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GEOLOGY AND CHEMISTRY[1]

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WE are here to-day with the pleasant duty of dedicating a splendid new building to the service of chemistry and geology. Some of you may have been led to wonder at the housing together under one roof of two sciences that are often placed in opposed categories, the one an experimental science, the other a natural science. But is it, after all, so strange a union?

Chemistry had a utilitarian beginning. It grew out of the attempts of man to convert natural materials to his uses. The first chemical process consciously employed was probably the process of combustion. Fire was to early man, as it is to us to-day, of outstanding importance, and one of its earliest services was that of reducing metals from their ores. A primitive hunter kindled a fire in the lee of a rusty boulder and was astounded to find in the ashes glistening pellets that he could shape at will by pounding them with a stone. From this beginning he and his fellows learned to associate the production of this lustrous, malleable material with the bringing together of fire and a certain kind of rock substance. When they wished more of that material, for which they found many uses, they learned to seek other occurrences of similar rock to be fired in a similar manner. The production of metals from natural rock substances was at first no more than a craft. But man does not long remain content with wholly utilitarian pursuits, else we should not find among primitive peoples the remarkable knowledge of such matters as the motions of heavenly bodies. Our nimrod metallurgist soon began to ponder upon the fundamental nature of his craft. In this act the science of chemistry was born, but no less also was the science of geology born, if indeed any purpose is served by attempting to classify the trains of thought instituted in those unpracticed minds. The desire to understand the real nature of the raw material, to grasp why it

[1] Address given at the dedication of the new Science Building of Bryn Mawr College, October, 22, 1938.

occurred in some places and not in others, knowledge which we should now call geological, must have been just as great as the desire to understand the process to which he subjected it and the product which he gained, nowadays chemical knowledge. It was all one problem. Increased knowledge of one aspect could not fail to shed light on other aspects. This condition persisted as knowledge advanced along these lines. One investigator engaged in all the necessary pursuits. Classification of activities was not emphasized and the broad general view prevailed well into the comparatively recent period during which the principal advances in chemical knowledge consisted in the progressive discovery of the elements. This was but natural, since they were found for the most part through the treatment of new raw materials, and each discovery threw new light on a naturally occurring substance. The system of knowledge that developed was regarded as a unit, and given the name "natural philosophy."

As the system grew, it was inevitable that some philosophers should pay greater attention to certain aspects of it. In the laboratory the investigator produced new compounds from old compounds and still newer compounds from these again, until finally he had substances so many steps removed from the natural raw materials that he might easily forget his ultimate dependence upon such materials. Thus there tended to grow up laboratory science as distinct from natural science and the connection between them was often temporarily lost to view. With what force must Marie Curie have been reminded of this connection when, with an electroscope of Pierre's construction, she examined a long series of geological specimens to determine what minerals emitted the mysterious Becquerel rays, and then, confining her efforts to the most promising material, she set to work in an old, draughty shed to treat ton after ton of a waste product of Bohemian uranium ores and isolated the astounding new element, radium. Her discovery revolutionized chemistry; it revolutionized geology, giving, for example, a wholly new vista of geologic time; it revolutionized all science. Just so thin, so unreal are the barriers between the sciences.

In their common interest in their common materials geology and the laboratory sciences tend to grow hand in hand. Chemists and physicists continue to discover new elements and new isotopes of the elements. The materials they treat come from the earth, and in their original home have long been studied by the geologist. Investigation of the chemical characters of minerals, rocks and ores, whether undertaken for utilitarian ends or with these fundamental problems of the constitution of matter in mind, will ever be an indissoluble bond between chemistry and geology—but it is not enough.

Geological science is not concerned solely with the nature of the materials of the earth. Geology is even more concerned with processes, with the changes to which earth materials have been subjected. It seeks to know not only what earth substances are, but how they have come to be what they are, what factors have led to the observed arrangements and associations. Such knowledge is the special domain of geology. Overlap into the fields of other branches of science is here not so obvious. The chemist may readily find it essential to the advance of his science to institute a study of the mineral pitchblende, but he is very unlikely, of his own accord, to investigate the chemical action of atmospheric ingredients upon the various constituents of rocks. He will ordinarily realize the importance of such studies only when the geologist points out to him the cumulative magnitude of such action in nature and then urges upon him the significance to both chemistry and geology of an exact knowledge of the processes involved. Absorbed in his own science the chemist might ordinarily never even realize the existence of such a phenomenon as rock weathering; yet, induced to study it, he might make discoveries of general significance to such problems as rates of reaction, adsorption by surfaces, formation of colloids and others destined to enrich scientific knowledge as a whole.

The weathering of rocks is only one of a great host of geologic processes, all of them chemical and physical processes occurring in or upon the earth, the true nature of which the geologist must seek to unravel. As a check upon his deductions regarding their nature it is in all cases most desirable that experimental studies be carried out under controlled and measured conditions and the actual importance of the various factors involved be thus ascertained.

At the risk of being technical and tedious it may be appropriate to point out very briefly a few of the many directions in which chemical studies have thrown or may be expected to throw new light on geological processes, with consequent enlargement of the domain of chemical science itself. Geologic processes may be regarded as beginning with the high-temperature phenomena. Some aspects of these are revealed in the outpourings of lava from volcanoes that have occurred throughout geologic time and have been observed by man with wonder and awe ever since he made his first appearance on the planet. Molten lavas solidify on cooling and ordinarily give rise to a crystalline aggregate of a number of different minerals, an igneous rock. The study of the manner in which minerals form from molten mixtures has now been carried on for some time. It constitutes a special branch of high-temperature chemistry or physical chemistry and has served to throw much light upon the temperatures prevailing and the processes at work during the consolidation of masses of molten rock. At the same time chemistry extended its domain and many facts came to light that are of fundamental significance to certain branches of the chemical industry, such as the manufacture of glass, cement and refractories.

In spite of notable progress in these laboratory investigations of igneous-rock formation much remains to be accomplished. The most superficial observer of volcanic eruptions realizes that the lavas poured out are not simple melts but that they contain dissolved in them many substances which are gaseous at the high temperatures prevailing. Investigation proves that the principal of these is water, but many others are present, among which may be mentioned chlorine, fluorine, sulfur. To the presence of these substances volcanic activity owes its frequent explosive character, and their reactions with each other and with the less fugitive constituents of the lavas are of great importance to an understanding of volcanic phenomena. The investigation of these reactions in the laboratory is a special field of high-temperature and high-pressure chemistry that is warranted to tax the ingenuity of the most accomplished experimenter, and the theoretical treatment of the results will require a most facile mind. If the reward is measured by obstacles overcome, a generous reward awaits the successful experimenter in this field. Significant results have already been obtained, but they serve principally to whet the appetite for more.

In discussing high-temperature geologic processes it is but natural to begin with those that are manifested directly upon the surface of the earth. At the same time it should be realized that the lava poured out during a volcanic eruption is ordinarily but an insignificant spurt from a large reservoir of molten rock existing at considerable depth within the earth and that this large mass itself cools and crystallizes with the passage of time. Thus have arisen many deep-seated masses of igneous rock. Frequently these have been laid bare as a result of the wearing away of mountains by streams, with consequent exposure of the "roots" of the mountains at the surface of the earth. The geologist is thus enabled to study the products of the aeon-long cooling of molten masses of rock, and these, not lavas, are the most important and the most abundant of the primary or igneous rocks. He finds here many interesting contrasts with the same materials when cooled quickly as surface lavas. Instead of making violent escape from the magma it is apparent that the volatile constituents, for the most part, remained in solution in the melt when it thus cooled under a considerable cover of overlying rocks. The volatile constituents were therefore enabled to exert important influence upon the crystallization of the magma. In large measure they remained in solution until late stages of crystallization and thus attained high concentrations in the residual liquids. In part they entered into the composition of the later-formed minerals. In part they escaped into surrounding rocks as liquid or gas and carried with them in solution many substances that were concentrated with them. These they often deposited at favorable localities in the surrounding rocks, and thus arose many of our most valuable ore deposits.

This is the general story of the formation of such deposits, as deciphered by the geologist from their field relations. The full details of the process and decision upon many moot points can be had only as a result of properly designed laboratory experiments. Such work constitutes a field of moderate-temperature, moderate-pressure chemistry of solutions of most complex character. Something has been accomplished in the field, but progress in it lies in the development of new techniques. Critical phenomena will be encountered and most complex relations between the various states of matter. The requirements are most exacting, the promise of results of general significance is great. The field should prove attractive to the chemical investigator.

At an earlier point I have mentioned the problem of rock weathering and its challenge to the chemist. From the moment a rock is exposed at the surface it suffers attack both mechanical and chemical, actions which, as we have seen, are susceptible of laboratory investigation. Running water transports the products of decomposition, partly in suspension, partly in solution. Broadly speaking, their ultimate destination is in the sea, where some remain in solution and are there building up to higher and higher concentrations with the passage of the ages, and others are deposited upon the sea floor as mechanical or chemical sediments. The mechanical sediments are sands and muds, and on first thought it might seem that their deposition presents no chemical problems. Yet closer examination reveals that this is far from the truth. Precipitation is in some measure related to the degree of concentration of electrolytes in solution, fine particles adsorb salts and do so selectively, so that even the detrital sediments raise many chemical questions.

Such questions are, of course, paramount for chemical sediments, the most important of which is perhaps limestone, though by no means all limestones are simple chemical precipitates. The chemistry of the formation of this common rock still presents many unsolved problems. There are other, less common chemical deposits of great interest. In some circumstances many substances of relatively low solubility in sea water have been deposited from it as extensive beds. Silica as beds of chert and silica interlaminated with iron oxides are prominent examples. To the reworking of the latter we owe the great bodies of iron ore in the Lake Superior region. Beds of calcium phosphate have also been formed, and they have great importance as a source of fertilizer. The special conditions under which these diverse materials are separated from sea water are at present not much more than a matter of conjecture and they will remain so until they have received adequate chemical investigation.

No purpose can be served by multiplying examples, but it would be an ill-balanced discussion of our present topic which failed to mention salt deposits. In the never-ending movements of the body of the earth, and consequent warping of its surface, it sometimes happens that arms of the sea are cut off and are subjected to slow evaporation. Under these conditions even the very soluble salts have been deposited and thus have arisen many salt and gypsum beds and, in extreme cases, beds containing potassium and magnesium salts. A laboratory investigation by Van't Hoff of the conditions of formation of these several deposits is a chemical classic.

All these processes of weathering, transportation and deposition of substances belong to a field of chemistry of ordinary temperatures and pressures. Laboratory investigation of them requires a minimum of apparatus and equipment and for the most part familiar techniques. A vast field is open.

Geology, we have seen, is concerned with the materials of the earth and with the processes that have wrought changes in these materials and we have striven to show how both these aspects of the science are connected with the science of chemistry. Geology has yet another aspect. It is concerned with the inhabitants of the earth, the various forms of life that have existed upon it and with the conditions under which they lived. The connection between geology and biology is here the more obvious one, yet we can not think of the environment of life through the ages without regard for its chemical aspects. Changes in the character of sea water and of the atmosphere are of great importance, and much chemical and biochemical research with an eye to geologic interpretation remains to be accomplished here. Living organisms have, too, contributed great deposits to the geologic column, the most significant, perhaps, limestone and coal. The chemistry of the processes involved, say in the development of coal from plant remains or in the development of petroleum, still requires much research for its elucidation. Limestone and coal have been listed among the five or six fundamental raw materials of the chemical industry, and even one engaged in the most abstruse research in pure chemistry should not be utterly oblivious to chemical industry's raw materials and the problems which they pose. Here again there is opportunity for collaboration between geology and chemistry.

Enough has been said to make it clear that each of the three major aspects of geology presents problems where chemistry and geology come together upon common ground. How appropriate it is then to bring these sciences together under one roof! As much could be said for housing physics and geology together, but it is, for the most part, unnecessary to say it. Cooperative efforts of physics and geology have in the recent past proven so fruitful in a commercial way that it is relatively easy to arouse interest in and obtain support for such investigations, even when extended to what might be termed problems of pure geology. Indeed, plans for extensive geophysical research in pure geology are now being pushed with great vigor. Such research has the great advantage, or should I say the seeming advantage, of great general appeal. What could be more stirring than artificial earthquakes, than weighing the earth or than boring holes in the bottom of the sea? In such work explanation is sought of such large-scale phenomena as thrustings of the earth's crust, changes in the level of the sea and many others. It has great promise and every effort is justified, yet it is possible that these actions have their ultimate origin in changes of phase equilibria within the earth, dominantly a chemical phenomena, if indeed we should here draw any boundary line. And if the good ship *Geophysica* should outsail her sister ship *Geochemica* she will soon find that she is off her course, that she can not hope to make port but must put about and join her sister. Together they can continually correct the course and sail on with confidence.

So, though the grouping of physics and geology would be entirely appropriate, I believe the grouping of chemistry and geology has its advantages in these times. Physics is here housed with biology. They have, I need hardly say, much common ground, and their grouping may lead to cooperation between branches which would otherwise go their separate ways. And when we have said these things we can not fail to be brought to a realization of the artificial nature of *any* particular grouping, of the arbitrary character of the boundaries that have been set up in science and of the essential unity of all science, a unity more fully appreciated in earlier days than in these days of extreme specialization. His own realization of this fact and his conviction that great benefit would accrue to science if this realization were more general are, no doubt, the factors that led Professor Tennent to formulate his plan of balanced instruction in science, without extreme specialization at the undergraduate level, a plan which the administrators of this college have wisely adopted. Many colleges turn out geologists with no more than a smattering of chemistry, and many turn out chemists altogether devoid of geological knowledge. Often enough the deficiency may not be a serious barrier to material success in either case, but surely we can not measure the value of an education solely by its prospect of material success. The broadening of interests that results from a well-rounded training may well lead to comparative indifference to material success and thus to a life in which there is time to observe our surroundings and to contemplate upon their meaning. The scientific outlook is not likely to be gained from too great and too early specialization in science with its feverish acquirement of techniques, but rather from a broad, general training in science; and the scientific outlook on life and living is sorely needed in these days of heated passions and rampant prejudices.

Yes, broad undergraduate training in science should be a valuable preparation for living. The exigencies of college curricula ordinarily make it necessary that the undergraduate training be also a preparation for specialization. Will such specialization be handicapped because the preparation was so broad that it could not be deep? Probably not. The specialist can benefit greatly from knowledge of other fields. More and more does one branch of science depend upon borrowing from other branches. As a result have grown up special branches that have been termed borderland sciences and have received names that emphasize that character. Among them there are biophysics and geophysics, biochemistry and geochemistry. The last is born of the union of geology and chemistry, the two subjects of which our building is to be the home. We have considered something of what has been accomplished and what we may look for in the field that is common to these two sciences, and in general it may be said that the major advances in the great natural sciences biology, geology, astronomy must come through the development of the borderlands where they march against chemistry, physics and mathematics. The past has been mainly a period of fact-finding, but science can be stifled by facts. It is only when processes are considered and properly understood that a horde of little facts becomes a single great fact and real scientific progress is made. The natural sciences have generalizations of surpassing grandeur that are truly their own; but it now seems that further generalizations will arise dominantly through development of their borderland fields.

The worker who prepares himself especially for investigation in the borderland between chemistry and geology may expect a singularly attractive existence. To-day he is in his laboratory making careful measurements and obtaining results the probable error of which he can state within certain definite limits, a condition that is most satisfying to the scientific type of mind. But confinement between four walls, close application and a sedentary existence eventually pall, and to-morrow he is in the great out-of-doors observing natural processes and their results, probing for the fundamentals of these processes, yet ever finding that too many questions remain unanswered. Whereupon he returns to his laboratory with increased vigor and renewed hope that he can there find some of the answers. He thus leads a double life, a very satisfactory double life.

There is need for men and women trained for this border field. It should not be necessary for the geologist to come hat in hand to the chemist's door and beg his advice and cooperation in the solution of a geochemical problem, only to be turned away, partly because he is unable to present his plea in a language intelligible to the chemist, and partly because there is currently too great a tendency to regard such collaboration as savoring of the famed collaboration between the monkey and the cat in the incident of the chestnuts, with the chemist in the rôle of the cat. No, chemistry has itself profited greatly from its efforts to aid geology, but since the impression noted is all too prevalent it is the more necessary that we should have an increasing number of workers trained in both geology and chemistry. To such workers the geologist proper may turn with confident expectation of sympathetic understanding. Extreme specialists in chemistry on the one hand and in geology on the other will still be needed as contributors to borderland activities. The man of dual training who spreads his energies over both fields can not hope to be absolute master of both, but will find it necessary to call such specialists to his aid. In particular he should be most effective in a liaison capacity, by making possible a collaboration between a chemist and a geologist who, without his aid, would be unable to get together upon common ground.

In this college it is definitely planned to coordinate the teaching of the sciences in such a way as to facilitate training in several border zones between the sciences, among them that between geology and chemistry. All honor to Bryn Mawr for its pioneer work in such development. Hitherto it has usually been necessary for the student himself to visualize the need for such dual training and to lay his plans accordingly, often to encounter many difficulties on account of the existing arrangements. Here the student will be set upon the right path and the path will be smoothed. Proximity is a potent influence in affairs of the heart. May it prove to be as potent in affairs of heart and mind, and may the common domicile of chemistry and geology further the schemes of Matchmaker Tennent and conduce to the development through the years of a succession of workers in the enticing borderland between these sciences, much needed for the balanced development of both of them.