ART. VII. — *The Rise of Petrology as a Science;*
by LOUIS V. PIRSSON.

This chapter is intended to present a brief sketch of the progress of the science of petrology from its early beginnings down to the present time. The field to be covered is so large that this can be done only in broadest outline, and it has therefore been restricted chiefly to what has been accomplished in America. Although the period covered by the life of this Journal extends backward for a century it is, however, practically only within the last fifty years that the rocks of the earth's crust have been made the subject of such systematic investigation by minute and delicately accurate methods of research as to give rise to a distinct branch of geologic science. It is not intended of course to affirm by this statement that the broader features of the rocks, especially those which may be observed in the field and which concern their relations as geological masses, had not been made the object of inquiry before this time, since this is the very foundation of geology itself. Moreover, a certain amount of investigation of rocks, as to the minerals of which they were composed, the significance of their textures, and their chemical composition, had been carried out, concomitant with the growth from early times of geology and mineralogy. Thus, in 1815, Cordier by a process of washing separated the components of a basalt and by chemical tests determined the constituent minerals. At the time this Journal was founded, and for many years following, the genesis of rocks, especially of igneous rocks, was a subject of inquiry and of prolonged discussion. The aid of the rapidly growing science of chemistry was invoked by the geologists and analyses of rocks were made in the attempt to throw light on important questions. It is remarkable, also, how keen were the observations that the geologists of those days made upon the rocks, as to their component minerals and structures, aided only by the pocket lens. Many ideas were put forward, the essentials of which have persisted to the present day and have become interwoven into the science, whereas others gave rise to contentions which have not yet been settled to the satisfaction of all. At times in

these earlier days the microscope was called into use to help in solving questions regarding the finer grained rocks, but this employment, as Zirkel has shown, was merely incidental, and no definite technique or purpose for the instrument was established.

On the other hand, the fact that up to the middle of the last century a large store of information relating to the occurrence of rocks, and to the mineral composition of those of coarser grain, and somewhat in respect to their structure, had been accumulated, caused attempts in one way or another to find means of coördinating these data and to produce classifications, such as those of Von Cotta and Cordier. The history of these attempts at classification, before the revelations made by the use of the microscope had become general, has been admirably reviewed by Whitman Cross¹ and need not be further enlarged upon here.

That a considerable amount of work was done along chemical lines also is testified to by the publication of Roth's *Tabellen* in 1861, in which all published analyses of rocks up to that date were collected. What was accomplished during this period was done chiefly on the continent of Europe, and little attention had been paid to the subject of rocks either in America or in Great Britain—even so late as 1870 Geikie remarks, as referred to by Cross,² that there was no good English treatise on petrography, or the classification and description of rocks. In this country still less had been accomplished, interest being almost wholly confined to the vigorous and growing sciences of geology and mineralogy. This was natural, for mineralogy is the chief buttress on which the structure of petrology rests and must naturally develop first, especially in a relatively new and unexplored region, whose mineral resources first attract attention. The geologists in carrying out their studies also observed the rocks as they saw them in the field and made incidental reference to them, but investigations of the rocks themselves was very little attempted. An inspection of the first two series of this Journal shows relatively little of importance in petrology published in this country; a few analyses of rocks, occasional mention of mineral composition, of weathering properties, and notices of

¹ For references, see the Bibliography at the end of this chapter.

methods of classification proposed by French and German geologists nearly exhaust the list.

INTRODUCTION OF THE MICROSCOPE.

The beginnings of a particular branch of science are generally obscure and rooted so imperceptibly in the foundations on which it rests that it is difficult to point to any particular place in its development and say that this is the start. There are exceptions of course, like the remarkable work of Willard Gibbs in physical chemistry, and it may chance that the happy inspiration of a single worker may give such direction to methods of investigation as to open the gates into a whole new realm of research, and to thus create a separate scientific field, as happened in Radiochemistry.

This is what occurred in petrology when Sorby in England, in 1858,³ pointed out the value of the microscope as an instrument of research in geologic investigations, and demonstrated that its employment in the study of thin sections of rocks would yield information of the highest value. Others beside Sorby had made use of the microscope, as pointed out by Zirkel,⁴ but, as he indicates, no one before him had recognized its value. During the next ten years or so, however, its recognition was very slow and the papers published by Sorby himself were mainly concerned in settling very special matters.

As Williams⁵ has suggested, the greatest service of Sorby was, perhaps, his instructing Zirkel in his ideas and methods, for the latter threw himself whole-heartedly into the study of rocks by the aid of the microscope and his discoveries stimulated other workers in this field in Germany, his native country, until the dawning science of petrology began to assume form. A further step forward was taken in 1873 in the appearance of the textbooks of Zirkel⁶ and Rosenbusch⁷ which collated the knowledge which had been gained and furnished the investigator more precise methods of work. It is difficult for the student of to-day to realize how much had been learned in the interval and, for that matter, how much has been gained since 1873, without an inspection of these now obsolete texts. In 1863, Zirkel, who was then at the beginning of his work, said in his first paper presented to the Vienna Academy of Sciences⁸ that if he

confined himself chiefly to the structure of the rocks investigated and of their component minerals, and stated little as to what these minerals were, the reason for that was because "although the microscope serves splendidly for the investigation of the former relations, it promises very little help for the latter. Labradorite, oligoclase and orthoclase, augite and hornblende, minerals whose recognition offers the most important problems in petrography, in most cases cannot be distinguished from one another under the microscope." How little could Zirkel have foreseen, at this time, less than forty years later, that not only could labradorite be accurately determined in a rock-section, but that in a few minutes by the making of two or three measurements on a properly selected section, its chemical composition and the crystallographic orientation of the section itself could be determined!

THE THIN SECTION.

Before going further we may pause here a moment to consider the origin and development of the thin section, without which no progress could have been made in this field of research. When we reflect upon the matter, it seems a marvelous thing indeed that the densest, blackest rock can be made to yield a section of the 1/1000 of an inch in thickness, so thin and transparent that fine printing can be easily read through it, and transmitting light so clearly that the most high-powered objectives of the microscope can be used to discern and study the minutest structures it presents with the same capacity that they can be employed upon sections of organic material prepared by the microtome. This is no small achievement.

The first thin sections appear to have been prepared in 1828 by William Nicol of Edinburgh, to whom we owe the prism which carries his name. He undertook the making of sections from fossil wood for the purpose of studying its structure. The method he developed was in principle the same as that employed to-day, where machinery is not used; that is, he ground a flat smooth surface upon one side of a chip of his petrified wood, then cemented this to a bit of glass plate with Canada balsam, and ground down the other side until the section was sufficiently thin. This method was used by others for the study of fossil woods, coal, etc., but it was not applied to

rocks until 1850, when Sorby used it for investigating a calcareous grit. Oschatz, in Germany, also about this time independently discovered the same method. A further advance was made in melting the cement, floating off the slice, and transferring it to a suitable object-glass with cover, a process still employed by many; though most operators now cement the first prepared surface of the rock chip directly to the object-glass, and mount the section without transferring it.

Next came the use of machinery to save labor in grinding, and another step was made in the introduction of the saw, a circular disk of sheet iron whose edge was furnished with embedded diamond dust. This makes it possible to cut relatively thin slices with comparative rapidity, but the final grinding which requires experience and skill must still be done by hand. Carborundum has also largely replaced emery. The skill and technique of preparers has reached a point where sections of rocks of the desired thinness (0.001 inch), and four or five inches square have been exhibited.

THE ERA OF PETROGRAPHY.

In these earlier days of the science, as noted above, great difficulty was at first experienced in the recognition of the minerals as they were encountered in the study of rocks under the microscope. At that time the chemical composition and outward crystal form of minerals were relatively much better known than their physical and, especially, their optical properties and constants. Some beginnings in this had been made by Brewster, Nicol, and other physicists, and the mineralogists had commenced to study minerals from this viewpoint. Especially Des Cloiseaux had devoted himself to determining the optical properties of many minerals, and the writer, when a student in the laboratory of Rosenbusch in 1890, well recalls the tribute that he paid to the work of Des Cloiseaux for the aid which it had afforded him in his earlier researches in petrography.

The twenty years following the publication of the texts of Rosenbusch and Zirkel may be characterized as the era of microscopical petrography. A distinction is drawn here between the latter word and petrology, a distinction often overlooked, for *petrography* means literally the description of rocks, whereas *petrology* denotes

the science of rocks. As time passed the broader and more fundamental features of rocks, especially of igneous and metamorphic rocks, in addition to their mineral constitution, were more studied and gained greater recognition, petrography gradually became a department of the larger field of petrology—the science of to-day.

The use of the microscope, as soon as the method became more generally understood, opened up so vast a field for investigation that at first the study and description of the rocks seemed of prime importance. This was natural, for hitherto the finer grained rocks had for the most part defied any adequate elucidation and here was a key which enabled one to read the cipher. A flood of literature upon the composition, structure, and other characters of rocks from all parts of the world began to appear in ever increasing volume. The demands of the petrographers for a greater and more accurate knowledge of the physical and optical constants of minerals stimulated this side of mineralogy, and increasing attention was given to investigations in this direction. No definite line between the two closely related sciences could be drawn, and a large part of the work published under the heading of petrography could perhaps be as well, or better, described under the title of micro-mineralogy. To some, in truth, the rocks presented themselves simply as aggregates of minerals, occurring in fine grains.

The work of the German petrographers attracted attention and drew students from all parts of the world to their laboratories, especially to those of Zirkel and Rosenbusch. The great opportunities, facilities, and freedom for work which the German universities had long offered to foreign students of science naturally encouraged this. In France a brilliant school of petrologists, under the able leadership of Michel-Lévy and Fouqué, had arisen whose work has been continued by Barrois, Lacroix and others, but the rigid structure of the French universities at that period did not permit of the offering of great inducements for the attendance of foreign students. The work of the French petrographers will be noticed in another connection.

In Great Britain, the home of Sorby, the new science progressed at first slowly, until it was taken up by Allport, Bonney, Judd, Rutley, and others. In 1885 the evidence of the advance that had been made and of the

firm basis on which the new science was now placed appeared in Teall's great work, "British Petrography," which marked an epoch in that country in petrographic publication. This work was of importance also in another direction than that of descriptive petrography, in that it contains valuable suggestions for the application of the principles of modern physical chemistry in solving the problems of the origin of igneous rocks. In it, as in the publications of Lagorio, we see the passage of the petrographic into the petrologic phase of the science.

The earliest publication in America of the results of microscopic investigation of rocks that the writer has been able to find is by A. A. Julien and C. E. Wright, chiefly on greenstones and chloritic schists from the iron-bearing regions of upper Michigan.⁹ Naturally, it was of a brief and elementary character. In 1874 E. S. Dana read a paper before the American Association for the Advancement of Science on the result of his studies on the "Trap-rocks of the Connecticut valley," an abstract of which was published in this Journal.¹⁰ Meanwhile Clarence King, in charge of the 40th Parallel survey, feeling the need of a systematic study of the crystalline rocks which had been encountered, and finding no one in this country prepared to undertake it, had induced Zirkel to give his attention to this task. The result of this labor appeared in 1876 in a fine volume¹¹ which attracted great attention. In the same year appeared also petrographical papers by J. H. Caswell,¹² E. S. Dana¹³ and G. W. Hawes.¹⁴ The latter devoted himself almost entirely to this field of research and may thus, perhaps, be termed the earliest of the petrographers in this country. His work, "The Mineralogy and Lithology of New Hampshire," issued in 1878 as one of the reports of the State Survey under Prof. C. H. Hitchcock, was the first considerable memoir by an American. This was followed by various papers, one on the "Albany Granite and its contact phenomena,"¹⁵ being of especial interest as one of the earliest studies of a contact zone, and in the fullness of methods employed in attacking the problem forecasting the change to the petrology era.

During the ten years following, or from 1880 to 1890, the new science of petrography flourished and grew exceedingly. Many young geologists abroad devoted

themselves to this field of research and the store of accumulated knowledge concerning rocks from all parts of the world, and their relations grew apace. The work of Teall has been noticed and among others might be mentioned the name of Brögger, whose first contribution¹⁶ in this field gave evidence that his publications would become classics in the science.

In America there appeared in this period a number of eager workers, trained in part in the laboratories of Rosenbusch and Zirkel, whose researches were destined to place the science on the secure footing in this country which it occupies to-day. Among the earlier of these may be mentioned Whitman Cross, R. D. Irving, J. P. Iddings, G. H. Williams, J. F. Kemp, J. S. Diller, B. K. Emerson, M. E. Wadsworth, G. P. Merrill, N. H. Winchell, and F. D. Adams in Canada. Others were added yearly to this group. As a result of their work a constantly growing volume of information about the rocks of America became available, and one has only to examine the files of this and other journals and the listed publications of the National and State Surveys to appreciate this.

In this Journal, for example, we may refer to papers¹⁷ by Emerson on the Deerfield dike and its minerals, and on the occurrence of nephelite syenite at Beemersville, N. J.; to various interesting articles by Cross on lavas from Colorado and the pneumatolytic and other minerals associated with them; to important papers by Iddings on the rocks of the volcanoes of the Northwest, and those of the Great Basin, to primary quartz in basalt, and the origin of lithophysæ; to the results of researches by G. H. Williams on the rocks of the Cortlandt series, and on peridotite near Syracuse, N. Y.; to papers by Diller on the peridotites of Kentucky, and recent volcanic eruptions in California; to articles by R. D. Irving on the copper-bearing and other rocks of the Lake Superior region, and to Kemp on dikes and other eruptives in southern New York and northern New Jersey. Other publications would greatly extend this list.

THE PETROLOGIC ERA.

As the chief facts regarding rocks, especially igneous rocks, as to their mineral and chemical composition, their structure and texture and the limits within which these

are enclosed, became better known; and the relations, which these bear to the associations of rocks and their modes of occurrence, began to be perceived, the science assumed a broader aspect. The perception that rocks were no longer to be regarded merely as interesting assemblages of minerals, but as entities whose characters and associations had a meaning, increased. More and better rock analyses stimulated interest on the chemical side and this and the genesis of their minerals led to a consideration of the magmas and their functions in rock-making. The fact that the different kinds of rocks were not scattered indiscriminately, but that different regions exhibited certain groupings with common characters, was noticed. These features led to attempts to classify igneous rocks on different lines from those hitherto employed, and to account for their origin on broad principles. In other words, the descriptive science of petrography merged into the broader one of petrology. No exact time can be set which marks this passage, since the evolution was gradual. Yet for this country, in reviewing the literature, for which the successive issues of the "Bibliography of North American Geology" published by the U. S. Geological Survey has been of the greatest value; the writer has been struck by the fact that in the first volume containing the index of papers down to and including 1891, the articles on subjects of this nature are listed under the heading of *petrography*, whereas in the second volume (1892-1900) they are grouped under *petrology* and the former heading is omitted. A justification for this is found in examining the list of publications and noting their character. With some reason, therefore, the beginning of this period may be placed as in the early years of this decade. Furthermore, it was at this time that the great work of Zirkel¹⁸ began to appear, which sums up so completely the results of the petrographic era. Rosenbusch¹⁹ was formulating more definitely his views on the division of rocks into magmatic groups, as displayed by their associations in the field, and using this in classification; an idea which, appearing first in the second edition of his "Physiographie der massigen Gesteine," finds fuller development in the third and last editions of this work. In this country Iddings²⁰ published an important paper, in which the family relationships of igneous rocks and

the derivation of diverse groups from a common magma by differentiation are clearly brought out. The fundamental problems underlying the genesis of igneous rocks had now been clearly recognized, and with this recognition the science passed into the petrologic phase. Brögger²¹ also had ascribed to the alkalic rocks of South Norway a common parentage and had pointed out their regional peculiarities.

From this time forward an attempt may be noted to find an analogy between rocks and the forms of organic life and to apply those principles of evolution and descent, which have proved so fruitful in the advancement of the biological sciences, to the genesis and classification of igneous rocks. This, perhaps, has on the whole been more apparent than real, in the constant borrowing of terms from those sciences to express certain features and relationships observed, or imagined, to obtain among rocks. Nevertheless, the perception of certain relations which we owe so largely to Rosenbusch and to Brögger²² has proved of undoubted value in furnishing a stimulus for the investigation of new regions, and in affording indications of what the petrologist should anticipate in his work.

Thus, the labors of the men previously mentioned, with those of Bayley, Bascom, Cushing, Daly, Lane, Lawson, Lindgren, Pirsson, J. F. Williams, Washington, and others, have thrown a flood of light upon the igneous rocks of this continent, and has made it possible to draw many broad generalizations concerning their origin and distribution. Thus, the differentiated laccoliths of Montana²³ have been of service in affording clear examples of the process of local differentiation. Many papers published in this Journal during the last twenty years show this evolution and growth of petrological ideas. The contributions from American sources during this later period, and of which those in the Journal form a considerable fraction, have indeed been of great weight in shaping the development and future of the science.

By referring to the files of the Journal, it will be seen that they cover a continually widening range of subjects concerning rocks, and articles of theoretical interest are more and more in evidence, along with those of a purely descriptive character.²⁴ Thus we find discussions by Becker on the physical constants of rocks, on fractional

crystallization, and on differentiation; by Cross on classification; by Adams on the physical properties of rocks; by Daly on the methods of igneous intrusion; by Wright on schistosity; by Fenner on the crystallization of basaltic magma; by Bowen on differentiation by crystallization; by the writer on complementary rocks and on the origin of phenocrysts; by Smyth on the origin of alkalic rocks; by Murgoci on the genesis of riebeckite rocks; and by Barrell on contact-metamorphism. These may serve as examples, selected almost at random, from the files of the *Journal*, and we find with them articles descriptive of the petrology of many particular regions, which often contain also matter of general interest and importance, such as papers by Lindgren on the granodiorite and related rocks of the Sierra Nevada; by Ransome on latite; by Cross on the Leucite Hills; by Hague on the lavas of the Yellowstone Park; by Pogue on ancient volcanic rocks from North Carolina; by Warren on peridotites from Cumberland, R. I.; on sandstone from Texas by Goldman; and on the petrology of various localities in central New Hampshire by Washington and the writer. Such a list could of course be much extended and other papers of importance be cited, but enough has been said to indicate how important a repository of the results of petrologic research the *Journal* has been and continues to be.

In thus looking backward over the list of active workers we are involuntarily led to pause and reflect how great a loss American petrology has sustained in the premature death of some of its most brilliant and promising exponents; it is only necessary to recall the names of R. D. Irving, G. H. Williams, G. W. Hawes, J. F. Williams and Carville Lewis, to appreciate this.

The store of material gathered during these years has led to the publication of extensive memoirs, in which the science is treated not from the older descriptive side, but from the theoretical standpoint and of classification.²⁵ In these works strong divergencies of views and opinions are observed, which is a healthy sign in a developing science.

It should be also noted that along with this evolution on the theoretical side there has been a constant improvement in the technique of investigating rocks. It is only necessary to compare the older handbooks of Zirkel and

Rosenbusch with the many modern treatises on petrographic methods to be assured of this.²⁶ It is due on the one hand to the vast amount of careful work which has been done in accurately determining the physical constants of rock-minerals* and in arranging these for their determination microscopically, as in the remarkable studies on the feldspars by Michel-Lévy, and on the other in researches on the apparatus employed, and in consequent improvements in them and in ways of using them, as exemplified in the delicately accurate methods introduced by Wright.²⁷ The development of the microscope itself as an instrument of research in this field and in mineralogy deserves a further word in this connection. The first step toward making the ordinary microscope of special use in this way was taken by Henry Fox Talbot of England, when he introduced in 1834 the employment of the recently invented nicol prisms for testing objects in polarized light. The modern instrument may be said to date from the design offered by Rosenbusch in 1876. Since that time there have been constant improvements, almost year by year, until the instrument has become one of great precision and convenience, remarkably well adapted for the work it is called upon to perform, with special designs for various kinds of use, and an almost endless number of accessory appliances for research in different branches of mineralogy and crystallography, as well as in petrography proper.²⁸ This also calls to mind the fact that for the convenience of those who are not able to use the microscope special manuals of petrology have been prepared in which rocks are treated from the megascopic standpoint.²⁹

METAMORPHIC ROCKS.

In this connection the metamorphic rocks should not be forgotten. They afford indeed the most difficult problems with which the geologist has to deal; every branch of geological science may in turn be called upon to furnish its quota for help in solving them. Under the

* We may mention here, for example, the work in mineralogy of Penfield, noticed in the accompanying chapter on mineralogy. In addition to the accurate determination of the composition and constants of many minerals, some of which have importance from the petrographic standpoint, we owe to him more than anyone the recognition of fluorine and hydroxyl in a variety of species, and thereby the perception of their pneumatolytic origin. His papers have been published almost entirely in this Journal.

attack of careful, accurate and persistent work in the field, under the microscope and in the chemical laboratory, with the aid of the garnered knowledge in petrology, stratigraphy, physiography, and other fields of geologic science, their mystery has in large part given way. The inaugural work of Lehmann, Lossen, Barrois, Bonney, Teall, and other European geologists, was paralleled in America by that of R. D. Irving, owing to whose efforts the Lake Superior region became the chief place of study of the metamorphic rocks in this country. Irving soon obtained the assistance of G. H. Williams, who had been engaged in the study of such rocks, and the latter published a memoir on the greenstone schist areas of Menominee and Marquette in Michigan³⁰ which will always remain one of the classics in the literature of metamorphic rocks. Irving's own contributions to petrology, though valuable, were cut short by his untimely death, but the study of this region under the direction of his associate and successor, C. R. Van Hise, with his co-laborers, has yielded a mass of information of fundamental importance in our understanding of metamorphism and the crystalline schists. Its fruitage appears in the memoir by Van Hise³¹ which is the authoritative work of reference on metamorphism, and in various publications by him and his assistants, Bayley, Clements, Leith, and others. The work of the Canadian geologists, and of Kemp, Cushing, Smyth and Miller in the Adirondack region, should also be mentioned in connection with this field of petrology.

CHEMICAL ANALYSES OF ROCKS.

It has been previously pointed out that, as the science of petrology grew, chemical investigations of rocks in bulk were undertaken. The object of such analyses was to obtain on the one hand a better control over the mineral composition and on the other to gain an idea of the nature of the magmas from which igneous rocks had formed. The earliest analysis of an American rock of which I can find record is of a "wacke" by J. W. Webster given in the first volume of this Journal, page 296. 1818.

During the next 40 years a few occasional analyses were undertaken by American chemists, by C. T. Jackson, T. Sterry Hunt, and others. In 1861, Justus Roth published the first edition of his *Tabellen*, in which he included all analyses which had been made to that date

and which he considered were worthy of preservation. Although, naturally, from the status of analytical chemistry up to that time, most of these would now be considered rather crude, the publication of the work was of great service and marked an epoch in geochemistry. In these tables Roth lists four analyses of American igneous rocks, two from the Lake Superior region by Jackson and J. D. Whitney and two by European chemists, one of whom was Bunsen. The material of the last two was a "dolerite" and the same locality is given for each—"Sierra Nevada between 38° and 41°" which was probably considered quite precise for western America in those days.

From these feeble beginnings the forward progress of petrology on the chemical side in this country has been a steady one until its development has reached the point which will be indicated in what follows.

The collection of material by the various State surveys and by those initiated by the National Government led to an increasing number of rocks being analyzed during the petrographic period. These became also increasingly good in quality, like those published by G. W. Hawes in his papers. When, however, chemists were appointed to definite positions on the staffs of the Government surveys and especially when, after the organization of the U. S. Geological Survey in 1879, a general central laboratory was founded in 1883 with F. W. Clarke in charge, then a new era in the chemical investigation of rocks may be said to have started. In this connection should be mentioned the work of W. F. Hillebrand, who set a standard of accuracy and detail in rock analysis which had not hitherto been attempted. As a consequence of his accurate and thorough methods and results the mass of analyses performed by him and his fellow chemists in this laboratory affords us the greatest single contribution to chemical petrology which has been made. Up to January, 1914, the report of Clarke³² lists some 8000 analyses of various kinds made in this laboratory for geologic purposes. Nearly everywhere also a great improvement in the quality of rock-analyses is to be noted, and in the manuals of Hillebrand³³ and Washington³⁴ the rock analyst has now at his command the methods of a greatly perfected technique which should insure him the best results.

Roth's Tabellen have been previously mentioned; sev-

eral supplements were published, but after his death a long interval elapsed before this convenient and useful work was again taken up by Washington³⁵ and Osann.³⁶ A new edition of Washington's Tables has recently been published, listing some 8600 analyses of igneous rocks made up to the close of 1913.³⁷

On the theoretical side also, where petrology passes into geology, the investigator of to-day will find a mass of most useful and accurate data well discussed in the modern representative of Bischof's Chemical Geology—Clarke's Data of Geochemistry.³⁸ The advance on the chemical side, therefore, has been quite commensurate with that in the microscope as an instrument, and in the results obtained by it.

PHYSICO-CHEMICAL WORK.

The study of geological results by experimental methods, which should gain information concerning the processes by which those results are caused, and the conditions under which they operate, has been from the earliest days of the developing science recognized as most important, and the record of the literature shows considerable was done in this direction. Experimental work in modern petrology may, however, be considered to date from 1882 when Fouqué and Michel-Lévy³⁹ published the results of their extensive researches on the synthesis of minerals and rocks by pyrogenous methods. The brilliant experiments of the French petrologists at once attracted attention, and since that time a considerable volume of valuable work has been done in this field by a number of men, among whom may be mentioned Morozewicz,⁴⁰ Doelter,⁴¹ Tamman,⁴² and Meunier.⁴³ As this work continued the results of the rapid advances made in physical chemistry began to be applied in this field with increasing value. To J. H. L. Vogt we owe a valuable series of papers,⁴⁴ in which the formation of minerals and rocks from magmas is treated from this standpoint. Most important of all for the future of petrology has been the founding in Washington of the splendid research institution, the Carnegie Geophysical Laboratory, under the leadership of Dr. A. L. Day with its corps of trained physicists, chemists and petrologists, devoted to the solving of the problems which the progress of geological science raises. The publications of this institution (many of them published in the Journal) are

too numerous to be mentioned here; many of them treat successfully of matters of the greatest importance in petrology. This is an earnest of what we may hope in the future. The accumulation of the exact physical and chemical data, which is its aim, will serve as a necessary check to hypothetical speculation and bring petrology, and especially petrogenesis, in line with the other more exact sciences by furnishing quantitative foundations for its structure of theory to rest upon.

While the achievements of this great organization seem to minimize the work of the individual investigator in this field, he may take heart by observing the important results on the strength of rocks under various conditions which have been obtained by Adams in recent years, data of wide application in theoretical geology. In this field also a special text has appeared in which the principles and acquired data are given.⁴⁵

SUMMARY.

In this brief retrospect, giving only the barest outlines and omitting from necessity much of importance, we have seen petrology grow from occasional crude experiments into a fully organized science in the last half century. It has to-day a well-perfected technique, a large volume of literature, texts treating of general principles, of methods of work, descriptive handbooks on the morphological side, and has attained general recognition as a field, which, though not large, is worthy of the concentration of intellectual endeavor. Like other healthy growing organisms it has given rise to offshoots, and the sciences of metallography and of the micro-study of ore deposits, which are rapidly assuming form, have branched from it.

What of the future? The old days of mostly descriptive work, and of theorizing purely from observed results, have passed. The science has entered upon the stage where work and theory must be continually brought into agreement with chemical, physical and mathematical laws and data, and in the application of these new problems present themselves. As we climb, in fact, new horizons open to our view indicating fresh regions for exploration, for acquiring human knowledge and for our satisfaction.

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