MEMOIRS PRESENTED TO THE CALIFORNIA ACADEMY OF SCIENCES. VOL. I PART. II. THE NATURAL SYSTEM OF VOLCANIC ROCKS

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FERDINAND RICHTHOFEN

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VOL. I, PART II.

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MEMOIRS

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VOLUME I.

II. *Principles of the Natural System of Volcanic Rocks.*

By F. Baron Richthofen, Dr. Phil.

[Presented, May 6th, 1867.]

Introductory. Among the features peculiar to modern Geology may be noticed a revival of that speculative tendency which prevailed among the cultivators of this science at the close of the last century. But while in those early times imagination exerted a dominant influence in the framing of hypotheses, and discussions between the adherents of different doctrines were conducted with all the bitterness peculiar to such struggles, when neither party has a firm basis upon which to found its arguments, the constant ascendency of the spirit of the inductive method has imparted to those theories more recently propounded a more logical and scientific form, while, at the same time, the increasing amount of positive knowledge has given to the different doctrines a more varied and more definite character, and enlarged the scope of dissenting views.

This renewed tendency to systematize and theorize, which is especially conspicuous in the records of the last twenty years, must be ascribed, partly, to the vast amount of well-established facts gathered during the previous decades, and which have since been multiplied and intensified in a constantly increasing ratio, as regards depth and distinctness of observation as well as the geographical area over which they extend; partly, and in no less degree, to the rapid progress made by those sciences on which geology has to draw for the general laws which are alone capable of affording a philosophical guide to speculation on the basis of facts gained by observing and comparing. The advance of the chemical and physical sciences, especially, has had a

powerful influence, by allowing an immediate application to geological problems of such general laws as are established beyond any doubt. Besides, the improvement of the practical methods applied in chemical and physical laboratories has given rise to the execution of numerous experiments, which were made with a view of imitating the processes applied in the great natural laboratories. They suggested frequently the causes of facts disclosed by the examination of a certain region, or obtained by comparing the observations made in different countries on one certain subject.

It appears to be mainly due to these causes that a number of theories have been proposed, in rapid succession, relating to the origin of rocks, to the mode and causes of metamorphism, to the agencies of vulcanism, to the structure and mode of formation of mountain ranges, to the structure of the entire globe, and other cognate subjects. It will be admitted, even by those who are most strongly opposed to theorizing, that geological science has in this way been promoted and enriched in various respects; since there is scarcely a theory which, even if insufficient to explain what it undertakes, has not some truth in it, or is applicable to some extent in certain cases, or has at least, even when proving to be erroneous itself, led to discussions on subjects of high interest, which is indeed a result of no little value. In reviewing the theories proposed on any particular subject, we find them, it is true, often in apparent contradiction with each other; yet almost every one is based upon arguments drawn from observed facts, and there are probably very few which will ultimately be entirely abandoned. The immense range of varied processes as applied by nature allows the applicability, in a limited way, of many a theory in certain instances, while in others it may be refuted on no less valid grounds; and the struggle between the defenders of different doctrines is often founded only in the difference of their standing-points. What appears to be true in one instance is frequently not applicable in others; it is the bold generalizations which render theories so often untenable in that form in which they are usually first expressed. An instructive example is presented by the different theories which have been proposed for explaining the mode of formation of mineral veins. Almost every one of them was based upon a limited range of observations, and was, from its first application to a few instances, extended to the generality of veins. Numerous exceptions to it were then found, leading to the rejection of the first, and the establishment of a different, theory, which, in its turn, shared a similar fate. Obscure as this subject still is, we are able to state this as certain, with our present state of knowledge, that every mineral vein is the product, not of one simple but of complex processes. Nearly every one of the theories proposed will, therefore, have its limited range of applicability, inasmuch as the agent it suggests may have been especially active in the formation of the veins of a certain order, while the same agent may have played a subordinate part in regard to the origin of other veins which were chiefly due to processes of another kind.

This instance points clearly towards the one principal cause of the divergence of opinions in regard to some of the most important geological questions. This cause is the want of latitude of the basis upon which arguments are founded. Conclusions which are obtained by reasoning on geological subjects solely on the strength of chemical analysis, are, when generalized, often found to be utterly in discordance with the

facts revealed by geological observation; and how unsatisfactory general theories may be when based upon the latter alone, is sufficiently exemplified by the fantastical attempts made in all ages of geological science to interpret the geological structure of the world from that of a limited region. The basis for argumentation can therefore never be broad enough, and its enlargement should be, as it indeed is, one of the chief objects of geological science. But it is not sufficient to content ourselves with an accumulation of primary observations, which are in fact being infinitely increased by the conjoint labors of geologists in all countries: it should be a higher object of the student of geology, to compare the established results of observation, and to investigate their mutual relations. The study of the structure of one mountain range, or of several ranges comprised within a limited district, may lead to the establishment of an elaborate theory of the mode of their formation, which may apparently answer perfectly well in that one case, but may be found inadmissible when generalized, even in those cases where, by imperfect observation, one would expect to detect a great similarity to the structure first observed. But in determining those features which are common to a number of mountain ranges, or to certain orders of them which we may discern among their generality, we may aspire to form conclusions which are more generally applicable. It is particularly the auxiliary branches of geology to which these remarks apply. The value of observations made in limited regions, or from a limited point of view, on subjects such as the outlines of the morphological features of the continents, the occurrence of mineral springs, the structure of mineral veins, the age of those among them which carry a certain metal, the generality of volcanic phenomena, the mode of action of earthquakes, the nature of certain kinds of rocks, and their part in the structure of the surface of the globe—cannot be fully realized unless the comparative method is applied in as wide a scope as we may be able to do, and the mutual relations among the different modes of manifestation of force, or among the properties of the kinds of matter upon which it acts, or the bearing of all these relations to each other and to the evolution of the globe, are investigated from as many points of view as we may detect, and in as many combinations as possible. We may then be able to gain a foundation for argumentation on more involved problems, consisting not of imperfect premises, nor of a confused accumulation of facts, but of established truths of a higher order.

The mode of origin of the non-foliated crystalline rocks, made up of silicates,* is among those subjects which have at all times, but at no time more than of late, commanded a great deal of attention, and given rise to the establishment of numerous theories, each of which was applied in a general way, if not by its author, then by his followers. It is well known how conflicting they apparently are, and what weighty arguments have been brought in favor of as well as against each of them. The only method, promising success, of weighing the merits of these different theories, or of modifying them in accordance with the general advance of science, appears to be, to

* I have for these applied the name "eruptive rocks" in the following pages, considering that, wherever we have occasion to observe them, they are not at their original seat, but ejected from it towards the surface. The reasons supporting this position will be more fully mentioned in the chapter on the origin of volcanic rocks.

ascend from the examination of the nature of these rocks to that of their mutual relations, to investigate these from as many points of view as we can discover, in regard to physical and chemical properties, mode of occurrence and age, as well as in regard to geographical distribution: that is, to try to establish the natural system of eruptive rocks. The results so obtained may then, in accordance with what we just remarked in a general way, be applicable to reasoning on remoter questions, of which we can only attempt to find the most probable solution. They regard chiefly the causes of those relations, the mode of origin of the eruptive rocks, and the processes connected with their ejection. The intricate nature of the subject, and the fact that the present changes on and below the face of the globe, as well as the events of the past, are often but dimly and imperfectly perceptible to our observation, demand that we should concentrate our endeavors in exploring first the laws of that which is definite and constant within the infinite range of phenomena, and await further experience to arrive at an explanation of those isolated facts which form apparent exceptions to the order of things.

It is with these views that the following pages were written. They extend chiefly over the comparatively limited, and yet very extensive class of "volcanic rocks," and are offered as a mere elementary attempt, which is necessarily very imperfect. The application to exact reasoning of the numerous observations which have been made on the subject of volcanic rocks in different countries, is nearly prevented by the extraordinary discrepancy existing in regard to the mode in which the names of rocks are used by different authors. The first condition of a uniform and harmonious mode of observation on volcanic rocks, and the phenomena connected with them, is the application of a uniform system of nomenclature.

In concluding these preliminary remarks, I dare express the hope that some indulgence may be had with the imperfections of this essay, if it is taken into consideration that it was written on the Pacific coast, where chemical laboratories are unknown, libraries scarce, and little opportunity is afforded of becoming acquainted with the current geological literature. I fulfill a deep-felt duty if I tender at this place my sincere thanks to Professor J. D. Whitney, not only for allowing me the use of his library and revising the manuscript of this essay, but also for the interest which he has constantly taken in my pursuits, and for what I owe to his personal intercourse, especially in a country where scientific communication is so extremely limited. The influence of this intercourse will, long after this, be kept in grateful memory by all those who are taking personally a part in the development of the California Academy, the members of which kindly allowed this paper to be published in their Memoirs.

THE NATURAL SYSTEM OF VOLCANIC ROCKS.

In reviewing the various attempts which have been made towards a classification of eruptive rocks—that is, those crystalline rocks made up of silicates, which, without showing themselves any traces either of stratified deposition or foliation, enter into the structure of the surface of the globe in such a way as to be unconformable with the stratification of the neighboring sedimentary rocks, and as a rule to abut against them without any gradual passage—we are struck by the observation that, if they are based on any principles at all, these are usually artificial, while none but unsatisfactory results have been obtained when the application of natural principles has been tried. This want of success is the more striking if we consider that it is peculiar to petrology, and that the efforts made in the same direction with other branches of descriptive natural sciences have been attended by extraordinary results. In zoölogy and botany, the natural system has long since been considered as the ultimate object of scientific research; and since the time when its first outlines were discovered, the progress of these sciences has been admirable. Since then only have the developments of their different branches coöperated harmoniously towards one common end: the profoundest investigations into the anatomy of animals and plants, the study of their geographical distribution in modern time, and of their gradual development in past ages, have in their final results but been subservient to the establishment of a foundation of the natural system, and the ingenious deductions made by Mr. Darwin on the origin of species are but its philosophical interpretation. As regards mineralogy, classification was for a long time a simple enumeration of minerals, governed by certain artificial principles. A new era was inaugurated for this science by the progress of chemistry, and its application to mineralogy, by Berzelius. It led to a more correct estimate of those principles which had been formerly applied, and to the discovery of the existence of an intimate connection between crystallographical form and chemical composition. The combination of these two principles gave rise to the natural system of minerals, which since their adoption has been constantly gaining in completeness.

These are results which surpass in a surprising degree those obtained in regard to the natural classification of eruptive rocks. Even the most recent and elaborate systematical arrangements, as those proposed by C. F. Naumann, F. Senfft, B. v. Cotta, and J. Roth, though marking a conspicuous progress, are based on almost purely artificial principles. In no other branch of the descriptive natural sciences, it is true, do difficulties arise so great as those which present themselves in petrology. Prominent