of the axiomatic truths of science, has come so slowly into popular recognition and the faculty itself has been so often misunderstood that one may perhaps be pardoned for recalling in this connection a passage that can never be too widely known. "The truth indeed is," wrote Playfair over a hundred years ago, "that in physical inquiries the work of theory and observation must go hand in hand and ought to be carried on at the same time, more especially if the matter is very complicated, for there the clue of theory is necessary to direct the observer. Though a man may begin to observe without any hypothesis he cannot continue long without seeing some general conclusion arise; and to this nascent theory it is his business to attend, because by seeking either to verify or to disprove it, he is led to new experiments or new observations. He is conducted to the places where the transitions of nature are most perceptible, and where the absence of former, or the presence of new circumstances, precludes the action of imaginary causes. By this correction of his first opinion, a new approximation is made to the truth; and by the repetition of the same process, certainty is finally attained. Thus theory and observation mutually assist one another; and the spirit of system, against which there are so many and such just complaints, appears, nevertheless, as the animating principle of inductive investigation. The business of sound philosophy is not to extinguish this spirit, but to restrain and direct its efforts."

With the growth of the appreciation of geological methods in connection with mining, the field of the mining engineer has broadened and he has developed a keen interest in geological problems. Not only is this interest bearing fruit in actual contributions to science by busy engineers but it has reacted noticeably upon economic geologists, who to an increasing degree find that, outside of their own ranks, their work appeals more to the members of the mining engineering profession than to their

brother geologists who have no desire to exchange the genial sunlight for the miner's candle.

That this relation contains elements of danger to the scientific investigator is obvious. In conjunction with the material rewards now within reach of mining geologists it tends to convert him into the geological engineer. In general such a change is to be regretted, not because one line of work is necessarily better or worse than the other, but because the best interests of all require that both fields be adequately filled, that mining engineers and economic geologists should continue in close sympathy and mutual helpfulness, but without obliteration of the shadowy boundary that still separates the men who are primarily investigators of natural phenomena from the men who are primarily concerned with the most effective methods of forcing the rocks to give up their treasures. To the maintenance of such a beneficial distinction it is believed that the new journal in which this brief article appears will materially contribute. It provides a place where the results of investigations of scientific character, recorded in the concise and accurate phraseology of science and addressed to readers who need no concessions to their knowledge or intelligence, may appropriately be assembled, and where questions of interpretation or theory may be freely discussed. If this ideal is steadfastly adhered to, there can be little doubt that the journal will not only be a potent means of maintaining the dignity and influence of one of the most important branches of geology but will be of the greatest ultimate service both to mining engineers and to general geologists.

Economic geology is preëminently an appropriate field for government activity. The cost of comprehensive studies of mining districts and of the proper presentation of the results is such that, if left to private enterprise, the investigations would necessarily be sporadic, unsystematic, and incomplete. The results of thorough economic studies, moreover, are of recognized value to the community and that value must always largely depend upon a well-founded confidence in the integrity, impartiality and ability of the members of the scientific corps having the work in charge. The American people, particularly in the

mining regions, and in the great arid tracts of the west where geology is being applied with such signal success to the problems of irrigation, have recognized these facts and have thereby advanced the science of geology as well as their own interests. But from the standpoint of applied geology, another step seems now desirable. That the publications of the United States Geological Survey will continue to record a preponderance of the investigations in economic geology carried out in this country is perhaps to be desired and is certainly to be expected. But that the official work of a single government bureau, however large and influential, should represent, so nearly to the point of exclusion, the activity of an important branch of science is best neither for the bureau nor for science. To some extent the various state surveys tend to prevent stagnation of the intellectual circulation, but the most efficient medium for the wide and free exchange of ideas is undoubtedly a thoroughly representative and vigorous journal.

It is impossible to review in an article of this brevity the practical achievements of applied geology in the last few years. They are most of them familiar to well-informed mining men and have received such substantial recognition that the economic geologist can regard with equanimity the occasional disparagement of his work, which springs in some cases from misunderstanding of his methods; in other cases from the disposition to magnify the importance of failures that, in a subject of such inherent difficulty, are inevitable, though surely not so frequent as they are in practical mining; and in still other cases from the rough-and-ready scheme of classification that in a double sense confounds the man of attainment and the impostor.

On the theoretical side, economic geology, particularly the study of ore deposits, has made notable progress, not so much in the way of new suggestions as in the firm establishment and definite enunciation of principles of which it is not difficult to find here and there a vague hint in earlier literature. As Mr. S. F. Emmons has well said with reference to the state of knowledge of ore deposits in the last quarter of the nineteenth century, "So fertile had been the imagination of previous thinkers on this subject that at this time it was practically impossible to

conceive a theory of origin for a given ore deposit that had not already been proposed, or at least suggested."

Probably the most important advance made in recent years in the theory of ore deposits was the independent recognition by S. F. Emmons, C. R. Van Hise and W. H. Weed, of the co-operation of more than one period of deposition in the formation of most masses of rich sulphide ores, and the clear presentation by these workers of what is now commonly known as the principle of secondary sulphide-enrichment.

The practical importance of this process was very quickly appreciated, particularly in relation to copper ores, and at the present day no valuation of a copper deposit containing cupriferous sulphides can be considered satisfactory unless the possible operation and probable results of such secondary processes are carefully weighed. To a less conspicuous extent, the same statement holds true of deposits carrying other metals. Incidentally, by focussing attention upon the vertical range of ore masses, the theory of secondary enrichment has aided in displacing the cheerful, optimistic, and popular doctrine that ore bodies in general continue to increase in size and richness to limitless depth, by the more rational view that every ore deposit has its lower limit, and that this limit should, if possible, be approximately determined before it is reached in actual mining.

That the process of secondary enrichment should be appealed to in many cases where there is little evidence to support it, is the natural tribute levied upon a novel theory that has just been clearly and attractively formulated. When, for example, it is maintained that below the rich ore shoots of the Cripple Creek district there will be found a deep secondarily enriched zone, it is certain that hope, rather than reason, dictates the prediction.

The common association of ore deposits with igneous rocks seems to have been first noted by von Humboldt, but the exact significance of this relation has long been a moot question. In this country, the pioneers in monographic economic work developed a modified lateral-secretion-ascension theory of ores derived from solidified rocks by circulating meteoric water, in most cases stimulated to greater activity by the heat of intruded

igneous masses. Even in the case of the Comstock lode, notwithstanding the evidence of former intense volcanicity that is so patent over this entire region and the presence of Steamboat Spring (whose flow of hot water is known to have decreased in the last twenty years) only six miles away, the only hypothesis suggested by Becker in explanation of the copious thermal waters, and probably the only one that would have occurred to most geologists at that time, was that they were meteoric and were derived by artesian flow from the Sierra Nevada.

For twenty years, the belief, either tacit or expressed, of the all-sufficiency of meteoric water to form nearly all ore deposits held full sway in this country and may be said to have reached its culminating expression in the notable paper by Van Hise on the principles controlling the deposition of ore. In Europe, however, Vogt, Beck, and other workers, were developing somewhat different views and in our own country, Kemp, Spurr, Lindgren, and Weed presented strong arguments for a return to views long singularly neglected and which, apart from the conception of a liquid interior of the earth prevalent in his time, are substantially those enunciated by Elie de Beaumont in his paper "*Sur les émanations volcaniques et métallifères*," published in 1847. De Beaumont held that most of the metalliferous ores were deposited from solutions that had been given off originally in a gaseous condition from cooling or solidifying magma.

Ores can undoubtedly be deposited under certain conditions by either meteoric or magmatic water and probably in many instances both have coöperated to effect the exceptional concentration of rare or generally dispersed constituents which we call an ore body. The range of action of these two agencies remains to be determined and constitutes a very difficult problem. The efficacy of magmatic water has clearly been exaggerated in certain specific cases and it is not improbable that the reaction from the meteoric hypothesis may gather such momentum as to overshoot the truth. But the movement itself, by breaking up a crust that we were in some danger of mistaking for solid ground, and by opening new avenues of thought and suggesting new problems for solution, is a step in general progress. How some

of these problems may be attacked has been well shown by Lindgren in his papers on "Metasomatic processes in fissure-veins" and on "The character and genesis of certain contact-deposits."

It is impossible for one to review the later chemical and physical contributions to economic geology without being impressed with the extent of the field for experimental research and with the little that has been accomplished in connection with the formation and alteration of ore bodies. Kohler has shown experimentally that the property possessed by porous materials, such as clay, or by colloidal substances, of precipitating certain constituents from solution, the process of adsorption, may be an important factor in ore deposition; H. V. Winchell has succeeded in demonstrating in the laboratory the formation of chalcocite by the action of dilute, acidified, cupriferous solutions upon pyrite at ordinary temperature and pressure; H. N. Stokes has obtained important but unpublished results along similar lines; but these, and the few other researches that might be mentioned, serve but to accentuate the need for further work. The possible osmotic action of wall-rocks upon ore-bearing solutions, the chemical character of these solutions, the manner in which telluride ores are concentrated and deposited, and pneumatolytic action, are all subjects whose experimental investigation presents more or less formidable difficulties, it is true, but which might be pursued with some hope of success in governmental or suitably endowed laboratories. Even the processes of oxidation in sulphide ores are very imperfectly understood although these take place under ordinary conditions of temperature and pressure. The common mineral chrysocolla, for example, seems never to have been artificially produced and we have no clear conception of the natural conditions under which it forms.

In conclusion, it may be pointed out to those considering the following of some branch of geology as a life work, that economic geology, while at first glance less attractive than the other lines of geological study, has some decided advantages. If work underground and the often sordid surroundings of a mining town are less congenial to a lover of natural beauty than the

quiet pursuit of knowledge among the hills, if the murky atmosphere of a stope is but a poor exchange for

"the glory of the sun,
And streams that murmur as they run,"

it may yet be remembered that contrasts give zest to our enjoyment and that the work of applied geology is by no means all underground. The most successful economic geologist is likely to be he who retains his interest in the broad aspects of the science and who sees to it that his capacity for general geological field study does not rust for want of use. For the investigation of most ore deposits a thorough knowledge of the local geology is indispensable and of this knowledge a considerable part at least should be gained at first hand. If the necessity of entering mines often involves vexing delays and loss of time, it brings the geologist into contact with men of many types and teaches him that a knowledge of human nature may in some cases be quite as useful an instrument of investigation as petrography. The problems connected with economic geology are many and varied and their solution calls for scientific ability of as high an order as is demanded in any other branch of earth study. If the fact that proficiency in economic work is coming to have a high market value be regarded as inimical to the spirit of science, the danger is one that most men can face, if not with confidence, at least with serenity.