THE SCOPE OF APPLIED GEOLOGY, AND ITS PLACE IN THE TECHNICAL SCHOOL.

DOUGLAS WILSON JOHNSON.

An attempt to classify scientific work and workers may be a hazardous undertaking. At the same time, it is occasionally necessary, for the sake of clearness, to make such an attempt. In order to present certain considerations relating to applied geology, it seems best to recognize three phases of scientific work, with corresponding groups of scientific investigators, students and schools. The broad classification thus suggested appears to follow lines that are natural and easily recognized, although individual cases may present special difficulties.

Scientific research may be pursued primarily for the discovery of Nature's truths and a knowledge of the workings of her laws. There may be no attempt to obtain knowledge that will have a market value, and when finally attained the results of such research may be wholly worthless from the commercial point of view. To say that they have no *practical* value is not just, for they may possess a very high educational value, and the extension of our educational resources is a consideration of the greatest practical importance. A study of the successive stages in the development of a group of fossil shells, together with the bearing of that development on the theory of evolution, is an example of that phase of scientific research which is generally carried on without regard to the cash selling price of the knowledge obtained.

On the other hand, research may be conducted in a thoroughly scientific manner, for the solution of a definite problem presented by commercial interests, with the primary object of making great financial gains. The investigator would not spend a moment on the work did it not promise to have a certain market value. The stimulus to prolonged and patient labor, as well as the initial cause of the investigation, must be considered as financial in

character. As an example of this class of scientific research we may cite the attempts to solve the problem of economically treating titaniferous magnetite, in the hope of making the great deposits of this ore of iron available, and of securing valuable monetary returns.

Intermediate between these two classes of scientific work is that class of study carried on with a certain regard to the commercial value of the results to be obtained, but not for commercial reasons primarily; and with an enthusiastic interest in the work for its own sake, but with the requirement that the branch of work selected must have something more than a merely educative value. It is apparent that such a class of work occupies the middle ground between the purely philosophical researches on the one side, and the purely commercial investigations on the other.

Associated with these three phases of scientific work we find three groups of investigators, both students and teachers, and three classes of schools. It is one function of our large universities to encourage the best in philosophical and educational work, and to this end they maintain schools of pure science. Research along lines that promise no financial reward is provided for by endowment. Here we find most of the teachers who have an enthusiastic interest in original investigations conducted without regard to the monetary value of the results to be obtained, and here come those students who have determined to devote their lives to the study of nature's laws, even at a great financial sacrifice.

The university is not a money-making institution, however, and we should not expect to find it actively engaged in furthering investigations for the main purpose of selling the results for a large cash consideration. Accordingly we must look elsewhere for the teachers and students engaged in scientific investigations which are stimulated by commercial needs and the promises of financial gain. From the nature of the case much of this class of work is done independently by individual workers, rather than by organized schools. Large commercial enterprises sometimes justify the maintenance of research laboratories, where special

problems of immediate importance to their success are worked out by skilful investigators, and where younger assistants may get valuable training. At other times these enterprises profit by securing the services of outside workers for a limited time or for a special problem; and such workers are often teachers in the universities or technical schools, who devote the most of their time to one of the other two classes of investigation here considered.

The intermediate phase of scientific work, neither purely philosophical nor purely commercial, occupies a most important place in our educational institutions. It is not alone the function of the university to provide for philosophical and educational advancement,—it must also provide training for those men who are to take the lead in commercial enterprises. Such a training, to be most efficient, must prepare the student to take the results of the more philosophical investigations and apply them to the practical problems of every-day life. So it is that our large universities maintain technical schools, or schools of applied science, as well as schools of pure science. The same field is occupied by our various independent technical schools. In these schools we find a class of teachers who are interested in their several lines of scientific work for something more than financial reward,—else they would be occupying better paying positions in commercial concerns. Yet they must be keenly interested in the practical commercial applications of their work, for that is the side of the work which they are called upon to emphasize. To these schools come those students who look forward to a life of professional business activity, and who desire to provide themselves with the best possible equipment with which to meet the keen competition of the commercial world, hoping thereby to be successful in financial enterprises. This whole question of the application of scientific principles to the solution of practical problems is one of engrossing interest, and of paramount importance to the technical school. Certain phases of this question, especially those involving the application of geological principles, are here presented.

The term *applied science* may be so interpreted as to cover a

very wide field. As here used, the term refers to the application of the principles of the pure sciences, such as psychology, biology, geology, physics, mathematics, etc., to the more practical problems encountered in engineering and other professions. The psychologist may spend years in investigating mental processes and discovering the reactions that normally take place in response to certain stimuli, without ever making use of the results obtained to determine the sanity or insanity of a person, to follow the workings of the criminal mind, or to locate an area of the brain that is suffering from some pathological condition. This is pure science. But when the psychologist himself, or the expert in the treatment of mental diseases, or the criminologist, takes advantage of the results obtained by the researches of the psychologist to solve some such practical problem as those indicated, we have to deal with applied science. The neurologist may spend a lifetime in studying the paths of certain nerves in the body of the fish, he being a teacher and investigator in pure science alone. The physician who profits by the discoveries of the neurologist to treat successfully certain nervous affections which before baffled every effort of the medical profession, is studying and practising applied science. The palæontologist studies, classifies and describes the various forms of fossil shells, and is properly regarded as an investigator in pure science. But when he or any other employs the knowledge thus acquired to locate beds of ore, rock valuable for economic purposes, or artesian water bearing horizons, a practical application of pure scientific knowledge has been made, and the work belongs in the realm of applied science.

The teacher of applied science occupies a unique position. He stands between the realm of pure philosophy and pure commercialism, and must have a good measure of familiarity with both. He must be in close touch with every advance in his special branch of pure science, and with modern methods of investigation. To do this successfully, he must himself be an original investigator, actively engaged in promoting the advance of knowledge in his particular field. Only thus can he hope to come into that vital touch with other workers along the same line that will enable him to fully appreciate all that they are attempt-

ing and accomplishing, and to judge intelligently the results of their labors. He cannot, however, shut himself up in the realm of pure science, for he must keep in close contact with those departments of the commercial world which find his branch of science of special value in the solution of practical problems. It is essential that he appreciate the needs of commercial enterprises, for only thus can he know where and how to apply his scientific knowledge for the accomplishment of the most good. He must know the problems of the commercial world, the possible solutions discovered by the scientific world, and be able to apply the latter to the former.

In referring to the broader aspects of this problem, "applied science" has been defined as the application of scientific methods and principles to the study of practical problems. If this definition be essentially correct, then "applied geology" is the application of geological methods and principles to the study of such problems. These problems are encountered for the most part by those engaged in engineering work, more especially the mining engineers, civil and sanitary engineers, topographers, and others whose duties involve a study of the earth's surface or extensive operations carried on below that surface.

In a recent number of this journal,¹ Mr. F. L. Ransome, in a most interesting article on "The Present Standing of Applied Geology," makes "applied geology" a synonym for "economic geology," and suggests very narrow limits for the term, in the following words: ". . . 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."

It would seem, however, that if applied science means more than the application of scientific principles to the study of valuable mineral deposits, then applied geology should include much more than the application of geological principles to the study of such deposits. So long as geological principles are applied,

¹ ECONOMIC GEOLOGY, Vol. I., No. 1, pp. 1-10.

we have to do with applied geology, whether that application be made to the excavation of a tunnel for a railway, the development of a body of iron ore, or the location of artesian water supplies.

One very important branch of the United States Geological Survey is engaged in applying geological methods and principles to the development of artesian and other supplies of water. Large railroad corporations retain the services of geologists for other purposes than the investigation of the mineral resources along their lines. Engineering companies engaged in the construction of subways for trolley lines, canals, dams, reservoirs, etc., have their consulting geologists. The dredging of ship channels in rivers and harbors and the keeping of those channels open, the construction of levees to prevent the flooding of great rivers, the building of jetties to direct and control the flow of rivers, all demand some knowledge of geological forces and the laws according to which they operate. Our engineering schools recognize these facts, and provide instruction in the application of geological methods and principles to engineering problems other than those which involve the study of mineral deposits. In some cases this instruction is given in connection with courses in general or structural geology, in others special courses in applied geology are offered. At the Massachusetts Institute of Technology there has been given to civil engineering students, for some years, a course entitled "Applied Geology." The bearing of geology upon the success of civil engineering operations is emphasized but with little or no reference to mineral deposits.

It is true, however, that the application of geological principles and methods to the study and development of mineral deposits constitutes one of the most important departments of applied geology. Probably the majority would consider it by far the most important of all, and it is not surprising therefore to find text-books entitled "Applied Geology" which actually deal with only this one branch of the subject. For example, we have Burat's "*Géologie Appliquée*," the more expanded title of which shows it to be simply a "*Traité du Gisement et de l'Exploitation des Minéraux Utiles*," with a few preliminary chapters on cer-

tain more general geological considerations. On the other hand, we have an American text ("Applied Geology," by S. G. Williams) which regards applied geology as "the applications of geology to the various uses of mankind," and which therefore discusses the relations of geology to railroad and other tunnels, foundations of engineering and architectural structures, dams, reservoirs, canals, springs, wells, drainage for agricultural and other purposes, sanitation, agriculture, etc., while the various economic minerals are treated at considerable length. An English text on "Practical Geology" (D. T. Ansted), a term used by most writers as a synonym of "applied geology," outlines the limits of the subject in the following words: "I understand by the expression 'practical application of science,' an account of the different methods by which the various facts of the science, as discovered by actual observation, and the general laws which have been deduced from a careful study of the true value and analogies of those facts, may be shown to bear upon the pursuits of practical men, assisting them in coming to right and useful conclusions in their ordinary business. I hope to be able to show that the facts of geology already recorded, and the general conclusions arrived at, may be thus made use of in the ordinary affairs of life, and applied immediately to practical purposes." This author considers that "the application of geology to mining must ever be the first, and the most deeply interesting of all branches of practical geology." He then devotes some nine chapters, including nearly two hundred pages, to various phases of mining geology. "But mining, in all its branches," we read, "is only one department of practical geology." So there follow some half a dozen chapters, including nearly a hundred pages, devoted to a discussion of the uses to be made of geology in road and canal making, the construction of harbors, breakwaters, quays and bridges, the location of railways and of building sites, the draining of lands, the driving of wells, and in coming to a proper understanding of the decomposition of building stones, the formation and mixture of soils, the behavior of springs and wells, etc. The German interpretation of "Praktische Geologie" is not always the same, Keilhack's "Lehrbuch

der Praktischen Geologie" dealing rather with the making of maps, the preparation of rocks and minerals for study and the methods of investigating their characters, the study of fossils, etc., than with mining geology.

The exact interpretation of such a general title as "Applied Geology" is not a matter of prime importance, however, and enough has been said to show how different such interpretations may be. It might be said, in partial explanation of the more limited usage of the term, that the time was when mining geology was the only "*praktische Geologie*," and the terms were more truly synonymous than to-day. As a result of the great growth of the science, many practical applications of geology are made to-day that were not dreamed of when the term *praktische Geologie* first came into use. It is also true that a writer often applies the general term to the more specialized work, without any intention of restricting it to that phase of the work alone.

It is believed, then, that the scope of applied geology most properly includes all applications of geology to practical problems. If this be true, then the subject must occupy an important place in every thoroughly equipped technical or engineering school. The students in mining engineering are not prepared to enter on their work until they have acquired a knowledge of the fundamental principles of general geology, and more especially a knowledge of the minerals and rocks with which they will have to deal, the structural features of the earth's crust and their relations to valuable deposits that may be involved in those structures, the geological relations and possible origin of the more important deposits in the country, together with some conception of the present state of our knowledge concerning the origin and classification of mineral deposits in general. They should, if possible, be given some practice in geological mapping, to the end that they may be able to plot the surface geology of a mining region and from that gain some idea regarding the underground structure in which the deposits are involved.

It is not the purpose of a course in mining engineering to fit a student to take up, immediately upon graduation, the duties and responsibilities of a full-fledged mining engineer. Practi-

cal experience in mining regions is a part of the training that must come after the years spent in a technical school. The object of the engineering education is to give the student a broader, and in some respects a more exacting training than he is likely to get in his practical experience in some one locality for years to come; to give him an extensive view over the whole field of his chosen work, such as he would otherwise get only after many years of experience; to open his eyes to the possibility of bringing to the solution of problems he may encounter many factors of which he must otherwise remain largely in ignorance; thus to fit him to meet successfully the emergencies that may arise in his professional duties with an intelligent, accurate, creative mind. Experience has shown that a knowledge of geology has often proven necessary to the proper solution of mining problems. Indeed, every mining proposition is a geological problem, be it simple or complicated. Hence a thorough training in geology is essential, if the engineer is to bring to his aid in solving mining questions, the factor that often affords the greatest help.

A recent editorial in the *Engineering and Mining Journal* calls attention to the great need of keeping careful and intelligent records of the geological features exposed in the course of underground workings, especially as those workings may later be abandoned, and become inaccessible through caving, or for some other reason. As is there pointed out, only the largest mining companies can afford to maintain a special geological department, and many cannot even retain the services of a geologist. Nevertheless the records should be kept as well as is possible, as "the results would be of more or less value according to the competence and fidelity of the observer." A geological training should be such as to enable the engineer to appreciate the great importance of the matter in question, and also enable him to keep such records intelligently, and work out from the evidence thus accumulated many points of value to his employers. That this is not asking too much of the young engineer, is indicated by the important results already achieved by recent graduates in certain cases.

The civil engineer must be prepared to meet many problems involving geological factors, and must therefore be equipped with an adequate geological training. As a foundation a general course in the fundamental principles of geology seems essential. Familiarity with the different rock species, and a knowledge of their relative values as building material, road metal, etc., will save the engineer from many costly errors. The effect of rock characters and rock structures on tunnelling, the need of lining tunnels which penetrate certain rocks which at first appear massive and strong, the danger of caving where shearing planes dip toward the excavation, the possibility of continued slipping of morainal deposits along a railroad cut in such material, the probable changes that may be expected in a river meandering in its floodplain, the possibility of locating water-bearing beds, building stones and cement rock even when they do not appear at the surface, the conditions essential for the accumulation of artesian waters and the methods of forecasting the probable behavior of wells to be drilled,—these and many other subjects afford abundant material which may be brought to the attention of the civil engineering student with profit. The topographer needs systematic training in the relations of geology to the varied topographic features of the earth's surface. He is called upon to represent the earth's surface not by an actual copy, but rather by an abstract of its features. No contour map is made by determining the position of every contour with accuracy; on the contrary, a limited number of points are so determined, while the topographer must sketch in the remaining areas. The scale does not admit of copying all features, and the topographer who is to make a map which will show the significant features with expressiveness, must have an understanding of the subject with which he is working. It is not good policy to have an important work on astronomy reviewed by a person who knows nothing of the science of astronomy. Having no appreciation of the subject with which he is asked to deal, he can hardly hope to present an accurate and properly proportioned abstract. Neither can the topographer achieve the best results so long as he has no knowledge of the land forms which he is required to reproduce in a map abstract.

The sanitary engineer finds that he must have certain kinds of soil for various processes of sewage disposal and water purification. Where the loose sands of glacial deltas, outwash plains, or other deposits of like composition, are available certain of these processes may prove practicable, but where only beds of compact clay or till are found, the cost would be prohibitive. The draining of swamps that prove a menace to public health may sometimes be accomplished by boring through to underlying beds of loose sand or gravel, from which the waters find a ready outlet. The direction in dip of the rock structures may determine the liability of cess-pools to contaminate sources of drinking water at considerable distances. The direction of flow of underground waters may cause or prevent such contamination. Such are a few of the considerations that appeal to the interest of the sanitary engineer.

The many applications of geology to these and other branches of engineering cannot be enumerated here, the points above mentioned merely serving to indicate in a general way the extensive scope of the subject. The methods of presenting these practical considerations to the students must vary with every school and every instructor. It will probably be agreed by most of those engaged in teaching applied geology that the geological training given to the engineering student must be far more fundamental and thorough than would be afforded by a brief course relating the details of certain instances of the application of geology to engineering problems. It is necessary that the student be grounded in the general principles of dynamical and structural geology especially, if he is to appreciate the significance of geological phenomena when he encounters them, and be able to reason intelligently and correctly concerning them. The instructor cannot hope that the members of his class will always have to deal with the same problems which he may present to them in the lecture room. Perhaps they may never meet just the same set of conditions which he describes as occurring in concrete cases. The important thing is to open the eyes of the men to the fact that in the past a knowledge of geology has made possible the solution of many difficult engineering problems, that the lack of

such knowledge has often caused disaster and failure, that in the future this history will certainly repeat itself, and that if they are to meet such emergencies properly they must provide themselves with the necessary equipment.

Nothing appeals so strongly to the practical man as a specific case to illustrate a given proposition. The value of concrete instances in illustrating the application of geology to engineering problems can hardly be over-estimated. The student may forget an abstract geological principle before he has left the lecture room; but he will remember an actual case, illustrating the application of that principle, for years. It seems to me that a most important part of the work in teaching applied geology is the securing of details regarding actual cases in which geology has been used to such advantage by practical men. Many such cases can be found by looking over the literature, but another source of wealth is to be found in the cases which come to the knowledge of geologists and engineers, but which have never found their way into print. One cannot help wishing that these edifying experiences might be made available for the benefit of the younger and less experienced men, by publication of the valuable technical details, stripped of the personal features which might otherwise make the publicity distasteful to some of those concerned. Many are the valuable object lessons that would thus be presented to the younger engineers and geologists.

Shall the courses in applied geology be given as distinct courses after the student has acquired a knowledge of the principles of dynamical and structural geology, or shall the two phases of the work be presented simultaneously? In some cases it has seemed best to present the more theoretical aspects of the subject together with the fundamental principles as established by careful investigation, as separate and systematic courses in dynamical and structural geology, embodying in a later course the application of these principles to practical problems. The alternative is to give the applied geology with the pure geology, by showing the possible application as soon as each principle is fairly established. It seems to me that the latter method has the great advantage of arousing and holding the interest of the engineering student, by

showing him the practical value of the knowledge he is acquiring, and of fixing firmly in his mind the general principle by means of the more readily remembered illustration. For example, if the general discussion of folded strata, including the different types of monoclinal, anticlinal and synclinal folds and their general effects upon the rocks affected, be followed by a consideration of the effects of such folds upon engineering enterprises, the student finds the subject of more vital interest to him than would be the general discussion alone. The mining engineer sees the practical value of the subject when he learns the effects of anticlines on the accumulation of oil and gas, the manner in which synclinal troughs serve to collect deposits of metallic ores, the manner in which saddle reefs and inverted saddles are formed, and the importance of such folding in developing fissures along the crests of anticlines and in the troughs of synclines. The detailed discussion of the various mining regions may come later in a course in economic geology, but some reference to the effects of folding on mining problems seems to prove helpful at this point. The fact that pitching troughs and anticlines may prove deceptive is then pointed out, the nature of their outcrops explained, and the effects on exploration and development work discussed. If this be followed by an account of some special case, as where two engineering students working on their thesis succeeded in demonstrating the presence of a pitching fold where none was suspected before, a discovery which eventually led to the opening up of valuable ore bodies, then the student is more ready to appreciate the value of the subject of folds than he would ever be if only the abstract discussion were presented at that time, leaving the practical application till a later course.

So also in the case of the civil engineer. If he is told that the folding of brittle sandstone in a low syncline is apt to break or fissure the rock so that it becomes like an arch inverted and with the "keystone" hanging downward, he may forget it. But when the case of a Pennsylvania tunnel driven into a hill composed of sandstone in this condition, which resulted in the removal of the support from under the keystone and the consequent caving in of extensive masses of the rock, is brought to his atten-

tion, the feature of folding referred to will not soon escape his memory. He might forget a statement that shales which appear solid and massive when first exposed to the air tend to crack and crumble later on. But he will not forget that a certain tunnel driven in such shales, and not lined because the rock appeared so solid and massive when penetrated, collapsed and caused disaster when the shales dried and crumbled.

The value of the general principle itself must not be overlooked in emphasizing the concrete illustration. The principle has a value independent of any application. But to that class of men who come to seek the practical applications of geology more especially, such illustrations serve a most important end in fixing the principal points in mind, in arousing a healthy interest in the work, and in awakening the student to the possibilities of practical utility offered by an intelligent application of the principles of the science.