Research Needed *in* Engineering Geology

THE
COLORADO SCIENTIFIC
SOCIETY

1951

PRICE 25c PER COPY

Colorado Scientific Society
214 New Customs House
Denver 2, Colorado

RESEARCH NEEDED IN ENGINEERING GEOLOGY

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Presidential Address
Delivered Before the Colorado Scientific Society
December 18, 1950

There is a very real difference between the Colorado Scientific Society as it was in 1930, when I first became associated with it, and the Society today. In summary, it is somewhat larger and far stronger now than it was 20 years ago. Ever since it was formed in 1882, the Society has varied in strength almost directly with the activities of the U. S. Geological Survey in Colorado. During the late twenties and thirties, it existed primarily as a medium for publication of preliminary reports that resulted from the cooperative ore deposits program between the Survey, the Colorado Geological Survey Board, and the Colorado Metal Mining Fund. Meetings were held intermittently—usually only when one of the few Survey geologists in Denver or Golden could be persuaded by Scotty Henderson to give a report on his season's field work.

Today the Geological Survey has around 100 geologists stationed in Denver, plus more than 400 other employees—mostly chemists, hydrologists, topographers, and physicists. Society membership was about 100 in 1930, but it dipped far below that in the late thirties and we became almost extinct during World War II. Now, since the revival that was initiated by A. H. Koschmann, membership has already risen to 140. More important, we now hold regular meetings, with attendance several times that of a few years ago. And we are still adding to the permanent fund of scientific knowledge through our publications, though not, perhaps, as actively as we should.

Moreover, we are gradually broadening the base of our interests and the character of our membership. It is for the Society as a whole, rather than for me, to say whether we can or should continue to be primarily a geologic organization or whether we should continue to depend on the U. S. Geological Survey for much of our membership. Whether we do or not, it is my own firm conviction that our present

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trend toward breadth of interest is a healthy one. The days of the old-time naturalist, when one man could possess a smattering of many sciences and even be master of several, are long gone. Nowadays, all of us must specialize, in greater or less degree. At the same time, however, there has never been a period in history when there was a greater realization of the interdependence of the separate sciences. No compartment of science can grow strong by feeding on its own flesh alone. Neither can any individual scientist grow evenly and healthily within the near-vacuum confines of a too-narrow specialty. I refer not only to the physical sciences. Everything we do within our science specialty or outside of it is done in a human as well as a physical environment. Everything we do, then, both affects and is affected by other humans. It follows that some contact with the social sciences is as necessary to our growth as contact with our own or related physical sciences.

The first tendency of most societies today, however broad their announced objectives, is to split into specialistic compartments. I should like to see the Colorado Scientific Society reverse this trend, or at least remain as a small bastion of resistance, for I firmly believe that only by increase in breadth of interest can we, as a Society or as individuals, continue to grow in vision, in stature, and in usefulness.

Let's get on with our subject—an examination of the need for research in engineering geology. Here, too, we will find that the interrelations of several sciences and professions are all-important, and that breadth of interest is paramount.

By putting the usual definitions of "science," "research," "engineering," and "geology" together and eliminating the overlapping terms, we find that our subject is really "the need for collection, arrangement, and interpretation of new facts about rocks and soils that can be put to practical use by man in building or in developing power." Engineering geology thus becomes not a special branch of geology at all; it is simply the art or profession or special skill—I prefer art—of putting the facts of geology to one of many kinds of useful work.

Few will deny that geology is an inexact science. A large part of this inexactitude is inevitable. With few exceptions, everything within our field is gradational, and gradations do not lend themselves to exact measurement. Moreover, virtually identical geologic results can be produced from entirely different origins or by different methods. Failure to realize this—that like products may have had unlike beginnings—has led to many of the classic differences of opinion among geologists.

Again, most of the forces of nature that combine to produce geologic effects are so grand that they cannot possibly be reproduced or even simulated in the laboratory. Yet again, unlike many of the other sciences, the phenomena of which can actually be observed, most geologic phenomena are unobservable; almost all geologic features we see today are a product of some earlier time, and we see the product, not the processes. The processes continue today, but many are hidden from view within the earth and those that take place at the surface operate so slowly as to prevent measurement by means available to us.

Thus we talk glibly, and come to "scientific" conclusions about ancient continental glaciers and their associated deposits while the study of present-day continental glaciers is hardly well begun. Our "scientific truths" about the origin of ore deposits must be based on observations of a few hot springs, and of reactions between a few components under controlled laboratory conditions—plus dangerously pyramided assumptions. Our "knowledge" of how igneous rocks form is perforce based on observations of what goes on in active volcanoes and slag dumps, in platinum crucibles, and in man-made contrivances to simulate the temperature and pressure of the earth's interior, aided by the reasoning and imagination of a few great, but not infallible, human minds.

Small wonder that geology is an inexact science or that we sometimes seem to be preoccupied with only one small segment of the research field—"the *revision* of accepted conclusions in the light of newly discovered facts."

Even granting all the difficulties that are inherent in the science, it seems to me that our collective knowledge of geology is even less exact than it should be, that we really know less about it than we should at this stage in the development of our science. If we really know all the facts we should, how could two leading geologists bicker for years as to whether or not the Golden Gate Bridge was on safe foundations? The very same facts, the very same body of knowledge and theory were available to both men. The foundations were either safe or they were not.

This same element of subjectivity applies to such a universal part of our science as a geologic map. Many geologic maps would bring high prices as examples of nonobjective art. Any teacher who has had more than one student map the same area can tell you that no two maps are alike, yet the same rocks are there for observation. This difficulty does not apply only to students, by any means; in any but the simplest problems, the selfsame geologist is likely to change his map again and again. *Yet, one of the basic tests of scientific proof is the ability to repeat an experiment and to get the same results each time!*

Every mining geologist who has ever tried to project a vein even a short distance has been painfully aware of his lack of knowledge of the behavior of materials and of structural geology. If we really could know how and why rocks break under natural forces, and if we could know enough facts about those forces, prediction of a vein at depth would be an easy job. *Yet the essence of truth, at least in the pragmatic sense, is successful prediction.*

The world's largest maker of wire rope becomes concerned with designing anchorages for suspension bridges. He asks us geologists for data on the "average strength of rocks under tension, compression, bending, and shear." Can we give him an answer, with or without qualifications? No!

It is well known that limestone is soluble in water. Can we predict, even qualitatively, the rate of solution of a given limestone if reservoir waters of known composition leak through joints in the rock? The facts needed should be easy to get, either by collection and interpretation of existing data or by experimentation; yet few data are available.

If we knew enough about how rocks break, and why, we could give at least semiquantitative answers to such diverse problems as the effect of various kinds of bombs on underground shelters, on the design of block-caving methods for stoping ore, and on blasting methods for tunneling. As it is, the mining engineers, the exposives makers, and the Air Force get their own answers, largely by hit or miss empirical methods. The geologist has contributed few facts to help them. Worse, he has not, generally speaking, bothered to put together facts obtained by these other groups and to correlate and interpret them—either for application to engineering problems or to satisfy his intellectual curiosity.

In order to answer questions like those I have just asked—and those few are chosen at random from a great many—it seems to me that we require many more fundamental facts than we now have. Too, we must spend far more effort than we have in the past in interpreting and correlating those facts—facts not only from geology, but from chemistry, physics and other sciences and professions. The need for research in engineering geology, then, is as broad as the field of geology.

One of the most fruitful lines of attack, I believe has to do with the physical properties of rocks, both consolidated and unconsolidated. Our knowledge of the age and structure of rocks, as well as our theories of most geologic processes, has far outstripped our determination and interpretation of their basic physical properties—yet these are the properties that are of most concern to engineers or to us as scientists if we really hope to make geology a more exact science.

We need, for one thing, more correlation between geologic maps and tests of physical properties. Geologists, by and large, are content to describe rocks in pathetically general terms—they are "hard" or "soft," "moderately durable" or "easily eroded." True, we list the fossils in excellent Latin, we define the color according to the most modern color classification chart, and we work out the fabric with a Universal stage. But these facts don't tell the engineer a great deal.

Few geologists actually make tests for physical properties. There are some who are engaged in purely scientific experiments on rocks or minerals—usually at temperatures and pressures or other conditions far different from those encountered in everyday life. Their work is utterly necessary and worth while; some day it will bring results that will not only add to our understanding of this planet but will also help solve engineering problems. Too, there are many geologists who make single-purpose tests of a single rock mass—the permeability of an aquifer or oil-bearing formation, for example, or the electrical conductivity of a given body of soil. Here, also, are the engineering geologists who perform single-purpose, single-use field or laboratory tests on infinitesimally small parts of the earth's crust to determine their suitability, say, as foundations for a proposed dam.

Engineers, on the other hand, do an enormous amount of rock testing—in the aggregate surely amounting to tens of thousands of tests annually. The samples tested are usually identified rather carefully as to location, but also rather loosely as to lithology. Very seldom are the test results accompanied by petrographic descriptions or chemical analyses. Very rarely, if ever, is any attempt made to correlate the samples with stratigraphic formations or lithologic units shown on geologic maps. In one large midwestern city, for instance, the same nearly uniform limestone formation has been tested several hundred times, at a cost to the city of around $100 for each set of tests. Yet it has apparently never occurred to anyone that all of the test results are nearly identical and that use of a geologic map showing this formation might make most of the testing unnecessary.

The indicated research problem is fairly obvious, and it could be tackled on almost any scale with some promise of results. It is simply to correlate the results of physical tests that have been and are being made, with the rock units shown on geologic maps. The objectives, of course, are to discover the *range* in physical properties that exist within each map unit, the average figures for those properties, and, eventually, the average figures for the various rock types. Armed with such facts, the geologist could move from the qualitative at least to the semiquantitative in his descriptions and in his theoretical considerations. The least of the benefits to the engineer would be a possible reduction in the number and cost of his tests. What other results might come from such research is anyone's guess—it's the unexpected in scientific inquiry that makes it at once worthwhile and exciting.

I am well aware that this suggestion has both flaws and drawbacks, but I do not believe these are insurmountable. Many formations change in character from place to place, yet many of them are remarkably uniform in lithology over thousands of square miles. I am confident, for example, that the range between high and low plasticity index values for all the tests that have ever been made on the Pierre shale would prove to be rather narrow—and the average P. I. value would probably be far different from the average P. I. value for the Mowry shale.

Obviously, if a formation changes laterally from sandstone to shale to limestone, a statistical study of physical properties would mean nothing. My answer for such problems is that if we want our geology to mean anything or to be of any use to anyone at all, we should pay at least as much attention to lithology as to time zones in our mapping. We should, indeed, take care to delineate on our maps or in our descriptions, all changes in the rocks that are significant in terms of physical properties. To do this we must, of course, conduct research on the discovery and portrayal of features that are missed by usual mapping techniques. Similarly, it can be said that local weathering, or concentrations of fractures, has more effect on the physical properties than does the intrinsic character of the original rock itself. That is true—but perhaps it means that there's something wrong with our method or scale of mapping. Perhaps the weathered or shattered zones should be mapped separately; surely they mark places where the rocks will react differently to either geologic or engineering processes.

A related field of research, and one that is even more promising, is the correlation between different physical properties of rocks. Engineers have devised dozens of machines and procedures for testing this, that, or another property of rocks; soils mechanists are doing the same for unconsolidated materials. The truth is that nearly all of these test methods, as well as the application of the results to practical problems, are almost entirely empirical. Comparatively little work has been done on such fundamental questions as why different rocks have different compressive strengths or of why or how they fail when they do. It seems to me that our first step in answering such questions is to find out the relation of all these physical properties, one to another as well as to the chemistry and mineralogy of the rocks. That is, a given specimen of rock, including its pore spaces, is made up of certain definite atoms and molecules, arranged in a certain way. Isn't it logical to ask if it is the properties of these molecules, plus their arrangement, that gives the rock the definite properties that it has—compressive and tensile strength, toughness, specific gravity, porosity, electrical and thermal conductivity, and all the rest? If this is so, we ought to find definite relation between these different properties. We already know some such relations. Rocks with high specific gravity, for instance, are likely to have high compressive strengths and very low porosity. But our knowledge, again, is both spotty and qualitative. If we should collect enough quantitative data to permit statistical analysis perhaps we would find that we could extrapolate the results of a few physical tests and be able to predict the other physical properties of the same specimen. If this could be done with any accuracy, we could at least eliminate many routine tests. More important ,however, we would have gained real, quantitative knowledge of the nature of rocks and soils, and we would have begun to know why they behave as they do in both field and laboratory.

I realize that this suggestion, too, is highly visionary. Yet some small beginnings have been made. L'Hermite, in Paris, has subjected a series of marbles to all the usual physical tests as well as to chemical analysis and petrographic examination. He has already found surprisingly good correlations between different properties. The same sort of thing has been done in this country and on a much wider variety of rocks, by Obert and Windes, of the U. S. Bureau of Mines, except that they have made little attempt to correlate the properties they record.

I have mentioned only a few among the dozens of problems that face us in geology. All have one common denominator—we need more fundamental facts before we can either understand the geology or put it to work for engineers.

Stresses around openings in rocks, whether the openings are fractures, caves, or man-made tunnels, deserve even more attention than they have had. Some of the most ambitious studies here, by the way, are being done by soils engineers without the fullest use of all applicable geologic tools. That very gap between soils mechanics and geology, incidentally, is an enormous field for research in itself, and one that is relatively untouched. Geology has much to offer the soils engineers and soils scientists, and they have at least as much to offer us.

The clay minerals are of very great importance to both geologists and engineers. Much work has been and is being done on them, but far more data are needed on everything from simple identification methods for the minerals, through studies of their physical properties, to chemical and electrical methods of clay consolidation.

We need to know much more about the weathering of rock, both chemical and physical, again for both scientific and practical reasons.

Ever since man learned to build, engineers have had to contend with landslides, or earth movements, of one kind or another. They have contrived many ingenious ways of controlling slides or even of preventing them. Even with the great advances made by soils engineers and soils physicists in recent years, however, knowledge of the causes and mechanics of slides has lagged far behind the application of control techniques. When, and only when, we know enough about the causes, we should be able to recognize potential slides and thus enable the engineer to avoid them entirely or at least to prevent them. This element of slide prediction is, I believe, a far more fruitful and more neglected field of research than that of developing cures and controls.

I've neglected, intentionally, one broad field of research—the development of better techniques and tools to aid the geologist in collecting facts or in applying them. We need more work, to be sure, on drilling methods, on field tests and their correlation with laboratory tests, and on geophysical methods. Much work is already being done on these and numerous related lines, and even more work should be done. I regard the development of techniques as of secondary importance, however, to recognition of our need for certain kinds of fundamental facts. Once we decide on what facts we are seeking, the gadgets and methods of obtaining those facts will come along as a matter of course.

Only because of lack of time, I am also largely neglecting another field of research, one that I consider next in importance to our need for basic facts. This is the essentially human problem of how to present geologic facts to engineers so that they will understand and use them to maximum advantage. This is a subject in itself, yet one that must be solved. It ranges from the discovery and training of potential engineering geologists, through methods of presenting our data, to research on the psychology of salesmanship. Suffice it to say now that the essence of the problem is the need for *conviction by demonstration.* The geologist and engineer think differently and work differently. The engineer thinks concrete facts and figures, he reasons from *cause* to *effect,* and he depends very largely on what he can see and measure. The geologist normally reasons from *effect to cause*, and is perhaps all too conscious that his is an inexact science. If he is as skillful and brave as he should be, however, and if he has observed and understood enough facts, he should be willing and able to predict the geologic conditions and their meaning to the engineer. If he continues to make such predictions accurately he will, by *demonstration,* bridge whatever gaps there are between himself and the engineer.

What I have said tonight can be summarized very quickly and easily. First, I believe that we geologists have made but a faltering start in determining the facts of geology, or in correlating and understanding the meaning of those facts; the opportunity for fundamental research in geology is, therefore, ahead of us and not behind us. Second, I believe that every engineer who deals with earth materials has some need for geology in his daily work. It is up to us geologists to determine the needed facts of geology and to find ways of putting those facts to work for the engineer.

To summarize in another way, and perhaps to explain incidentally why I am a geologist, let me quote something that was written long ago by a scientist with breadth of interest and vision—Aristotle.

"The search for truth is in one way hard and another easy. For it is evident that no one can master it fully nor miss it wholly. But each adds a little to our knowledge of nature, and from all the facts assembled there arises a certain grandeur."