

ART. XIX.—*The Classification of Igneous Rocks—A Study for Students*; by L. V. PIRSSON.

[Professor Pirsson was engaged during the last years of his life in preparing a text book of petrography, based on microscopical methods. This book was planned to consist of 15 chapters and to cover the igneous, sedimentary, and metamorphic rocks. Unfortunately, however, but five of the fifteen chapters had been completed at the time of his death: the four chapters of Part I that comprise the necessary introductory matter to the volume (methods of studying rocks, determination of rock minerals, rock minerals and textures, and classification of rocks), and a large part of Chapter V, describing the phanocrystalline igneous rocks.

The following paper consists of the larger part of Chapter IV, with only minor verbal changes, and is presented here in the knowledge that Professor Pirsson's matured views on the classification of igneous rocks will be of wide interest. The subtitle, "A Study for Students," has been added in recognition of the obvious purpose of the author to present the subject matter primarily for the student.—ADOLPH KNOPF.]

*Igneous Rocks.*

*General Discussion.*—There are probably few matters in the domain of natural science in which there is less general agreement than in the classification of igneous rocks. The reason for this is very simple, and it lies in the fact that there are no natural absolute division lines to be found among them, which are obvious to every one and which compel unquestioning assent from all as a basis for classification. Everywhere there are gradations among igneous rocks, geologically in the form and mode of occurrence of their masses, and petrographically in the kinds of material composing these masses. Thus, geologically, we divide them into intrusive and extrusive rocks, and yet in one rock-body we may observe a dike passing upward into a flow without break in the mass; indeed, every extrusive flow, unless separated by erosion, must in principle pass into an intrusive mass. Again

in intrusive occurrences we find laccoliths grading into intrusive sheets, stocks running out in dikes, etc. This is true not only of the individual bodies, but of the masses grouped collectively; thus we may find occurrences in which it is arbitrary whether we shall call them intrusive sheets or laccoliths, dikes or stocks, stocks or batholiths. And so petrographically we may find one rock mass, like a stock, composed of different kinds of material sharply separated from one another, whereas in another mass one variety of rock substance passes most gradually into another variety, while collectively if the materials composing all igneous rock bodies are compared there will be found, mineralogically, and therefore chemically, whole series giving complete transitions from one kind into another.

It is therefore clear that any system of classification of the igneous rocks must be an arbitrary one, and an examination of those that have hitherto been attempted will prove the truth of this statement. Some which have been termed natural by their authors will be found to have divisions that seem natural only to the authors who made them. Others see no natural divisions in these places but would draw distinctions elsewhere. This is inevitable when one perceives that they are matters of opinion, and history teaches us that in matters of opinion men have always differed, and from this we infer that they are likely to continue to differ. The situation is similar to that of any continuous field which requires to be divided, like that of temperature or length for example, in which we see that one nation uses one scale and another nation uses a different scale. It will be profitable for us to consider briefly some of the more important attempts at classification and the principles upon which they are grounded.

*Some Systems of Classification.*—At the outset we must observe that it is possible to regard and classify igneous rocks from two different view-points. In one we may take account of the form, disposition, and relation of an igneous rock-mass and its relation to other rock-masses, in short its nature as a component unit in the architecture of the earth's outer shell. This is its mode of occurrence, whether intrusive or extrusive, whether a flow, dike, stock, etc., and is a *geologic* way of regarding it.

In the other we consider the kinds of material that make up such occurrences and the endeavor here is to classify the rocks according to those characters that would be inherent in representative masses selected from the rock-bodies. These characters would refer to the chemical composition of the mass, the kinds and relative proportions of the minerals composing it, if it is crystalline, and the sizes and arrangement of the mineral grains (texture), the specific gravity, etc. This we may term the *petrographic* way of viewing the rock. The geologic way considers its outward relations to other rocks, whereas the petrographic one regards its inward characters. The student will do well to bear these two viewpoints clearly in mind.<sup>1</sup>

We do not need to describe here the various systems of classification that have been suggested and more or less used in the past, but which are not now in vogue. Their interest is now historical and they have been clearly described and their merits and defects pointed out by Cross.<sup>2</sup> We shall consider briefly only those which are more or less in force to-day, and which consequently may be held to be of influence on the science of petrography.

*Qualitative Classification*—One of these is what may be called a purely petrographical classification and its chief exponent has, perhaps, been Zirkel.<sup>3</sup>

According to this the rocks are divided into classes dependent upon the kinds of minerals, the absence or presence and varieties of feldspars being given predominance, and then subdivided following the texture, that is whether granular, dense, glassy, etc. One other feature has been incorporated with this, especially in Germany, which demands notice, and this is a further subdivision of the fine, dense, and glassy rocks, which are often porphyritic, into two groups depending on their geologic age. Those that were older than the Tertiary received one set of names, whereas those that were of Tertiary age or younger were named differently, though

<sup>1</sup> See Whitman Cross, *Geological versus Petrographical Classification of Igneous Rocks*; Jour. of Geol., Vol. 6, p. 79; 1898.

<sup>2</sup> Whitman Cross, *Development of systematic Petrography in the Nineteenth Century*; Jour. of Geol., Vol. 10, p. 331, 451; 1902. Also in *Quantitative Classification of Igneous Rocks*, by Cross, Iddings, Pirsson, and Washington: Chicago; 1903.

<sup>3</sup> F. Zirkel, *Lehrbuch der Petrographie*; Vol. I, p. 829, 1893.

of very similar composition and texture. This was based on historical grounds; the older rocks are more likely to have suffered various modifications which cause them to appear somewhat differently from fresh recent ones of similar nature. Such differences were thought to be fundamental in character, to belong to the period at which the rocks were formed, and to thus deserve recognition by giving such rocks an especial set of names. Since it has been perceived, however, that these characters have been superposed on the rocks, and are therefore secondary in nature, this distinction has lost its force and has practically been given up, even in Germany, though the names have been in large measure retained, as a matter of convenience, to denote rocks which present these characters, without regard to their geologic age. This historical usage, which never obtained much currency in America and Great Britain, the student should note, in order that he may understand the literature which he may consult, particularly the older part of it, and appreciate the meaning of these terms when he meets them. They will be mentioned in appropriate places. Returning now to our classification, we may illustrate its

TABLE No. 1. ILLUSTRATING QUALITATIVE CLASSIFICATION OF IGNEOUS ROCKS

Even-granular.	Predominant Alkalic Feldspar			Predominant Soda-lime Feldspar			No Feldspar
	With Quartz	No Quartz	With Nephelite	With Hornblende	With Pyroxene	With Nephelite	
	Granite	Syenite	Nephelite-Syenite	Diorite	Gabbro & Norite	Theralite	Peridotite
Porphyritic, dense, glassy	Pre-Tertiary						
	Granite-Porphry	Syenite-Porphry	Neph. Syen. Porphry	Diorite-Porphry	Diabase.		
	Quartz-Porphry	Keratophyre		Quartz Porphry	Augite-Porphry		
Dense, glassy, porphyritic	Tertiary and Recent						
	Rhyolite	Trachyte	Phonolite	Dacite & Andesite	Basalt	Basanite	Augitite

principles by grouping some of the more important rocks into a table, No. 1, which will show its practical application. It should be noted that the coarser granular, non-porphyrific rocks are not divided according to geologic age.

*Remarks.*—Aside from the question of age, which is now practically obsolete, it should be observed that the system is defective in that little or no account is taken of the relative *quantities* of the component minerals that may be present in a rock. Thus syenite may contain some pyroxene, but a rock composed mostly of pyroxene with a very little alkalic feldspar, although chemically it may differ widely from the former, is equally classed as a syenite. The chemical composition of a rock is, however, its most fundamental property. The defect runs through the whole scheme and it is for this reason spoken of as the *qualitative system*.

It is to be noted also that the system is arbitrary; thus in texture, whether a rock shall be classed as granular, porphyritic, or dense is purely a matter of opinion in many cases. Also what is meant by “predominant” may be very often an open question. It is customary to class rocks as syenites when they contain a little quartz, but not if they contain a little nephelite; they then pass into the next division. Such examples might be greatly multiplied, but these are sufficient to indicate that the division lines are largely artificial, or arbitrary. The valuable feature of the system is, from the petrographic point of view, that it is based on the inherent, inward properties of the rocks, and not upon outward geologic relations.

*Geologic-Petrographic Classification.*—In this system of classification, which has been given a wide circulation and usage by the writings of Rosenbusch,<sup>4</sup> the effort is made to combine the geologic outward relations with the inward petrographic characters of the rocks. They are divided into abyssal (deeply-formed intrusive or plutonic) rocks (*Tiefengesteine*), and the volcanic or extrusive lavas (*Ergussgesteine*), as the chief groups, with a smaller subordinate group of dike rocks (*Ganggesteine*), with intermediate characters. The effusive rocks, or lavas, were again divided according to their geologic age on the same basis as in the system previously mentioned, but in the last edition of Rosenbusch’s work

<sup>4</sup> *Mikro-physiographie der massigen Gesteine* 1st, 2d, 3d, and 4th Eds. 1877-1908. *Elemente der Gesteinslehre*, 1st, 2d, and 3d Eds. 1898-1910.

this age distinction was laid aside. The groups of plutonic and effusive rocks thus formed on a geologic basis were subdivided according to their mineral composition on the same general lines as in the preceding classification. Texture in them is not used as a means of classification, except in so far that certain textures are held to accompany each group and to be characteristic of them; that is, the abyssal rocks are granular and the effusives are porphyritic. The dike rocks are subdivided

TABLE NO. 2, ROSENBUSCH CLASSIFICATION OF IGNEOUS ROCKS.

Characterized by	Plutonic Group Granular	Group of Dike Rocks Porphyritic and Panidiomorphic.			Volcanic Group Porphyritic.
		Granite-porph'ritic	Aplitic	Lamprophyric	
Alkalic } +Qtz. feldsp's } -Qtz.	Granite	Granite-porph'ry	Aplite		Quartz-porph'ry Rhyolite
	Syenite	Syen.-porph'y	Bostonite	Minette Vogesite	Orthophyre Trachyte
Alk. Feldspars and Nephelite, or Leucite	Nephelite-Syenite Leuc.Syen.	Neph.Syenite-porph'ry Leu.Syen.por'y	Tinguaite Leuc. Ting.		Phonolite Leucitophyre
Feldspathoids Nephe- } +Oliv. lite } -Oliv.	Bekinkinite Ijolite	-----	-----	-----	Neph. Basalt Nephelinite
		-----	-----	-----	
Leucite } +Oliv. } -Oliv.	Missourite Fergusite	-----	-----	-----	Leucite-Basalt Leucitite
		-----	-----	-----	
Melilite		-----		Alnöite	Melilite-Basalt
Alkalic or Lime-soda - Feldspars + Nephelite.	(Mafic) Theralite Shonkinite	-----	-----	Monchiquite ? (glass-base.)	Basanite (+Oliv.) Tephrite (-Oliv.)
Lime-soda Feldspars + Alkalic minerals (Mafic)	Essexite	Essexite-porph'ry	Gauteite	Camptonite	Trachydolerite
Lime-soda Feldspars (Andesine)	Diorite and Quartz-Diorite	Diorite-porph'ry	Malchite	Kersantite Spessartite	Porphyrite (+ or - quartz) Dacite (+qtz.) Andesite(-qtz)
Lime-soda Feldspar (Labradorite) + Pyroxenes.	Gabbro and Norite	Gabbro porphyrite	Beerbachite	Odinite	Diabase Basalt
No feldspar only Mafic mins.	Peridotite Pyroxenite				Picrite-porph'ry

into three groups; the first is identical with the abyssal plutonic, in chemical and mineral composition, but differs in texture, being distinguished as pronouncedly porphyritic; it is called the granite-porphyrific group. The second and third groups of dike-rocks are termed the aplitic and lamprophyric groups respectively, and they are formed on grounds of their chemical-genesis, a matter discussed more fully in a succeeding section; it is sufficient to say here that the aplitic group is felsic, the lamprophyres mafic in character, and they are held to be derived from the magmas which form the abyssal groups by the splitting process called differentiation. The two genetic groups are subdivided on mineralogical lines. The system may be seen summarized in Table No. 2.

Remarks.—In this table, No. 2, only a part of the many rocks named by Rosenbusch are given; they are, however, the most important ones defining the groups, and those omitted are mostly of the value of subordinate varieties. Anorthosite for example is treated as a variety under gabbro, though he is inclined to give it a group distinction on magmatic grounds. The table, however, will serve to illustrate the chief features of the system, though it is impossible in a set scheme of this kind to show the genetic relations of the aplitic and lamprophyric dike rocks to the plutonic groups that they accompany, and also some similar relations advanced for a small group of lavas that are held to be the effusive representatives of the lamprophyres.

Probably the most valuable feature of Rosenbusch's system is that in it was first clearly expressed the recognition of the genetic dependence of the so-called dike rocks upon the plutonic types, and the mutual derivation of aplites and lamprophyres from a single magma, though whether such relations furnish the best basis for a systematic classification which shall define the different varieties of igneous rocks is open to question. Aside from this point the chief defect of the system for petrographic purposes is the use of geologic relations to other masses in making definitions. The precise mode of occurrence of a rock-mass must be known before its component substance can be determined. This is of course a necessity in classifying occurrences geologically, but, as every one with any experience knows, it is often impossible in the field to determine the mode of occurrence of a rock-mass, and yet for description, mapping and other purposes it is necessary to state the kind of rock composing it. In a practical way the petrographer is constantly confronted with the problem of determining rocks of different kinds, for scientific and economic purposes, of whose mode of occurrence he knows little

or nothing. In actual practice, since this difficulty must be met, those using this system in such cases fall back upon the texture of the rock, for Rosenbusch holds that the textures are characteristic of the modes of occurrence, and that from the former the latter can be told.<sup>5</sup> He confesses however that this determination of the geologic character from the texture (structure) is unsafe, but feels that this should have no influence on the naming of the rock, since a granite-porphry is a granite porphyry, whether it occurs in the normal form of a dike, or the border facies of a stock of granite (plutonic), or, finally, as a central facies of a mass of quartz-porphry (effusive).<sup>6</sup> One sees from this then, that, whereas in theory the mode of occurrence is the basis of classification, this must really be largely replaced by texture. Since the petrographic result is the same, it would seem more logical to adopt a uniform practice and use texture in all cases.

Another defect is that so little weight is placed on quantitative relations in the mineral groups. The value of this factor was felt by Rosenbusch and applied in places, as in the theralite-shonkinite group, which is stated to have a mafic character, but it finds no formal expression in the system. It obtains to some extent an underlying recognition in the division into groups of some of the rocks on the genetic-magmatic basis.

It is to be observed that in this system, as in others, the division lines must be arbitrarily drawn; thus, whereas a rock consisting of orthoclase with a little hornblende is a syenite, and one composed of andesine with hornblende is a diorite, a rock containing equal parts of orthoclase and andesine must leave the petrographer in doubt as to its classification. The same is true in divisions by texture, and even at times in the geologic mode of occurrence, as pointed out in a previous section.

*Modifications of the Geologic-Petrographic System.*—The Norwegian geologist Brögger has made some changes in the geologic-petrographic system, as presented in the foregoing section. He prefers first to divide the rocks into large families on chemical grounds (Granite family, Syenite family, etc.) and then to apply the method of geological occurrence to each family to form plutonic and effusive groups.<sup>7</sup> He adds a third group which he calls the *hypabyssal* as transitional between the other two. The idea is to include the minor intrusions, which in the form of dikes, sills, laccoliths, etc., appear above

<sup>5</sup> Elemente der Gesteinslehre, 3d Ed. p. 74, 1910.

<sup>6</sup> Ibid.

<sup>7</sup> Grorudit-Tinguait-Serie. Eruptivgest. Kristiania-gebietes. Videnskap. Skrift. I Math-nat. KL. 1894. No. 4. p. 125.

the deep-seated stocks and batholiths, and thus at a higher level form an intermediate group with the surface lavas. These differences in the occurrences produce corresponding variations in the physical conditions attending the solidification of a magma, and this shows itself in the textures. Thus a suitable magma forms a plutonic granite, a hypabyssal granite porphyry, and a rhyolite lava. This group includes the dike rocks of Rosenbusch, but is obviously of greater scope. The division of these geologic groups into families (granite, syenite, etc.), although based in theory on chemical composition, in practice is mostly performed by considering the minerals, thus Brögger in the effort to solve the problem presented by rocks containing approximately equal quantities of orthoclase and plagioclase, mentioned in the foregoing section, proposed the recognition of a new family intermediate between granite and quartz diorite, when the rock contains quartz, and between syenite and diorite when quartz is absent, and of equal value with them in classification.<sup>8</sup> To this family he gives the name of *monzonite*, previously used by a few geologists to designate a rock of this character occurring at Monzoni in the Tyrol. This proposal has been generally accepted and the name widely used, especially by the geologists of the U. S. Geological Survey.

Brögger urges even more strongly than Rosenbusch the principle of the common genesis of groups of rocks from particular magmas distinguished by their chemical properties, as a means of classification. Thus he would not classify all aplites by themselves in one group and all lamprophyres in another group, but would assign to each plutonic mass, representing a magma (or family) the aplites and lamprophyres to which it has given rise by differentiative splitting. The mutual relation that the aplites and lamprophyres bear to another he designates under the term of "*complementary rocks.*"<sup>9</sup> It will be seen from what has been stated that Brögger classifies the igneous rocks, partly on geological, partly on genetic, and partly on petrographic characters, the genetic predominating. He has applied his method very

<sup>8</sup> Triadische Eruptionsfolge bei Predazzo, Erupt. Gest. Kristiania-gebietes; Videnskab. Skrift. M. N. KL. 1895; p. 21.

<sup>9</sup> Basic Eruptive Rocks of Gran; Quar. Jour. Geol. Soc. Vol. 50, p. 15, 1894.

strikingly to a group of the nephelite-syenite family occurring in the Christiania region.<sup>10</sup> These ideas of Rosenbusch and Brögger respecting the genetic origin of rock-groups, as well as the family relationships of rocks over particular areas, comprised by Iddings<sup>11</sup> under the term *consanguinity*, have had a wide influence, not only on classification, but on the development of petrology.<sup>12</sup>

The geologic-petrographic classification has also been used in England by Harker<sup>13</sup> who divides the rocks into plutonic, hypabyssal, and volcanic. They are then subdivided according to their petrographic characters. On the other hand Teall had earlier pronounced for a purely petrographic classification, based primarily on composition and texture.<sup>14</sup> In none of these systems is there any distinct recognition of the quantitative relation of variable minerals within a group.

*Remarks on the Geologic-petrographic System.*—Brögger evidently finds difficulty in using the geologic characters as a means of discriminating, classifying, and naming different *kinds* of rocks, since he remarks . . . “a rhombic porphyry (a variety of syenite porphyry) is to use a hypabyssal rock type, indifferently whether it occurs as a dike rock as border facies of augite syenite, or even as a lava flow.”<sup>15</sup> He also says, relative to the dependence of texture on the rate of cooling—“But whether this slow cooling (which yet in comparison with the extremely slow cooling in the central part of a laccolith is relatively more rapid) has taken place along the border portion of an abyssal magma, in a very large dike fissure, or finally in the more central part of a very thick extension, must be regarded as quite irrelevant, if, eventually, the consolidation has furnished practically the same rock with essentially the same texture and composition.”<sup>16</sup>

The student is desired to note this because it shows clearly the struggle to unite in one and the same classification very different features that relate to quite different things. As an instance of what happens when we use geologic position and petrographic characters in the same classification to determine a kind of rock

<sup>10</sup> Das Ganggefölge des Laurdalits; Eruptiv. Gest. Kristiania-gebietes; Videnskab. Skrift. M. N. KL, 1897.

<sup>11</sup> Origin of Igneous Rocks. Bull. Phil. Soc. Washington, vol. 12, p. 128; 1892.

<sup>12</sup> See also Daly, R. A. Igneous Rocks and their Origin; p. 311; 1914.

<sup>13</sup> Petrology for Students, 3d Ed. 1902; p. 22.

<sup>14</sup> British Petrography, 1888, p. 69 et. seq.

<sup>15</sup> Grorudit-Tinguait-Serie, quoted ante, p. 123.

<sup>16</sup> Ibid. p. 124.

we may cite the fact that a granite stock is frequently cut by dikes of the lamprophyre called minette. Then the granite is called a plutonic rock, whereas the minette is referred to the hypabyssal group! The truth is that most petrographers who do this are using, unconsciously perhaps, *two* classifications; they first determine in their mind by petrographic characters, that is by texture and mineral composition, which is one sort of classification, what the kind of rock is with which they are dealing, and then place it in a geologic-genetic scheme. The bearing of this will be treated in a succeeding section.

*Quantitative Classification.* Several American petrographers, including the author, proposed in 1902 an exact classification of igneous rocks based on chemical composition, expressed, however, in terms of minerals of definite composition, called standard minerals.<sup>17</sup> For this purpose a chemical analysis of the rock is necessary, but where this cannot be obtained an approximately correct result may be achieved by measurement of the minerals under the microscope, computing from this their relative bulk and weight, and, their composition being known, reckoning from this the chemical composition of the rock as a whole.

The chemical composition is then computed, according to a set plan, into the relative amounts of standard minerals. These standard minerals are divided into two main groups: one characterized by the presence of alumina and silica, such as the feldspars, nephelite, corundum, and quartz, but without iron or magnesia; the second characterized by iron and magnesia, but without alumina, such as olivine, diopside, hypersthene, aegirite, and iron ores. The complex ferromagnesian minerals which contain alumina, such as hornblendes, biotite, augite, etc., are not treated as standard minerals because it is better to consider them as compounds of simpler molecules of two preceding groups. The first of these is called the *salic* (Si and Al) the second the *femic* (Fe and Mg) groups of standard minerals, and the composition of the rock computed in quantities of them is called its *norm*, which may thus, when hornblende or biotite are really present in it in notable quantities, differ considerably from its actual mineral composition or *mode*.

<sup>17</sup> Cross, Iddings, Pirsson, and Washington; Quantitative Classification of Igneous Rocks; Chicago Univ. Press, 1903, pp. 286. See also, Jour. of Geol. Vol. 10, pp. 555-690, 1902.

All igneous rocks may be expressed in salic and femic minerals, and according to the relative amount of each group as compared with the other, they are divided into five classes, *persalane*, nearly or entirely composed of salic minerals:

(sal: fem > 7:1);

*dosalane*, mostly salic

(sal: fem < 7:1 > 5:3);

*salfemane*, equal or nearly equal quantities of each

(sal: fem < 5:3 > 3:5);

*dofemane*, mostly femic minerals

(sal: fem < 3:5 > 1:7);

and lastly *perfemane*, nearly or entirely femic

(sal: fem < 1:7).

The *classes* thus obtained are subdivided into *orders* on the relations of the salic minerals, quartz, feldspars, and feldspathoids (generally nephelite) to one another in the first three classes and on somewhat similar relations among the femic minerals in the last two. More minute consideration of the mineral oxides divides the orders into *rangs*, and the rangs into *grads*. The proportions by which they are thus divided are always the same as those by which classes are made.

Further details regarding this system will be found in the work referred to. It is the most exact system that has hitherto been proposed, and is based upon the fundamental property of the rock—its chemical composition. Aside from this, its most striking feature is the recognition of the quantitative relations among the component rock-minerals, the bearing of which we shall presently see. As must be the case in all petrographic systems the divisional lines of classification are arbitrarily drawn, but they are carried out logically on a consistent plan. It has been much used in careful and exact work, but the requirement of the knowledge of the chemical composition of a rock, and the difficulty in many cases of obtaining this, has doubtless prevented its wider extension.

*General Remarks on Classification.* From what has been stated in the foregoing discussions the student will have doubtless perceived that the chief difficulties in the systems described, excepting the last one, have been two; first, the attempt to introduce simultaneously into one scheme too many of the different properties and affinities

of rocks that we must consider, with the result of making the system confused, and second, the failure to recognize quantitative relations among the minerals, with the result of making it inexact. When we observe that which is to entitle one kind of rock to recognition as an individual entity is based on geologic occurrence and mineral composition, whereas another kind is based on petrogenetic relations and texture combined with mineral composition, and a third is based on geologic occurrence, geologic age, and the minerals, it seems clear that there is an attempt to accomplish too many things at one time. Leaving aside the matter of geologic age, three systems of classification, each of which endeavors to express something different from the others, have been telescoped together, and the result is to the advantage of none of them.

It now seems clear that we need three systems of classification of igneous rocks in order to express our knowledge of their properties and relations and that we may put like things together; these are:

A. A *petrographic* classification based on those inherent characters of rocks, expressed by their minerals and textures, which shall define in a material way the *kind of rock* we are dealing with. This covers the idea, previously stated, that a granite porphyry is a granite porphyry, no matter where it occurs.

B. A *petrologic* classification based on petrogenesis which attempts to group the rocks according to their family relationships and co-magmatic origin, as expressed by their relative geologic positions, and the evidences of consanguinity that they may present. Here, for example, the dike rocks of Rosenbusch would find logical expression. This will be more fully explained later.

C. A *geologic* classification based on the method of occurrence that determines the form of the mass of an igneous rock and its outward space relations to other rocks. This states whether it is plutonic or volcanic, whether a stock, laccolith, sheet, dike, etc. This kind of classification is generally explained in more or less detail in the standard text books of geology, and, with reference to intrusive bodies, has been quite fully elaborated by Daly.<sup>18</sup>

<sup>18</sup> Classification of Igneous Intrusive Bodies, *Jour. of Geol.*, vol. 13, p. 485; 1905. Also, *Igneous Rocks and their Origin*, p. 61, 1914.

Each of these classifications has distinct aims of its own, which can only be properly expressed by separate treatment. The aims of each are legitimate and entitled to full recognition; the difficulty has been that in mixing them together and insisting on one compound classification there has naturally resulted wide divergence of views as to what the aims of the classification really are. We may find an analogy for these classifications in the stratified rocks; in one system they are arranged according to their geologic age; and we speak of them as Cambrian, Jurassic, etc.; in another, according to the nature of the materials composing them, and we have limestones, sandstones, etc.; again we divide them into series, stages, formations, etc.

The geologic classification, it is presumed, is already familiar to the student, and need not be further considered here. Petrologic classifications, with the meaning mentioned above, have not yet been definitely and clearly stated. The nearest approach to one is given by Rosenbusch, but mingled, as has been shown, with the petrographic system. Brögger has stated principles that must be essential in their formation and has offered an example with the rocks of the Christiania region, somewhat complicated with their geologic occurrence. Such a classification really belongs in the field of theoretic petrology, and should be given in a work treating of that subject.

This book is devoted to descriptive petrography, and obviously the rocks should be treated in it according to a petrographic system; until the student has mastered this he is not in a position to comprehend fully a petrologic one. For his benefit a preliminary attempt at a petrologic system is appended to that part of the book dealing with the igneous rocks.

*Petrographic System of this Book.* The petrographic system to be employed should be based on the inherent and fundamental properties that express the rock. The most important one is the chemical composition, but the ones that have generally been employed are the minerals and the texture, since these are the more obvious and readily determined. Moreover the chemical composition can to some extent be recognized, provided attention is given to the quantitative relations of the minerals. In

a text book also the classification should be formed in such a manner as not to cut the student off from the historical aspect of the subject, or from current usages, and the volume of literature that has grown up based upon them. For these reasons a system has been adopted that is founded upon the older qualitative one, with modifications tending to greater definiteness in the statement of mineral composition, and at the same time a quantitative element has been introduced, and carried as far as seems advisable at present, in order not to introduce too great complexity into the scheme, and too great a departure from prevailing usages. The quantitative elements are derived in some degree from the quantitative chemical-mineralogical classification previously mentioned and the scheme is somewhat similar to that advanced by Iddings,<sup>19</sup> but with important modifications. It is shown in Table No. 3.

*Explanation of Table No. 3.* It should be understood at the outset that it is not intended in this table to present a scheme of classification that shall embrace all the different kinds of igneous rocks that have been described and named. Many of these differ from common well-known types in modifications of texture, or the proportions of the minerals, or the presence of some other mineral in relatively small quantity, and are to be regarded as having the value of varieties. For simplicity's sake only more common or important types are given for illustration in each division, and varieties are treated later in the descriptive part of the work.

The rocks are divided into five large groups, A, B, C, D and E, according to the nature of the feldspars that they contain. In A these are dominantly alkalic, orthoclase, albite, etc.; in B, alkalic and sodacalcic, that is to say, mixtures of alkalic feldspars with plagioclase, as for example orthoclase and andesine or oligoclase. Various types of mixtures may occur, but the essential thing is that lime is associated in the feldspars in notable quantities with the alkalies. In C on the contrary the soda-lime feldspars dominate over or replace the alkalic and may run through oligoclase and andesine to labradorite. In D the alkalic feldspars have practically disappeared

<sup>19</sup> *Igneous Rocks*; vol. II, p. 347, 1909.

and the plagioclases are normally those rich in lime, from labradorite to anorthite. In E are the rocks that contain no feldspar, or only negligible quantities of it. In a chemical sense then we may say that the horizontal

TABLE NO 3, PETROGRAPHIC

DOMINANT	A ALKALIC FELDSPARS		B ALKALIC AND SODALCALCIC FELDSPARS	
	1. Felsic	2. Mafic	3. Felsic	4. Mafic
QUARTZ and FELDSPARS	<b>Granite</b> <i>Granite Porp'y</i> Rhyolite	----- ----- -----	<b>Quartz Monzonite and Granodiorite</b> <i>Qtz. Mon. Porp'y</i> Dellenite	----- ----- -----
FELDSPARS  (little or no quartz or lenad)	10. <b>Syenite</b> <i>Syenite Porp'y</i> Trachyte and Bostonite	11. <b>Shonkinite</b> <i>Minette and Vogesite</i>	12. <b>Monzonite</b> <i>Monzon. porp'y</i>  Latite	13. <b>Kentallenite</b> <i>Camptonite</i>  Trachydolerite
FELDSPARS and LENADS (feldspathoids)	19. <b>Felenites Neph - Syenite Group.</b> <i>Neph. Syen. Porp'y</i> Phonolite and Tinguaitite	20. <b>Malignite</b> ----- -----	21. <b>Theralite</b> (in part)	22. <b>Essexite</b> (in part)
LENADS  (little or no feldspar)	28. <b>Lenites Ijolite Urtite Fergusite Group</b> Nephelinite Leucitite (in part)	29. <b>Bekinkinite Missouriite Gr.</b> Neph. Leuc- & Melilite Basalts. Nephelinite and Leucitite(inpart) Monchiquite	30.	31.
			Tephrites	

arrangement represents a reciprocal relation between alkalis and lime.

In the vertical direction the chemical relation expressed is that of silica (SiO<sub>2</sub>). When the silica is in excess over that amount required to form feldspars, etc., we have free quartz; as it diminishes quartz disappears; next, there is not enough to turn all the alkalis and

alumina into feldspar, and a feldspathoid (*lenad*) appears; this increases with lowering silica until no feldspar is present.

The quantitative relation of the ferromagnesian

CLASSIFICATION OF IGNEOUS ROCKS.

C SODACALCIC FELDSPARS		D CALCISODIC FELDSPARS		E NO FELDSPAR
5 Felsic	6 Mafic	7 Felsic	8 Mafic	9 Mafic
Quartz		Quartz		
Diorite		Gabbro		
Qtz. Dior. Porp'y				
Dacite				
14	15	16	17	18
Diorite		Anorthosite		Peridotite Group
Diorite Porphyry		Gabbro and Norite Group		Hornblendite
Kersantite		Diabase		Pyroxenite
Andesite		Basalt and Melaphyre		Pierite and Augitite
23	24	25	26	27
Theralite (in part)	Essexite (in part)	Rouvillite	Teschenite	Jacupirangite Yamaskite
		Basanites		Limburgite
32	33	34	35	36

(*mafic*) minerals to the quartz, feldspars, and feldspathoids (*felsic* minerals) in the A, B, C, D divisions is expressed under a felsic and mafic column in each. In one, felsic minerals dominate and form 50-100 per cent of the rock; in the mafic, the ferromagnesian ones dominate in like manner. Other quantitative relations, like those affecting the felsic minerals among themselves, will be discussed later in appropriate places.

*Texture in Classification.* The factor of texture has so far never been given any very precise definition in classification. Different varieties of texture themselves have been minutely described, and, since textures merge into one another gradually in various directions and division lines between them must be arbitrary, quantitative definitions and limits to textures have been suggested, as set forth in the preceding chapter. But so far as textures have been used in systematic classification this has been done in a purely megascopic manner, and mostly with very vague limitations. Only the broadest distinctions are employed; divisions of granular, dense, and glassy are used, and whether the rock is porphyritic in fabric or not. No quantitative values as to the use of these distinctions are suggested. The greatest stress is laid upon the character of whether a rock is porphyritic or not; this shows itself in the terminology in that the term, as one of texture, is embodied in the name, either complete, as in *syenite porphyry*, *rhombic porphyry*, etc., or in the contractional suffix *phyre*, as in *orthophyre*, *keratophyre*, etc.

All that Zirkel<sup>20</sup> remarks as to the relation between texture (structure) and classification is that he lays stress on the contrast between porphyritic and nonporphyritic rocks. He notes also that this gives rise to some inconsistencies, since some basalts are not porphyritic, but granular. Rosenbusch does not use texture as a primary factor in classification, but only in a secondary sense as connected with mode of occurrence; when the latter is unknown he then falls back on texture, and the porphyritic quality plays the chief role. Brögger essentially follows Rosenbusch but has only offered an outline of his suggested classification. Iddings<sup>21</sup> merely remarks that on the basis of texture the rocks are divided into the phanocrystalline (grained) and aphanitic (dense) groups; the latter is subdivided into those with paleotypal, and cenotypal habits, this distinction being based on the appearance of the rock due to more or less alteration from, in general, greater age,<sup>22</sup> as suggested by Brögger. Harker<sup>23</sup> does not use texture in primary classification but, in general, follows Rosenbusch and Brögger in relegating it to a secondary position.

These examples will serve to show that no general agreement either as to the use of texture in classification, or if used, as to its limits, obtains among petrographers.

<sup>20</sup> Lehrbuch der Petrographie, Vol. I, p. 837.

<sup>21</sup> Igneous Rocks, Vol. I, p. 350.

<sup>22</sup> Op. cit. p. 353.

<sup>23</sup> Petrology for Students, 3d Ed. 1902.

One reason for this is the feeling that as a character its importance is secondary to chemical-mineral composition, and another, that if all the various ramifications of texture, strictly defined, were introduced into a primary system of classification as divisions in one direction, and mineral groupings as divisions in another direction, the variety of rocks produced would be bewildering in number. Nevertheless the texture of a rock has always been held to be one of its most obvious features and the recognition of it, in the simple forms mentioned above, is seen in classifications, either directly or indirectly. We propose to employ it in a megascopic manner, but will attempt to give it a more precise definition than is usual, for the benefit of the student. The scheme is as follows:

*Grained Rocks; mineral constituents megascopically determinable.*

- A. Apparently even-granular in fabric; fine to coarse; rarely subporphyritic.
- B. Distinctly porphyritic in fabric.
  - 1. Groundmass grained, constituents determinable.
  - 2. Groundmass dense, but semipatic to presemic; phenocrysts determinable.

*Dense and Glassy Rocks; constituents mostly or wholly indeterminate.*

- C.
  - 1. Porphyritic, but semipatic to prepatie.
  - 2. Nonporphyritic.

This is probably as far, in preciseness of definition, as it is wise to go at present; to be more detailed would introduce such radical differences with the existing literature as would confuse the mind of the student, and greatly hinder his use of it. As it is, the scheme introduces a number of differences, not however of major importance, and these will be pointed out in proper places.

We have then three textural divisions, which may be summarized as A, granular; the names of these rocks are shown in the table in bold-face type; B, porphyritic, in *italics*, and C dense or glassy, printed in roman type.

The fragmental volcanic rocks, the tuffs and breccias composed of dust, ashes, bombs, etc., might well form a fourth textural division, but for the sake of simplicity

of treatment they are not subdivided into groups in this book but are considered in a section by themselves, as will appear later.

It is obvious that the character of rocks, which texture affords, might be employed for classification at the very beginning, or after the rocks have been separated by mineral grouping. In either case the final result would be the same, so far as classifying and naming the rock is concerned. In the first case, if rocks are first divided into granular, porphyritic, and dense classes and then subdivided on mineral composition, we should have three such tables as No. 2 to refer to; whereas, if the texture is applied after the mineral grouping, the whole can be condensed into one table, as has been done, with greater convenience of reference.

It is not, however, a necessity that we should follow the latter plan in describing the rocks for the benefit of the student. It is very much easier and more logical for him to take up the coarser-grained rocks first; he can learn to make his determinations of the minerals, and their groupings and relative quantities and relations, which settle the classification, much more quickly and accurately, with them, and the knowledge thus gained can then be applied efficiently to the more difficult fine-grained and dense rocks. Moreover, in this one follows the usual mental course of procedure in determining a rock: we first examine the rock megascopically and notice whether it is sufficiently coarse-grained to permit us to recognize the component minerals; we study them and then assign the rock to its proper position in the scheme of classification we have in mind.