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ON ROCK CLASSIFICATION

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“To **CLASS** rightly—to put in the same group things which are of essentially the same natures, and in other groups things of natures essentially different—is the fundamental condition to right guidance of actions.” These words of Herbert Spencer¹ may well form the introduction to this discussion, for they not only declare the importance of right classification, but state clearly in what it consists. It is because of the possibility of losing sight of its actual character in the approaching conflict over the reformation of rock nomenclature, that emphasis is laid at this time upon what seems to the writer to be the true character of rock classification. According to high authority² classification is “the act of forming a class or of dividing into classes.” And further, a class is defined as “a number of objects distinguished by common characters from all others, a collection capable of a general definition.”

To class rocks rightly would be to put in the same group or class those which are of essentially the same natures, or which may be distinguished by common characters from all others, and which may be capable of a general definition. This leads at once to a consideration of the nature of rocks and of the characters by which they may be distinguished from one another and which may be employed in their definition.

Nature and characteristics of rocks.—The origin or formation of rocks affects their nature to so great an extent, that it has been made a first basis for their subdivision, resulting in three categories: eruptive, sedimentary, and metamorphic. These, however, do not occupy the same position in the order of formation, but may be considered in one case as essentially primary, and in the others as secondary or derivative. The character of the rocks of these three categories, while possessing some points

¹ *Man vs. State*, p. 5.

² *The Century Dictionary*.

of similarity, are, nevertheless, so diverse in others, and the laws of their relationships are so unlike, that it is advisable to consider them separately. The present discussion will be confined to rocks of the first category—that is, eruptive or igneous rocks.

The most distinctive features of any igneous rock are those inherent in the mass, namely, the chemical composition, the mineral composition, and the manner in which the constituents are grouped together—the texture and physical aspect of the rock.¹ Other characters of quite as essential natures are, however, less distinctive; such are the form or dimensions of the body of the rock and its formal relations to adjacent rock masses; that is, its body as a geological unit and its occurrence or habitat, and finally its connection or relation to other igneous rocks—its association—and hence its origin.

These two groups of characters are of different orders. The first are clearly material, having to do with the chemical elements and the minerals making the substance of a rock. The second are modal, having to do with forms and relationships among rocks. Failure to recognize this difference has led to confusion of ideas and of methods in classification and in didactic treatment. The rapid development of speculation along the lines of rock genesis in conjunction with the accumulation of many facts regarding the composition, occurrence, and association of igneous rocks, has prevented the proper consideration of these phases of the science apart from one another.

It seems necessary to call attention to a difference which in this science, at least, must always exist between a classification of the material under investigation—the rocks—and a treatment for purposes of instruction or of discussion of the whole subject of petrology, or of the rocks of any petrographical province.

It may be thought at this point that the writer's conception of a classification is too narrow and restricted, and that a system

¹Cf. MICHEL-LÉVY, A., *Structures et Classification des Roches Eruptives*, Paris, 1889, p. 34.

of classification may be found, such that the two objects may be accomplished at one and the same time. It is the purpose of this paper to show that this is not consistent with the nature of the case, and that a classification of rocks and the didactic treatment of them cannot be based on the same method of procedure. In order to do this it will be necessary to consider: (1) the character of the constituents of individual rocks, both chemical and mineral; (2) the results of a study of the chemical composition of all kinds of igneous rocks; (3) the occurrence of these constituents in any rock as a result of processes of differentiation, according to generally accepted theories; (4) the chemical relations of series of rocks genetically connected; (5) the nature of a rock-body or geological unit; (6) the nature of rock-association, as in petrographical provinces.

The character of the constituents of igneous rocks both chemical and mineral.—The same chemical elements occur as constituents of nearly all igneous rocks. In the great majority of those analyzed oxygen, silicon, aluminium, iron, magnesium, calcium, sodium, and potassium occur in measurable proportions; while other elements, as phosphorus, titanium, manganese, barium, strontium, chromium, nickel, cobalt, lithium, zirconium occur in determinable amounts in many rocks, and in traces in others. In many cases their presence has not been sought. In numerous cases other elements are present in very minute quantities as shown by the frequent occurrence of allanite containing the rare elements cerium, lanthanum, didimium.¹ Neglecting for the present elements commonly occurring in very small amounts, the eight elements first named are those which chiefly characterize igneous rocks. In very few cases one or two of these may be absent or in traces only, but in almost every case they are all present. Chemical differences among these rocks consist in the proportions in which all of these elements exist in each case. Hence a classification of igneous rocks

¹CLARKE, F. W., On the Relative Abundance of the Chemical Elements, Bull. U. S. Geol. Survey, No. 78, 1891, p. 34. Also Bull. U. S. Geol. Survey, No. 148, 1897. See also ZIRKEL, F., Lehrbuch d. Petrographie, 2d ed., 1893, Vol. I, p. 648.

upon a chemical basis in nearly every instance is the grouping together of rocks that have like proportions of the same chemical elements.

The mineral components of igneous rocks are somewhat less constant in character than the chemical elements. Rocks occur that have distinctly different mineral components such as a granite with quartz, orthoclase and biotite, and a gabbro with labradorite, augite and hypersthene. But others occur having the same kinds of minerals in quite different proportions, such as a granite with much quartz and orthoclase and little biotite, and a syenite with much orthoclase and little quartz and biotite. Neglecting for the present the rarer or least abundant minerals that are found in igneous rocks, the characteristic ones are: quartz, feldspar, leucite, nephelite, sodalites, analcite, micas, pyroxenes, amphiboles, olivine, magnetite. Of these only one possesses a fixed composition, that is, quartz. Magnetite may contain a variable amount of titanium. Leucite, nephelite, and analcrite may vary in the relative proportions of potassium and sodium present. Olivines differ in the proportions of iron and magnesium. While the others represent series of minerals grouped together on crystallographic grounds, but varying often widely in chemical composition. The feldspars embrace polysilicates with variable amounts of potassium and sodium, besides compounds assumed to consist of polysilicate and orthosilicate, varying in alkali metals, calcium and silicon. Micas, pyroxenes, and amphiboles present groups which are chemically still more variable. The chief mineral components of rocks then are not definite chemical compounds, but are substances that may vary within limits according to the proportions of the chemical elements in the magma from which the rock solidified. Moreover the same chemical elements appear in several of these minerals: oxygen in all, silicon in all but one, aluminium and the alkali metals in five, iron and magnesium in four, calcium in three and so on. Hence a change in the relative proportions of the chemical elements in a magma may affect nearly all of the mineral constituents.

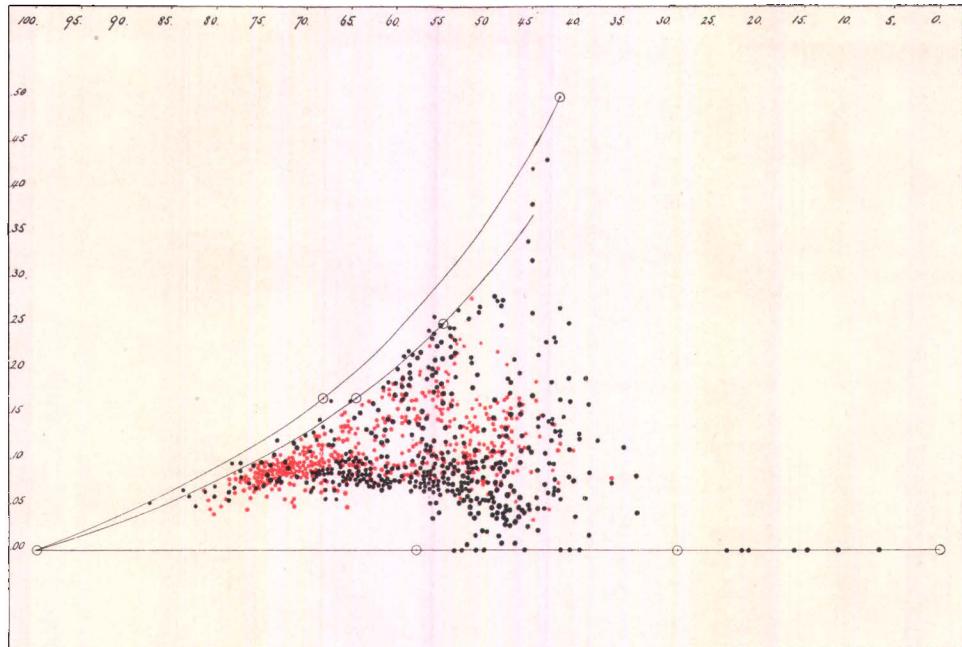


DIAGRAM 1.

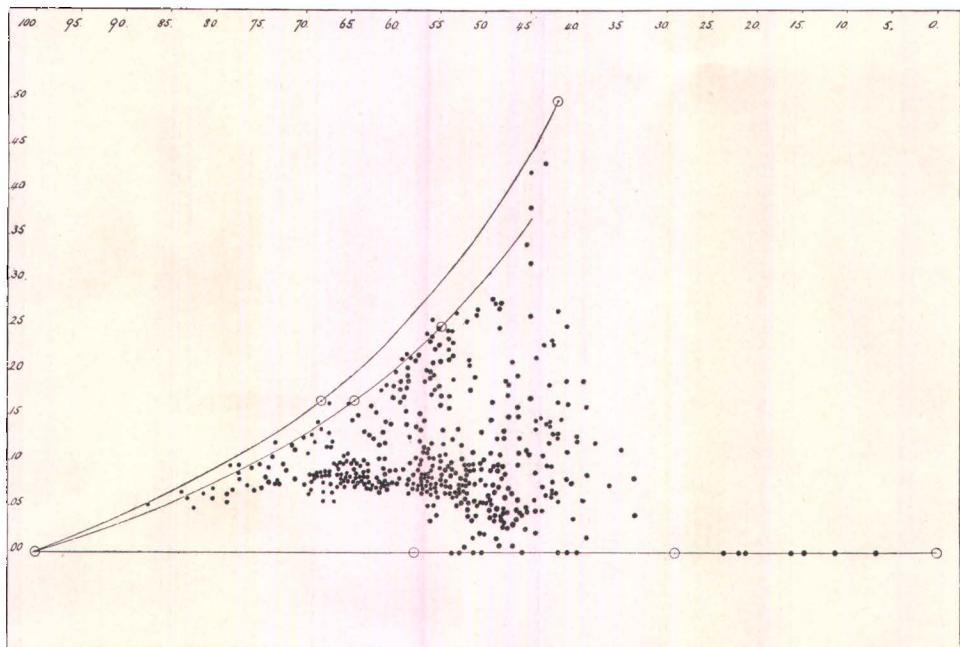


DIAGRAM 2.

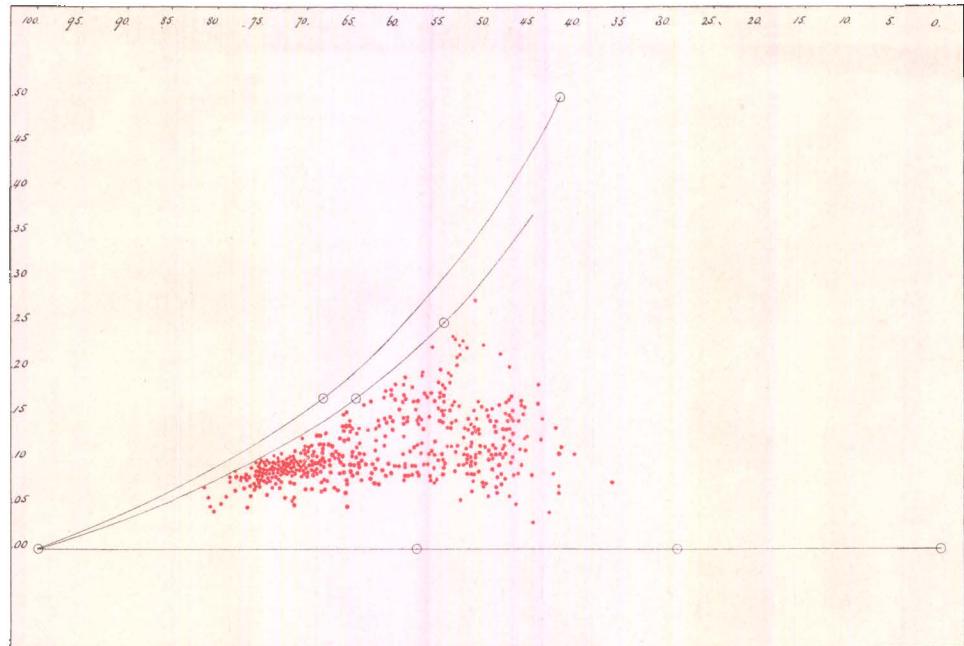


DIAGRAM 3.

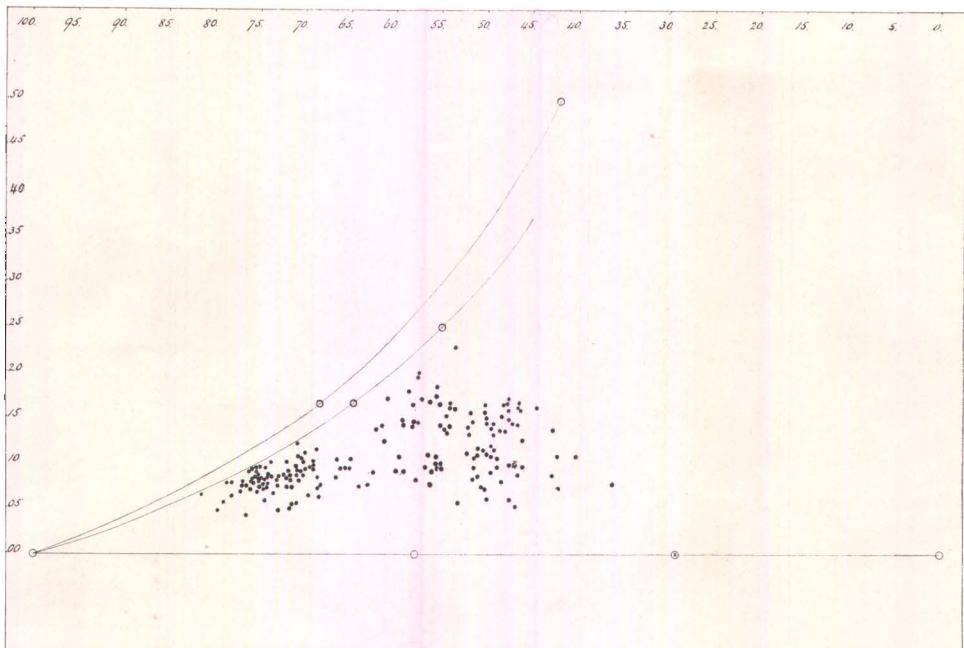


DIAGRAM 4.

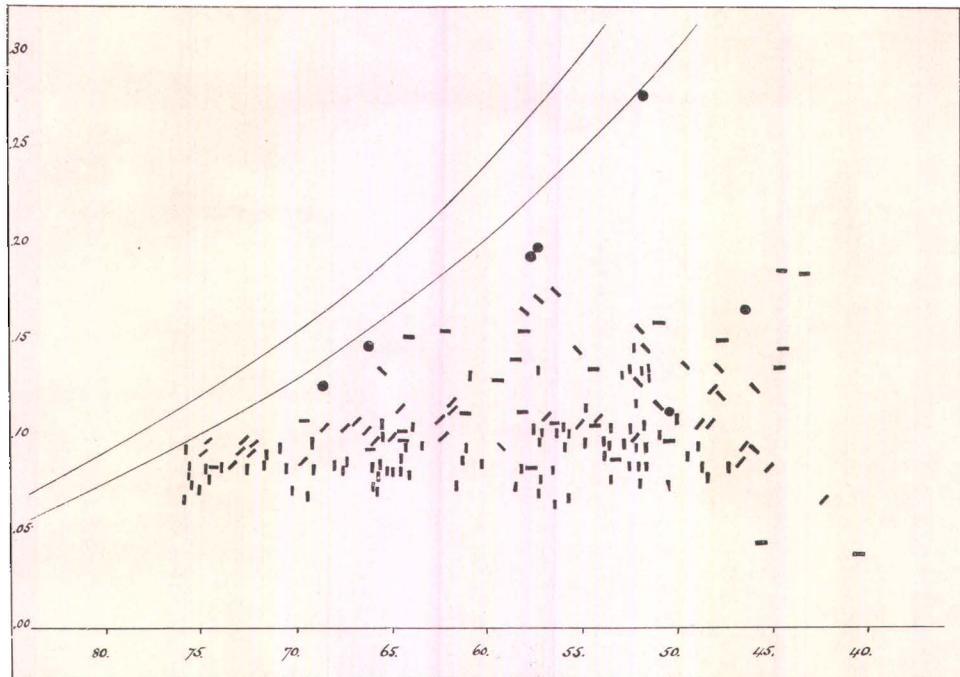


DIAGRAM 5.

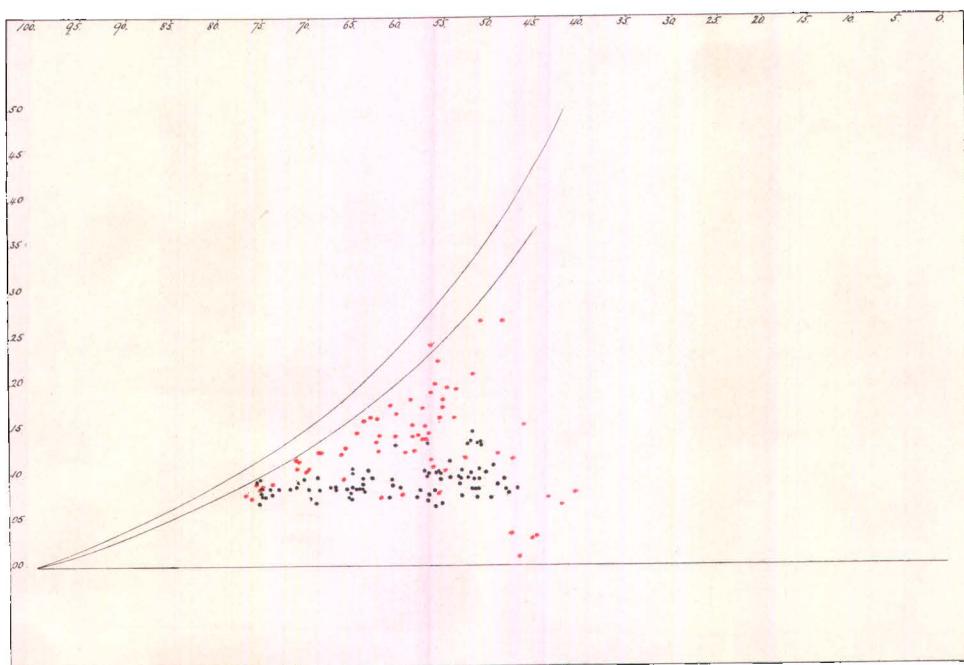


DIAGRAM 6.

The results of a study of the chemical composition of all kinds of igneous rocks.—In attempting a study of the chemical composition of all kinds of igneous rocks it was found necessary at the outset to devise some means by which the variations in the chemical analyses could be compared with one another graphically or by tabulation. It was also thought desirable to consider the chemical composition in its relations to the mineral composition, as far as possible. Further it was necessary to reduce the number of variable quantities to be treated in any one scheme. And for convenience and economy of labor the oxides of the metals were employed instead of the metals themselves, in all cases their molecular proportions¹ being used and not their percentages by weight.

In order to reach a basis for the correlation of the minerals and the chemical compositions of the rocks, the minerals may be divided into two groups, one embracing quartz, feldspars and the feldspathoid minerals: leucite, nephelite, sodalite, and analcite; all except quartz containing aluminium and the alkali metals or calcium, and being free from iron and magnesium. The other group contains the amphiboles, pyroxenes, micas, olivine, magnetite; all excepting magnetite containing magnesium as well as iron. Muscovite may be classed with the first group, but grades into biotite and may also be classed with the second group. The first group includes orthosilicates of aluminium and sodium, metasilicates of aluminium, sodium, and potassium, polysilicates of aluminium, sodium, and potassium, and free silica. In each case the ratio between alumina and the alkalis is a constant 1:1; except in the sodalites, in which soda is somewhat in excess of alumina. Calcium combines with aluminium in an orthosilicate molecule in which the ratio between the alumina and lime is also 1:1. This anorthite molecule combines with albite molecules so as to form a continuous series of compounds from orthosilicate to polysilicate. A consideration of the occurrence of these minerals in igneous rocks shows that quartz

¹Found by dividing the proportionate weights of each oxide by its molecular weight.

does not occur with the alkali metasilicate or orthosilicate feldspathoid minerals. And these are found in rocks comparatively low in silica, the orthosilicate being most abundant in the least siliceous rocks. But quartz is found in variable proportions with polysilicate feldspars, usually in rocks high in silica. So that it appears to be a law that so far as the alkali-aluminous silicates are concerned the highest silicate forms which is possible with the available silica in the magma. Thus a close relationship exists between the amount of silica in the magma and the development of these ortho-, meta-, and polysilicates; as does also, quite naturally, the presence of free silica or quartz. No such evident relationship has as yet been discovered between the occurrence of the ferromagnesian minerals and the amount of silica in the magma.

Investigation also reveals the law, apparently of quite general application that to a great extent the alkalis in a magma control the alumina in such a manner as to compel it to enter a feldspathic mineral if possible,¹ so that a reasonable estimate of the amount of feldspathic constituents in a rock may be formed by reckoning the alkalis and alumina together with the available silica as alkali-feldspathic constituents. And while it is well known that the alkalis may enter abundantly into micas and to a less extent into amphiboles and pyroxenes, it seems to be the rule that they do not enter the two latter minerals to any considerable extent unless the alumina present in the magma is insufficient to form feldspathic minerals. The case of biotite is different and does not conform to the rule, necessitating some modification of it.

It seems true also that in a great majority of cases aluminium does not combine with calcium to form anorthite molecules unless there is an excess of alumina over the alkalis in the magma. Exceptions to this rule, of course, occur, but its appli-

¹ This assumption which has been used by the writer in his lectures as a working hypothesis for several years has also been advocated recently by MICHEL-LÉVY in his paper entitled *Classification des Magmas des Roches Éruptives*, Bull. de la Soc. Géol. de France, 3d series, Vol. XXV, pp. 342-343, Paris, 1897.

cation appears to be more general than was at first suspected ; and by means of both laws a crude approximation to the composition of the feldspathic constituents in any rock may be obtained.

With regard to the occurrence of the minerals of the second group, it is a general law that they are most abundant in proportion to the diminution of silica and of the feldspathic minerals, so that an expression of the variations in these will also express inverse variations in the ferromagnesian minerals. To a very considerable extent the occurrence of the orthosilicate, olivine, and of the metasilicate, hypersthene, depends on the available silica in the magma, the former occurring in rocks with lower silica.

From these considerations it is evident that a comparison of the chemical composition of rocks may be undertaken so as to bring out the relations between the alkalis and the silica, and between these components and the feldspathic constituents, and that indirectly some notion may be had of the relations of the ferromagnesian constituents. Since two coördinates or variables only can be employed in a plane diagram or table, and a third involves a representation in three dimensions, or by some other device, it is necessary to reduce the factors to at least three. Those selected for the present investigation are, first, the silica on account of its important rôle in conditioning the character of the alkali-feldspathic constituents ; second, the molecular ratio between the alkalis, soda, and potash, taken together, and the silica $\left(\frac{Na_2O + K_2O}{SiO_2} \right)$, for this corresponds to the relative proportions of orthosilicate, metasilicate, and polysilicate feldspar and quartz. The amount of silica in each case was made the abscissa and the alkali-silica ratio the ordinate, and since these quantities are not of the same kind, it is not necessary that the scale of parts should be the same for both. For convenience the amounts of silica were plotted directly from the percentages in each analysis. By this means it is possible to investigate the distribution of all the rock analyses studied with

reference to these two factors. A third factor may be expressed by inserting a number at the locus in the diagram of each rock analysis which shall indicate some other molecular ratio, such as that of the approximate feldspar

$$\left(\frac{Al_2O_3 - (Na_2O + K_2O)}{2(Na_2O + K_2O)} \right)$$

Or in another case the molecular ratio between the ferrous oxide, magnesia, and the lime not calculated with the anorthite molecule, and the silica.

$$\left(\frac{FeO + MgO + CaO - (Al_2O_3 - [Na_2O + K_2O])}{SiO_2} \right)$$

The comparison by the method just indicated of 928 chemical analyses of igneous rocks has given rise to the accompanying diagrams. The analyses were selected with care in order to avoid those of much altered rocks, or those likely to be untrustworthy. The greater part have been made by chemists of the U. S. Geological Survey, which has furnished the most considerable contribution to the knowledge of the chemistry of rocks ever made by any organization. The analyses include those of all known kinds of igneous rocks that have been analyzed, so far as the writer has encountered them.¹

Diagram 1 shows the distribution of all the analyses, the black spots representing those in which soda is more than twice the potash molecularly; the red spots those in which it is less than twice the potash. Diagram 2 is for all those in which the

molecular ratio of soda to potash is greater than 2, $-\frac{Na_2O}{K_2O} > 2$.

Diagram 3 is for all those in which this ratio is less than 2, $-\frac{Na_2O}{K_2O} < 2$. Diagram 4 is for those analyses in which this ratio is equal to or less than 1, $-\frac{Na_2O}{K_2O} \leq 1$. One of

¹The analyses have been taken from the following sources: Analyses of Rocks and Analytical Methods, Bull. 148, U. S. Geol. Survey, 1897. Analyses in papers published by PIRSSON and WEED. ROTH's tables of rock analyses. BRÖGGER's publications, and many others.

the most notable features of Diagram 1, is the evident limitation of the range of alkali-ratios along the curved lines. These lines were suggested by the distribution of analyses in the diagram and represent in one case, the upper line, the possible range of analyses for rocks consisting wholly of silica, alumina, and soda, the two last elements being always in the proportion of 1:1; corresponding to nephelite at one extreme, succeeded by a mixture of nephelite and a possible metasilicate of these bases, or of nephelite and albite, and of albite and quartz, and finally of quartz alone. In the case of the lower line the curve corresponds to a possible range of analyses for rocks consisting of silica, alumina, and potash, the latter being in the proportion of 1:1. The mineral range would be from pure quartz, through a mixture of quartz and potash feldspar, to one of potash feldspar and leucite, to a possible orthosilicate of aluminium and potassium, corresponding to a potassium nephelite. In not a single instance is the sodium-aluminium limit transgressed, and only a few cases occur beyond the potassium limit. The rocks actually consist of the minerals just named. A nearly pure nephelite rock exists as urtite from the Kola peninsula,¹ and as portions of the nephelite-syenite of Dungannon township, Canada, described by Professor F. D. Adams.² A nearly pure albite rock has been found in California, by Mr. H. W. Turner.³

The fact that these limits are so closely approached, but never transgressed, is a clear indication that the alkalis do not exist in greater proportions than may satisfy this series of ortho-, meta- and polysilicate molecules. There are instances, however, in which part of the requisite alumina is replaced by ferric oxide.⁴ There are a few cases in the neighborhood of

¹ RAMSAY, W.. Urtit, ein basisches Endglied der Augitsyenit-Nephelinsyenit-Serie, Geol. Fören. i Stockholm Förhandl,— Bd. 18, Häft 6, 1896, p. 459.

² ADAMS, F. D., On the Occurrence of a Large Area of Nepheline-Syenite in the Township of Dungannon, Ontario, Am. Jour. Sci., Vol. XLVIII, July 1894, p. 10.

³ Further Contributions to the Geology of the Sierra Nevada, 17th Ann. Rep. U. S. Geol. Survey, Washington, 1896, p. 728.

⁴ The most marked exception to this rule is the group of rocks from Leucite Hills, Wyo., described by CROSS, Igneous Rocks of the Leucite Hills and Pilot Butte, Wyoming, Am. Jour. Sci., Vol. IV, 1897, pp. 115-141.

these limits in which alkalis are in excess of the alumina, when sodalite minerals abound;¹ and others in which alumina is in excess, when muscovite forms. From the foregoing it appears that if differentiation has taken place to produce these magmas there has been no considerable accumulation of alkalis independently of all other constituents. And from the approach to the pure nephelite molecule by sodium magmas, and from the limitations of the potassium magmas in the neighborhood of the leucite molecule, there is the strongest indication that the differentiation of the magmas affected molecules more complex than simple oxides of potassium and sodium, and probably as complex as silicates of aluminium and sodium or potassium, corresponding to known mineral molecules. However, as already stated, there are proofs deducible from the laws of crystallization that the molecules in molten magmas are not stable or fixed, and the aluminium and potassium, for example, may enter orthoclase, leucite or biotite according to circumstances in the form of ortho-, meta- or polysilicate.²

In the direction of the maximum limit of silica, there are rocks consisting of alkali-feldspars and abundant quartz, which may grade into pure quartz, as suggested by Lehmann³ and Howitt;⁴ certain quartz veins being eruptive and extreme forms of aplitic intrusions. Thus the oxide molecule, SiO_2 , appears to be capable of separation by processes of differentiation from other silicate molecules. If analyses had been made from these rocks, the diagrams would have shown a distribution of analyses as far as 100 per cent. of silica. The minimum limit of silica should occur in connection with differentiation products free

¹ WEED, W. H. and PIRSSON, L. V., The Bearpaw Mountains of Montana, *Am. Jour. Sci.*, Vol. II, No. 9, 1896, p. 197.

² IDDINGS, J. P., The Origin of Igneous Rocks, *Bull. Phil. Soc.*, Washington, Vol. XII, 1892, p. 176.

³ Untersuchungen über die Entstehung der altkristallinischen Schiefergesteine, etc., Bonn., 1884, p. 55.

⁴ Notes on the Area of Intrusive Rocks at Dargo, *Trans. Royal Soc.*, Victoria, 1887, Vol. XIII, p. 152. Also Notes on Certain Metamorphic and Plutonic Rocks at Omeo, p. 10.

from silicate minerals, such as certain iron ores¹ whose analyses occur at the extreme lower right hand corner of Diagram 1. From these it is evident that molecules of iron oxides may separate by differentiation from silicate molecules. The maximum limit for soda will be when the soda-silica ratio is 0.5, that is when $\text{NaO}_2 = 21.75$ per cent. and $\text{SiO}_2 = 42.10$ per cent. The maximum limit for potash will be when the potash-silica ratio is 0.25, that is when $\text{K}_2\text{O} = 21.51$ per cent. and $\text{SiO}_2 = 54.92$ per cent. Both alkalis sink to a minimum of zero in certain kinds of peridotites, pyroxenites, and in certain eruptive iron ores. They may disappear in anorthosite composed of pure anorthite.

The limit of distribution of analyses toward low silica appears to be a line which would correspond to a variable mixture of the lowest alkali-alumina silicate—nephelite for soda magmas, and leucite for potash-magmas—and the least siliceous ferromagnesian silicate, fayalite. This limit will probably be modified when series of rocks are analyzed grading from gabbros to the iron ores. The range of variations in the proportions of iron oxides, magnesia, lime and alumina, does not appear in these diagrams.

In this connection it may be pointed out that the variations in all of the chemical constituents, other than silica, must increase in proportion as silica decreases. When 75 per cent. of the magmas is silica, only 25 per cent. remains for other constituents, but when there is only 40 per cent. of silica, 60 per cent. must consist of other compounds. It is known that rocks high in silica contain much more alumina and alkalis than other constituents, hence the variation in these other constituents cannot be great. The greatest variation occurs when part of the alumina is replaced by ferric oxide. But in rocks low in silica there is no general law controlling the other constituents, which may, therefore, vary widely in different rocks. Consequently the number of different kinds of rocks possible

¹ Voigt, J. H. L., Bildung von Erzlagerstätten durch Differentiationsprozesse in basischen Eruptivmagmata, *Zeitschr. für prakt. Geol.*, Berlin, 1893, Jan., Apr.

for any given percentage of silica is much greater the lower the percentage of silica.

Diagram 1 shows that within the limitations above mentioned there are nearly all possible transitions in relative proportions of alkalis and silica, and the same is true for other constituents. Diagrams 2, 3 and 4 show that the range of alkali variation is greatest for rocks in which the ratio of the soda to the potash is greater than 2, and least for those in which it is less than 1. That is, it is greatest for distinctly sodic rocks and least for those very rich in potash.

While there is a clustering of analyses in the parts of the diagrams corresponding to lower alkali-silica ratios, there are no loci of specially marked aggregation, except toward the most siliceous end of the more potassic groups, and no such clustering as to suggest natural subdivisions of the analyses on any chemical basis. A chemical subdivision must be an arbitrary one, making breaks in continuous series. Comparison of Diagrams 2, 3 and 4 shows that the most siliceous rocks are generally richer in potash than in soda, also that the rocks in which alkalis decrease to nearly zero contain much more soda than potash. Those parts of the diagrams in which few analyses occur will undoubtedly be filled up as more rocks are analyzed.

It is to be noted that analyses occurring in close proximity to one another in these diagrams, and nearly alike in percentages of silica and alkalis, may in some cases differ more or less widely in other respects, so as to belong properly to different classes of rocks. They are by this method of comparison the more strongly contrasted and their essential differences more clearly recognized. This method of comparison brings closely together rocks agreeing in chemical composition, but often differing in mineral composition and physical characters, and having quite different names, and in this way emphasizes the necessity for improved definitions of names already in use and for the creation of a systematic nomenclature.

The occurrence of these constituents in any rock as a result of proc-

esses of differentiation according to generally accepted theories.—A study of the crystallization of rocks has shown¹ that different minerals and combinations of minerals may form from magmas chemically alike, according to physical conditions influencing the crystallization, proving that the chemical constituents in the molten magma do not exist, wholly at least, in definite or fixed combinations or molecules corresponding to distinct mineral molecules. Moreover, if the molecular character of a molten magma shortly before it solidifies is not fixed, but is flexible, its molecular character at an earlier period, when differentiation may take place is undoubtedly flexible or unstable, and probably to a greater degree. This is indicated by the variability in the composition of minerals of the same group, such as pyroxenes, feldspars, etc., in rocks genetically related, and assumed to have been derived by differentiation from a common parent magma. Thus in genetically related rocks the feldspars may range from those high in potash to those high in sodium and to others low in alkali metals and high in calcium; pyroxenes may range from those rich in calcium and magnesium, with little iron and aluminium, to others richer in the latter elements and to those rich in sodium and iron. Several members of either of these mineral series or groups may occur together in one rock, and may occur in varying proportions in different rocks.

The facts known regarding the mineral composition of genetically related rocks, to which the theory of differentiation has been made to correspond, are that the proportions of the component minerals, as well as their chemical compositions vary not only with different bodies of rocks, but not infrequently with one rock-body. Furthermore, this variation is in many cases gradual, with known transitions, while in other instances differences of composition are marked, and transitional forms have not yet been found. Consequently from the theory of differentiation

¹ ROTH, J., *Gesteinsanalysen in tabellarischer Übersicht*, etc., Berlin, 1861, p. 21.

IDDINGS, J. P., *Bull. Phil. Soc. Washington*, 1892, Vol. II, p. 217. Also 12th Ann. Rep. U. S. Geol. Survey, Washington, 1892, p. 659.

LINDGREN, W., *A Sodalite-Syenite and other Rocks from Montana*, Am. Jour. Sci., Vol. XLV, 1893, p. 297.

rocks with variable proportions of the mineral constituents are to be expected to be the rule rather than the exception. And when all igneous rocks are taken into consideration all possible combinations of mineral proportions may be anticipated.

The chemical relations of series of rocks genetically connected.—The chemical characters of genetic series of rocks has been considered their most distinguishing and essential characteristic—the one quality that established their consanguinity.¹ It might be thought then that such a feature could be employed as a means of classifying igneous rocks in groups corresponding to genetic series. Careful consideration of the actual nature of this chemical character will lead to the opposite conclusion.

Certain genetic groups of rocks are distinguished by relatively high alkalis, in one instance largely potash, in another largely soda. Other genetic groups are characterized by relatively low alkalis. But even in these series not every rock contains the same high or low alkali ratio as the preponderating varieties. In fact there are often members of the series which are chemically quite different from the greater number of rocks belonging to the series. In some genetic series it is the ratio between the potash and soda that is characteristic, the total alkalis being large in some rocks of the series and low in others. But here again the ratio is never constant, and the variation may be quite large.² In no one genetic series yet described has any single chemical character been found to be persistent throughout the series. Nevertheless the transitions between the rocks of the series are sufficiently pronounced to leave no reasonable doubt that the rocks in question have been derived from

¹ ROSENBUSCH, H., Ueber die chemischen Beziehungen der Eruptivgesteine, Min. u. petr. Mitth., Vienna 1889, Vol. II, pp. 144-178.

BRÖGGER, W. C., Die Mineralien der Syenitpegmatitgänge der Südnorwegischen augit- und nephelinsyenite, Zeitsch. für Kryst. u. Min., Leipzig, 1890, Vol. XVI.

IDDINGS, J. P., Origin of Igneous Rocks, Bull. Phil. Soc. Washington, 1892, Vol. XII, p. 135.

² BRÖGGER, W. C., Die Eruptivgesteine des Kristianiagebietes. I. Die Gesteine der Grorudit-Tinguait-Serie, Christiania, 1894, 165.

WEED, W. H. and PIRSON, L. V., Geology of Castle Mountain Mining District, Montana, Bull. U. S. Geol. Survey, No. 139, 1896, p. 137.

some parent magma by some process of chemico-physical separation or differentiation.

Besides genetic series that are chemically quite distinct from one another there are others much less so, and others that resemble one another closely. Petrographical provinces are in some cases strongly contrasted chemically. But in certain regions there appears to be a gradual shifting in chemical composition of the rocks from one locality to another. This is well illustrated in the region embracing the Yellowstone National Park, the Crazy Mountains, Castle Mountain, Little Belt Mountains, Highwood, and Bearpaw Mountains in Montana.¹ The series of rocks at each of the localities named becomes relatively richer in alkalis from the south northward, potash assuming a very prominent rôle. The analyses from these localities to the number of 175 are compared with one another in Diagram 5, which shows the gradual shifting of the alkali-silica ratios.

In general a more or less gradual shifting of chemical characters with increase in alkalis obtains for genetic series of rocks from the Great Basin in Nevada, Idaho, and Utah eastward across the Rocky Mountains to the Black Hills, S. D., Leucite Hills, Wyo., Cripple Creek, Colo., into Arkansas and southward into the Transpecos region of Texas. Throughout this vast region there are innumerable genetic series of igneous rocks. The series from somewhat remote parts of the region are chemically quite clearly distinguished, but series from intermediate localities grade into one another so that there are in reality series of series. The term series in the sense here used applies to all igneous rocks of one petrographical province that belong to one period of volcanic activity, which may be of very great

¹ IDDINGS, J. P., The Eruptive Rocks of Electric Park and Sepulchre Mountain, Yellowstone National Park, 12th Ann. Rep. U. S. Geol. Survey, 1892, pp. 569-664. Origin of Igneous Rock, loc. cit. Absarokite-Shoshonite-Banakite-Series, JOUR. GEOL., Vol. III, Chicago, 1895, p. 935.

WEED, W. H. and PIRSSON, L. V., Geology of the Castle Mountain Mining District, Montana, loc. cit. Highwood Mountains of Montana, Bull. Geol. Soc. Am., Vol. VI, Rochester, 1895, pp. 389-422. The Bearpaw Mountains of Montana, Am. Jour. Sci., Vol. I, 1896, pp. 283, 351; Vol. II, pp. 136-188. Also Bull. U. S. Geol. Survey No. 148, Washington, 1897, pp. 117-136, 142-157.

duration, embracing a whole geologic period, as, for example, the Tertiary. It may include a number of lesser series of eruptions localized within the province, as at centers of eruptions such as volcanoes; and may be highly complex, having many branchings. In some series the range of chemical variations is comparatively small, in others it is comparatively great. Examples of these appear in the rocks of the Yellowstone Park and in those of the Christiania region, whose analyses have been plotted in Diagram 6; the red spots representing those of the Christiania region.

If more limited genetic series are compared it is found that in one case the chemical variation is chiefly in the line of silica, from much to little, accompanied by abundance of feldspar molecules for the higher silica, and abundance of ferromagnesian molecules for lower silica. While in another case the chemical variation affects the silica but slightly, and shows itself in the relative abundance of alkalis and alumina on the one hand, and of ferromagnesian molecules on the other.¹ The definition of a genetic group or family of rocks, as expressed chemically, must, therefore, be very flexible and indefinite.

The natural consequence of the variability of composition among rocks of one genetic series, and of the existence of genetic series closely similar to one another chemically, is the close resemblance of some rocks of one series to certain rocks of other series. And since the differences in most cases consist in the relative proportions of the same chemical elements, it follows that some rocks of one genetic series are quite as much like certain rocks of another series as these are like other rocks of the same series. Hence, a chemical definition broad enough to cover several closely similar rocks of one genetic series may apply equally well to similar members of another genetic series, and it cannot be framed so as to exclude them. In other words, it follows from the very nature of a chemico-physical differentiation of rock magmas that some rocks belong-

¹ IDDINGS, J. P., Absarokite-Shoshonite-Banakite Series, *JOUR. GEOL.*, Vol. III, Chicago, 1895, p. 935.

ing to different genetic series, or to different petrographical provinces, may be chemically alike.

The same is true with regard to the mineralogical characteristics of rocks. Since these are primarily dependent on the chemical composition of the magma of each rock, and also on the physical conditions attending its solidification, it follows that the minerals composing certain members of any genetic series of rocks must be like the minerals in some members of other genetic series. Definitions based on the character and proportions of these minerals must apply equally well to members of several genetic rock series.

Moreover, the texture, granularity, and physical aspect of rocks depend on both the composition of the magma and the physical conditions under which solidification took place. The latter are independent of geographical position; that is, are not localized, but are universal, and cannot be peculiar to any petrographical province. They depend on the environment of the magma in each instance, and magmas in different provinces may have existed amid similar environment and have been exposed to almost identical physical conditions.

The most distinctive features of igneous rocks, then, their chemical and mineral composition and texture, cannot serve as means of discrimination of rocks of all genetic series, consequently a group or class of rocks which may be of essentially the same natures as regards these essential qualities may embrace rocks belonging to different genetic series. It follows from this that the classing of all known igneous rocks into groups that shall have essentially the same chemical and mineral composition and texture, and which may be designated by definitions expressed in terms of these qualities, must disregard the genetic relations among the rocks of different classes.

The nature of a rock-body or geological unit.—In the foregoing discussion the term rock has been used as though applied to a mass having in each case some definite composition and texture. But it is well known that in large masses this is not always the case. In some masses the texture varies in different parts of

the whole; in others the chemical and mineral composition varies.¹ These variations may be slight and within what may be considered the limits of variation for a given class of rocks, or they may be so great as to exceed these limits, and different parts of one continuous rock-mass may have characters belonging to different classes of rocks in the usual sense. The same variations and relations exist between different parts of some rock-masses as those just mentioned as existing between some rock members of various genetic series of rocks, and for exactly the same reason. Hence, definitions of rocks based on the essential, material characters—composition and texture—cannot be made so as to discriminate always between various rock-masses.

Rock-masses of this kind are geological bodies, in that they form integral parts of the crust of the earth, such as lava streams or sheets, dikes, laccoliths, stocks, etc. Rock-masses or rock-bodies, in distinction from rocks as considered in this discussion, can not be grouped in classes on the same basis as those on which the rocks can. They may be classified according to their form or dimensions, or their mode of occurrence, or according to some general idea of composition, as homogeneity and heterogeneity.

A knowledge of the characteristics of all rock-bodies as such is necessary to a proper understanding of the mode of occurrence of igneous rocks, and is essential to any comprehensive treatment of the science of petrology.

The nature of genetic series of rocks.—The character of series of rocks that occur associated in any region so as to be considered as genetically related, differ widely in different cases. Aside from the fact that all those in one region may have solidified within the crust of the earth, while those in another region may have reached the earth's surface and have consolidated at the surface and also within the crust, there are the subsequent geological events that have transpired in each case since solidification whereby the present exposure of the rocks has been

¹ IDDINGS, J. P., Genetic Relationships among Igneous Rocks, JOUR. GEOL., Vol. I, Chicago, 1893, pp. 833-844.

brought about. This may reveal parts of all the rock-bodies originally present, or much more probably only a certain number of all once in existence, some having been entirely removed or still remaining covered. The rocks exposed in any region seldom represent the whole series of varieties that actually exist or did exist in the region. Consequently some series or associations represent comparatively few varieties of rocks, and these often quite different from one another, as when only basalt, rhyolite, and one or two varieties of andesite occur in a region, whereas other series exhibit many varieties and frequent transitions from one to another as in the dissected volcanoes in the Yellowstone Park region. Again, it is found that the range of rock varieties in some regions is limited, and in others is very wide, indicating less differentiation of the parent magma in one case than in another.

A knowledge of these associations in various regions leads to a comprehension of the laws governing the production of varieties of igneous rocks, both their probable differentiation from a parent magma, and something of the mechanism of their eruption, consequently its importance in a treatise on petrology cannot be overestimated. The consideration of these relationships is absolutely essential to a right conception of the true nature of igneous rocks.

Classification of igneous rocks and the didactic treatment of petrology.—It is hoped that the foregoing discussion has made it apparent that a systematic classification of all kinds of igneous rocks cannot be put on the same basis as a philosophical treatment of the subject-matter of petrology, which takes cognizance not only of the material character of rocks, but also of the laws governing their production, eruption, mode of occurrence, and solidification, as well as their subsequent alteration.

The object of a classification of rocks is clearly the bringing together of those that have like characters in order that they may receive a common name, and that their descriptions may be systematically arranged for convenient reference. The use of names common to all similar rocks instead of individual names, such as are given to men, is also solely for convenience; it being

considered more useful to emphasize the characters common to the rocks bearing a common name than those which might distinguish them as individuals. Moreover, it must be admitted that there is need of a systematic arrangement of descriptions of rocks, and that the descriptions of all similar rocks should be found together.

With the need of systematic classification of descriptions of rocks is an equal necessity for a systematic nomenclature. The present nomenclature is an inheritance of the most fortuitous creations of the earliest investigators, whose knowledge was of necessity often imperfect or faulty, and of recent petrographers, whose suggestions of names have been based on no uniform system. The earlier names have undergone such changes of definition as in more than one case to shift them entirely from their original application. Terms derived from geographical localities, from physical characters, or from mineral components, have been used indiscriminately. Rocks differing from one another but slightly have in some cases received totally different names, in other cases names alike except for qualifying prefixes. The time has nearly arrived for a complete reformation of petrographic nomenclature. The need is urgent but the condition of our knowledge at present is scarcely such as to warrant the immediate attempt to create a systematic nomenclature. When it is devised it should not only be sufficient for present needs, but should be capable of further development along with the growth of our knowledge of the rocks themselves.

The object of a treatise on igneous rocks should be to convey an idea of the origin and geological history of such rocks, their intricate relationships with one another, and their material characteristics. To accomplish this, the known facts may be presented in a number of ways, and the subject may be approached from different directions. Different methods of procedure may commend themselves to different writers, and may be followed with equal success. But there should be one systematic nomenclature based upon some universally accepted classification. The exact nature of this classification has yet to be determined.

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