ART. XLVIII.—*On certain Points in Petrographic Classification;* by WHITMAN CROSS.

THE Quantitative Classification of Igneous Rocks, proposed by Cross, Iddings, Pirsson and Washington,* is based on principles and conceptions which, at the time the system was first published, in 1902, had been given but little prominence in petrography. Both principles and essential features have been discussed in a scientific spirit by petrographers of various countries. This discussion and the criticism or suggestion based on it have been helpful to the backward science of systematic petrography and are, of course, welcomed by the authors of the Quantitative system.

The name "Quantitative System" was used because it was desired to emphasize the fact that definite quantitative factors were used in it throughout, making it contrast with earlier systems. But manifestly there may be many other quantitative systems and I shall here refer to this first one as the C. I. P. W. classification or system, following a precedent established by several writers.

Some of the criticisms and comments which have been freely, and in certain cases casually, made concerning the C. I. P. W. system, have seemed to its authors too evidently fallacious to need reply. But when such critical comments are repeated by petrographers with the reputation enjoyed by R. A. Daly and Waldemar Lindgren we must take a different attitude, for their remarks should certainly be free from the suspicion of prejudice or flippancy.

Dr. Daly has severely assailed the C. I. P. W. classification in his interesting work "Igneous rocks and their origin"† and while the criticism appears to me clearly fallacious, I must assume that it was carefully considered and deliberately made. The classification is said to be fatally defective in that "even its minor subdivisions individually include rock types which are strongly contrasted chemically and separate others which are almost alike chemically, mineralogically and genetically." The system is then stigmatized, on account of this "defect," as one which "disregards vital principles of scientific classification." These principles are not formulated.

The main conception, quite erroneously called a "principle," which is involved in Daly's criticism, may, I hope, be fairly expressed thus: *A division of a classification of rocks should not include types that differ very markedly in character*

* Whitman Cross, Joseph P. Iddings, Louis V. Pirsson and Henry S. Washington, "Quantitative Classification of Igneous Rocks," Jour. Geol., vol. x, 1902, pp. 555–690 and in book form, Univ. of Chicago Press, 1903.

† R. A. Daly, "Igneous Rocks and their Origin," New York, pp. 10, 11, 1914.

nor separate types that are very much alike. I suspect that this idea is entertained by many petrographers, with whom "the wish is father to the thought."

A principle is defined as "a truth which is evident and general." I should state the real principle involved in this matter as follows: *Since igneous rocks form a continuous series or field, as to chemical, mineral, and textural characters, the divisions of their systematic classification by these factors necessarily separate types that are nearly alike and include types that are relatively very unlike.* Petrographic system is in this respect analogous to any regular division of mass, space or time. The conception I attribute to Daly is antithetical to this principle. The C. I. P. W. system operates as Daly has pointed out, but this result is in harmony with the nature of things.

The criticism by Daly is strongly inconsistent as well as untenable, for the same "defect" he abhors in the C. I. P. W. system is clearly present even in the one he himself uses and advocates. For example, certain monzonites are very closely related to certain syenites but are relatively very different from those monzonites which are near relatives of essexite or gabbro.

Perhaps the prevailing vagueness of the current modal or mineralogical system of rock classification, whose partitions are elastic like rubber and permit some dilation or complementary contraction of its subdivisions according to the desires of the individual petrographer regarding certain rocks, may blind Daly to the existence in it of the same "defect" found by him in the C. I. P. W. classification.

An inconsistency in Daly's criticism, suggesting the control of prejudice, is further strikingly shown on the page following his denunciation of the C. I. P. W. system. He there states his adoption of the modal or Rosenbusch scheme, which he thinks will be improved in the course of time. To this Daly adds that "To become an ideal Mode classification it should be made quantitative."* But the divisions of this "ideal" modal, quantitative system would have sharpedly defined boundaries and necessarily include contrasting and separate similar rock types, under the general principle enunciated above.

Another fallacious comment on the C. I. P. W. system has been recently repeated by Lindgren † in a note on Iddings' review of Daly's book, above referred to. Lindgren says that Daly "does not stand quite alone" in his criticisms of

*Op. cit., p. 12. †Science, vol. xli, p. 166, 1915.

the Quantitative classification, and adds: "There are many of us who fail to see in this elaborate system anything but an admirable card classification of analyses." The same idea has been expressed before in the remark that the system classifies analyses, not rocks.

Now the authors of the C. I. P. W. system attempted a chemical classification of igneous rocks and spent long study on it. I must personally express my surprise and regret that a petrographer of Lindgren's standing should feel warranted in making a belittling and by no means lucid criticism of this work without a word of justification. His comment fails to explain (1) what he finds admirable in the system as a card classification of analyses, (2) how a classification of analyses, using the data presented by them, can be admirable if it does not classify the rocks analyzed, (3) why the system does not classify the rocks, (4) how chemical data should be used to classify rocks so that his objection may not apply.

Like Daly's criticism this comment touches abstract principles, in this case of chemical classification, but it rests partly, I think, on a misconception of the C. I. P. W. system.

The main interest a petrographer, as such, can have in classifying rock analyses is as to their usefulness to him, as complete or incomplete, good, bad, or indifferent, as Washington has done. He is interested in a good analysis only when it represents the composition of a known rock.

The fundamental importance of chemical composition of an igneous rock, bearing, together with variable and in part extraneous physical factors, primarily on its magmatic and genetic relations and later on its mineral composition, is beyond any need of discussion. To be sure, an Irish petrographer makes the claim that the chemical composition represented by analysis is not fundamental because the chemical composition of a specimen depends entirely on its mineral composition, while the latter depends partly on physical conditions. The classificatory value of chemical composition is stated by Daly, after an admirable review of the difficulties of accurate mineralogical classification, in these words—"the basis for an ultimate classification is now universally found in the chemical analysis (total analysis) of the rocks" (op. cit. p. 9).

In discussing rock classification by chemical composition it is desirable to first consider what a complete analysis of an igneous rock represents. 1. It represents as nearly as we can ever determine it the composition of the magma the consolidation of which has produced the hyaline, hypohyaline or crystalline rock. 2. It is a concise report, exhaustive in its way, made by an expert, on the fundamental material property of a rock. But this report is far from satisfactory in form when

the power of chemical composition to influence the mineral composition of the rock is considered. It is apparently this power which is the natural factor in chemical composition which should be used in systematic classification of rocks.

The customary statement of an analysis follows an old conventional form, giving simply the sum total of certain acid or basic radicals found in the material analyzed. The petrographer, in his attempts to interpret the significance of the proportions of a single analysis or of the differences in a series of analyses, as bearing on mineral development, has restated the analyses in various ways. They have been translated into a percentage statement of the elements. The molecular proportions of substances stated by analysis have been calculated and expressed in percentages. It is clearly possible, moreover, to transform all rock analyses into terms of a certain set of mineral molecules, selected for the purpose, and following some invariable rule for the calculation, as is necessary to secure comparable results. Such a set of molecules is the norm on which the C. I. P. W. system is based.

This primary character of the norm was not pointed out with sufficient clearness by the authors of the C. I. P. W. system in their original publication. They were too intent on explaining the reasons for the norm chosen, its practicability, and relation to the mode of the rock. Nevertheless the abstract character of a norm is evident from the discussion of the question as to the particular norm best suited to the purpose of the C. I. P. W. system.

The interpretation of analyses has also been attempted by means of various ratios between single constituents or groups of constituents and these factors have been used to characterize rock types established on mineral composition. In fact the use of chemical composition in a systematic way most frequently attempted by petrographers has been not a true chemical classification but rather a chemical characterization of primary mineral types, themselves established on a very faulty basis.

The chemical classification of igneous rocks may be effected by the use of the data presented in the analyses as stated by the chemist, as by percentage of silica, or of any consistent restatement or interpretation of those analyses, as in Rosenbusch's use of Atomzahlen. If chemical composition be chosen as the first and mineral constitution as the second factor in a system, it seems natural to apply the first factor in some way which expresses as nearly as possible some definite relation to the second. The C. I. P. W. system is an attempt to do this, recognizing that variable physical conditions attending the formation of the rock from the magma modify in dif-

ferent degrees and in different ways the specific mineral constitution but not the chemical character of the whole.

If this view of chemical classification is correct the criticism by Lindgren and others that the C. I. P. W. system classifies analyses and not rocks is not true. It appears to be an incorrect generalization based on the fact that the system leading to the new nomenclature is founded on proportions of normative molecules named after minerals of the same composition, while the crystalline rock analyzed usually does not have exactly that composition. But the C. I. P. W. system recognizes this fact most explicitly. It makes no assumption that the mode of a rock is, or, deploring the vagaries of Nature, that it ought to be, like the norm. The norm is merely a restatement of the chemical analysis in terms of mineral molecules, by which the major significance of complex variations in analyses may be expressed and more clearly comprehended.

The authors of the C. I. P. W. system call it "chemico-mineralogical,"* referring to the statement of the analysis in mineral molecules, and call the systematic terms "magmatic names"† since they may be considered as applying to the magma before the rock has formed from it. The C. I. P. W. system is extended to the actual rock by modifying terms expressing its motex‡ (mode and texture), but if one has in mind simply the chemical classification the magmatic name clearly applies also to the rock.

The criticisms of the C. I. P. W. system here considered really go back of that system to fundamental questions, in one case to petrographic system in general and in the other to methods of chemical classification. It is not the object of this discussion to consider the particular norm adopted by the authors of the C. I. P. W. system or the classification founded on it. I wish to say, however, that there are reasons for that norm, and that it is made up mainly of mineral molecules used by Michel-Lévy, Rosenbusch, Brögger, Harker and many other petrographers, in studies of the relation between the chemical and mineral constitution of igneous rocks. But the C. I. P. W. system is not assumed by its authors to be the "ultimate" classification of igneous rocks, although they believe it to be a step toward that end. Discussion of its merits and demerits and the test of use will determine its future, but criticisms in which fundamental principles or conditions of petrographic system are disregarded can not affect the issue.

* Op. cit., p. 111.
† Op. cit., p. 163.
‡ Op. cit., pp. 168-172.