ART. IX.—*The Statement of Rock Analyses*; by HENRY S. WASHINGTON.

OF late years the importance of chemical analyses in the study of igneous rocks is generally recognized, and their publication and use is becoming more and more common.

Apart from improvements in methods and facilities, as well as increase in the number of workers, the main factor in this increase in the number of analyses published is the growing appreciation of their vital importance for a thorough comprehension of the rocks of the globe.

This importance of rock analyses to-day lies in their disclosing the bearing of the chemical composition of the rock masses on the deeper theoretical problems of petrology. Many of these, such as the differentiation of magmas, the genetic relationships of various rock bodies or parts of a complex to each other, or the true character and meaning of the so-called "petrographic provinces," are only to be solved by means of thoroughly good and trustworthy analyses.

There is an increasing tendency among some petrographers to regard the magma as one of the main objects of study, of which the solid rocks are simply the consolidated and accessible portions, many of their characters being to a great extent fortuitous and dependent on extraneous conditions of solidification and the like.

The chemical composition of the magma either persists as such in the rocks formed from it (as in Brögger's aschistic dikes), or is to be inferred if the magma has undergone changes such as those induced by differentiation (as in Brögger's diaschistic dikes), absorption of country rock or other causes. This chemical composition is, as far as we can tell at present, the single original character of the magma which is open to study after it has undergone the physical and physico-chemical changes which result in the formation of igneous rocks, whether aschistic or diaschistic.

Hence for obtaining a knowledge of these vast and highly important portions of the earth's crust, of their original characters, the conditions under which they exist and the changes which they may undergo, rock analyses are absolutely essential. It is true that physics also comes to our aid in certain directions, but this does not lessen the importance of the chemical investigation.

The practical use of analyses involves their collation or comparison one with another, either those of the rocks of one given region, or those of different regions with each other, or

of rocks belonging to any given group or kind. Scattered as they are through the literature, it is often a matter of some practical difficulty, or at least inconvenience, to bring several together under the eye so as to observe readily the features which it is desired to see. This inconvenience is increased by the fact that there is no uniformly adopted sequence in which the various constituents are stated.

In some cases, as in the publications of the U. S. Geological Survey, the analytical order is followed. The constituents are put roughly in the order in which they are determined in the course of the analysis.

Again a roughly chemical order is followed, either by putting all the acid radicals at the top of the column and the basic radicals below, as is usually done in Tschermak's *Mittheilungen*, or by putting SiO_2 first, followed by TiO_2 , then the metallic oxides in the order R_2O_3 , RO , R_2O , with H_2O , P_2O_5 , Cl , etc. last of all, as is the custom of Roth, Zirkel, Rosenbusch, and many others, including the writer. But even here there are variations in the order followed, as in some cases CaO is put before MgO , and K_2O before Na_2O .

A third method is that adopted of late years by Pirsson. This, which may be called the petrographic order, consists in putting the nine most important oxides first, beginning with SiO_2 and ending with H_2O , while the subordinate and more rarely occurring constituents follow after in the same general order.

A last method shows a lack of any system, the constituents being put down almost at haphazard, and with little apparent attempt at order or natural association. This method is fortunately rarely met with, and is to be dismissed at once as quite unworthy of consideration.

In consequence of this confusion not only is the inconvenience of and time required for copying and comparing analyses greatly increased, but there is introduced a positive danger of error due to unavoidable slips, which, unless the results are carefully and laboriously checked, is apt to lead to wrong conclusions.

The benefits then of a uniform system are evident, and it is probable that every petrographer has realized this to a greater or less extent. After some experience in the copying and use of rock analyses and full consideration of the subject, as well as discussion of the matter with other petrographers, I would propose that the third method mentioned above, which was, I think, inaugurated by Prof. Pirsson, be generally adopted, this presenting the greatest advantages to the petrographer, with a minimum of disadvantage.

A rock analysis, it must be remembered, is primarily intended for, and almost exclusively used by, petrographers. Therefore for him an arrangement on analytical or strictly chemical lines is neither advantageous nor appropriate. What he needs especially is an arrangement which shall bring the essential chemical features—both the percentage figures and the molecular ratios—prominently and compactly before the eye, so that the general chemical character and the relations of the various constituents may be seen at a glance. It is also of importance that the arrangement be such as to facilitate comparison of one analysis with another.

To the petrographer the eight oxides, SiO_2 , Al_2O_3 , Fe_2O_3 , FeO , MgO , CaO , Na_2O , and K_2O , which in practically every case are present in preponderating amount, are, and must always remain, of prime importance. They are the oxides which, by their relative amounts, determine the chemical character of the rock. H_2O and CO_2 , which are also found sometimes in notable quantity, are chiefly of value as a measure of the freshness of the rock. The other constituents, while of great interest, are present in minute quantities and in general, especially as compared with the main oxides, influence the character of the rock only to a very limited extent, either entering into the composition of accessory and subordinate minerals, or replacing to a very small extent the more important oxides in the essential minerals.

Hillebrand's plea* for their determination is well founded, and it is of course a desideratum that all analyses should be complete as to the rarer constituents. This, however, is not always possible, and it will probably remain true as it is at present, that many otherwise good and serviceable analyses are incomplete in this respect, or only show determinations of a few of the rarer constituents, notably TiO_2 , MnO , P_2O_5 , and Cl .

By putting the eight main oxides together, then, the petrographer is able to see at a glance the character of the rock under study, and the molecular ratios of these oxides, which are the only ones of practical importance, may be written after them and so easily compared *inter se*. Furthermore, whether an analysis is complete or incomplete, these oxides, which are determined in every case, are always in the same relative position, so that the eye finds them without trouble, thus immensely facilitating comparison and study.

The question naturally arises as to the advisability of stating the analytical results, not in oxides, but in terms of the elements, oxygen being given as a separate constituent. This is

* Hillebrand, Bull. 148, U. S. G. S., p. 15, 1897.

done by some petrographers in the reduction of analyses for certain lines of work, though in these cases oxygen is omitted. This last seems to me a somewhat unjustifiable procedure, in view of the fact that oxygen makes up by far the greatest percentage in all the known terrestrial rocks.

It is true that we do not yet know whether the oxides exist as such in the magma or not, though the theories of physical chemistry seem to favor the view that they do. But apart from such considerations, the possible benefits to be obtained are so doubtful and meager that it seems scarcely justifiable at present to make any such sweeping change. Experience has shown the convenience and practicability of the present method for the study of rocks, and as it is sanctioned by long and universal usage, it had better be retained, and the results stated in oxides.

The statement of the analysis then will be divided into two divisions, the main portion, in which are placed the principal oxides, and the subordinate in which occur all the rest.

The order in which the constituents may be put is the next consideration. That which is here proposed is as follows :

SiO₂, Al₂O₃, Fe₂O₃, FeO, MgO, CaO, Na₂O, K₂O, H₂O (ignit.), H₂O (110°), CO₂, TiO₂, ZrO₂, P₂O₅, SO₃, Cl, F, S (FeS₂), Cr₂O₃, NiO, CoO, MnO, BaO, SrO, Li₂O.

As regards the main portion the sequence usually adopted seems eminently proper. This is SiO₂, Al₂O₃, Fe₂O₃, FeO, MgO, CaO, Na₂O and K₂O. In this we start out with the chief acid radical and the constituent present in largest amount, and go through successively lower orders of oxides to the most positive radicals, the alkalis. At the same time they are presented in a way which brings the oxides together in their natural petrographic and mineralogic relations. The sesquioxides are together; ferrous iron follows ferric, MgO is next to FeO, as the two go hand in hand in the ferro-magnesian minerals; CaO is intermediate as is proper, since it is a constituent both of these and of the feldspars, and it is next to Na₂O, as it is associated with it in plagioclase.

H₂O should follow K₂O, as it is a highly important and regularly determined constituent. I follow Hillebrand* in urging the separation of ignition and hygroscopic water, putting the former first, as being an essential ingredient. Next to these should come CO₂, as this, with H₂O, is a measure of the freshness of the specimen, and this character can, therefore, be told at a glance. Together also they constitute the "loss on ignition" so often given, and in this case can be connected by a bracket.

* Hillebrand, Bull. 148, U. S. G. S., p. 29, 1897.

After these it seems well to put the acid radicals which have been determined, following the main principle of the other division; TiO_2 and ZrO_2 should come first, then P_2O_5 and V_2O_5 . SO_3 is put next instead of at the head of the lesser acid radicals, as it, like Cl which follows, is a constituent of the sodalite group. F comes after Cl, and then S or FeS_2 may be put.

Then come the subordinate metallic oxides, in the order R_2O_3 , RO , R_2O . These would include Cr_2O_3 , (Ce_2O_3) , NiO , (CoO) , MnO , (CuO) , BaO , SrO , Li_2O . Finally in rare cases C or N may be put at the last.

While the above order of arrangement is undoubtedly open to criticism in certain respects, yet it seems to the writer, as well as to other petrographers to whom it has been submitted, to be on the whole the most logical and convenient. It may be added that practical experience of it in the collection of a large number of analyses sustains this view.

I would also urge the advisability of printing the important molecular ratios with each new analysis, wherever this is possible. The reader will be saved the trouble of calculating them for himself, and will thus immediately have a fuller comprehension of the character of the rock.

In this connection I would suggest, as a practical and convenient method for using analyses, the use of a card catalogue, the cards being printed with the oxides in their proper order. Experience has shown the utility of such a plan, and the time given to its preparation will be more than compensated for by that saved in reference and collation.