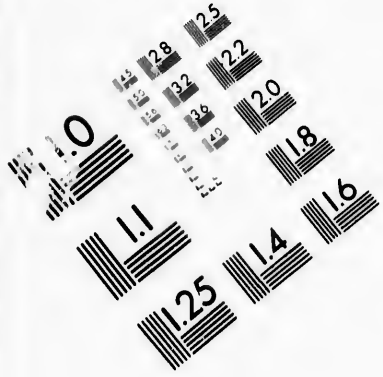

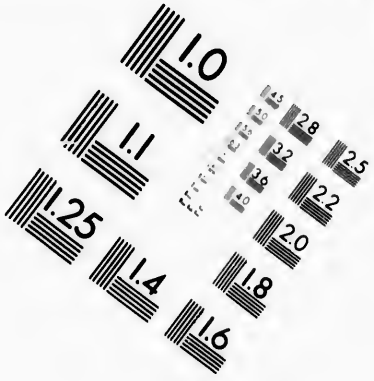

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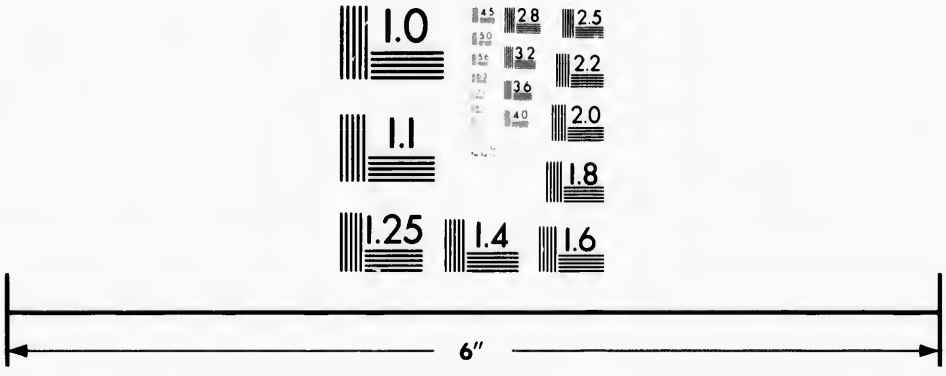

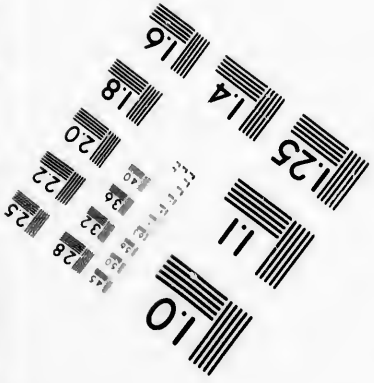

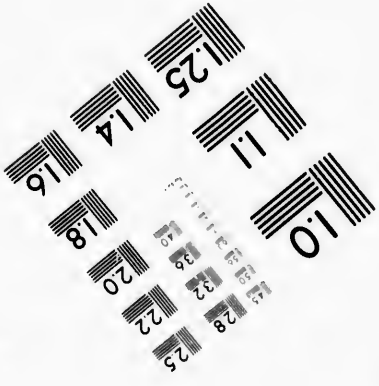

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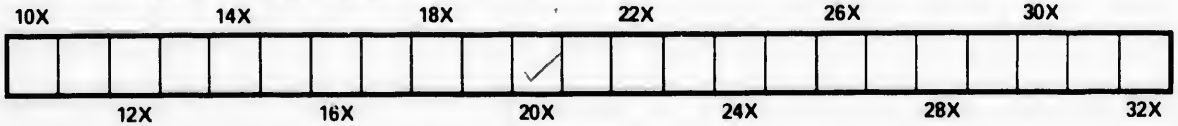

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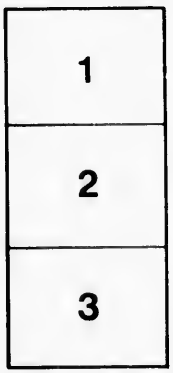

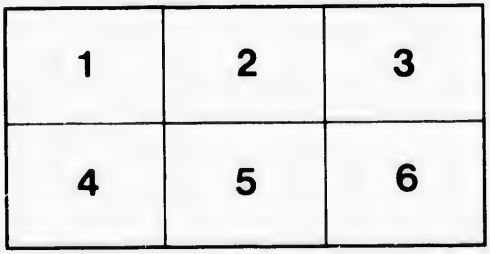

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ON THE

ORIGIN AND CLASSIFICATION

OF

ORIGINAL ROCKS.

BY

THOMAS MACFARLANE.

MONTREAL:
PRINTED BY MITCHELL AND WILSON,
102 ST. PETER STREET.
1872.

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ON THE

ORIGIN AND CLASSIFICATION

OF

ORIGINAL OR CRYSTALLINE ROCKS.

By Thomas Macfarlane.

I.—INTRODUCTION.

"All attempts to separate sharply from each other the various "rocks or mineral aggregates of which the earth's crust is com- "posed, and to arrange them systematically, have failed." "We "cannot consider the rocks as species, nor arrange them in a "system corresponding to their nature, nor even, in describing "them, treat them all in the same manner." *

So wrote Bernhard Von Cotta in 1862. On reading such sentences we are tempted to ask: Are species always sharply defined in other sciences? Are all systems perfect or natural? Why should lithology be an exception to other sciences, and its

* Cotta; Die Gesteinslehre, pp. 1, 4.

students be deprived of the advantages of a systematic arrangement of the objects to be studied? A "natural" system is not demanded, even were such a thing possible, in this or any other science. The more rigid any method of classification, and the more marked and unbending its divisional lines are made, the more unnatural it becomes.

It is exceedingly gratifying to find that, undeterred by the difficulties of rock classification, such lithologists as Von Hochstetter, Kjerulf and Zirkel, have been found willing to attempt it. Their labours, and those of other workers in the same field, have shed a flood of light upon a previously obscure and uninteresting subject. Although a perfect system will, perhaps, never be attained, still each attempt at properly arranging our knowledge of the subject has its value. Chemical analysis and microscopical examinations of rocks have very much contributed towards rendering such attempts successful. In the present paper it is proposed to give a systematic view of the various classes and species of crystalline rocks, in arranging which it is intended that their chemical composition shall have greater prominence and weight than has been usual heretofore.

However much it may seem desirable in this department of science, where all the systems of classification have been confessedly imperfect, to invent a system independent altogether of the ideas, more or less well founded, which prevail as to their origin and age, and in which their physical and chemical characters should only have consideration, it must not, on the other hand, be forgotten that what is still more desirable in such a system is that it should re-arrange our knowledge of the subject in a clearer form, render it more easy of comprehension to the student, and be so dovetailed into the past of the science as to be useful for its advancement in the future. On this account it becomes impossible to neglect even the theoretical views of our forerunners in this science of petrology, far less their arduous and often underrated geognostic labours. It also becomes requisite to give a proper value to all the considerations which may have influenced their views, and to build upon the foundation which they have left us, the results of the observations and research of the investigators of our own day.

Considerations as to the manner of formation, texture, chemical

and mineralogical composition, age and localities of rocks, have all, more or less, influenced geologists in naming and classifying them. The well-known distinction between eruptive and sedimentary rocks will occur to every reader as an instance of classification according to origin. Hunt's division of crystalline rocks into indigenous and exotic, and Scheerer's distinction of plutonites and vulcanites are both founded upon their real or supposed manner of formation. Lava and Rhyolite are examples of special rocks similarly named. Then, with regard to texture, probably no other character possessed by rocks has given rise to a greater number of generic terms. Schist, slate, porphyry, trachyte, amygdaloid, conglomerate, and breccia, are examples of this, but of special names founded on texture only a few can be instanced, such as granite and aphanite. The influence of chemical composition on a lithological nomenclature is, not, as yet, very marked, for it is only recently that the analysis of rocks has had much attention. Quite lately, however, Cotta has proposed to distinguish as basites those eruptive rocks containing less, and as acidites those containing more than sixty per cent. of silica; and Scheerer, Kjerulf and Roth have each indicated methods of classification, founded, to a very considerable extent, on general chemical composition. By far the greater number of special names in lithology are based upon mineralogical characters. This is the case with pyroxenite, hornblende schist, quartzite, and many simple rocks, while among those of a compound nature where it was impossible to indicate their mineralogical composition in one word, recourse was had to special names, with definite ideas attached to them as to mineralogical constitution. Thus, diorite came to denote a rock composed of triclinic felspar and hornblende; granulite, a schistose compound of quartz, orthoclase and garnet; dolerite, a mixture of labradorite, augite and magnetite. As regards classification, the mineralogical nature of rocks has always been abundantly considered. In this way we have Hunt's orthosites and anorthosites; Senft's labradorites, and alabradorites, while Zirkel has made the nature of the different felspar species the corner stone of his system of classification,—crystalline or original rocks, being divided into orthoclase rocks, oligoclase rocks, labradorite rocks, anorthite rocks, and rocks void of felspar. The manner in which con-

siderations as to geological age influence the names of rocks may be illustrated by the following examples. Sometimes certain porphyries and trachytes are, in hand specimens, scarcely distinguishable from each other. When, however, such rocks occur among carboniferous or peruvian strata, geologists have been inclined to term them porphyries; and on the other hand, when they are of tertiary or recent age, the name trachyte is generally given them. Exactly the same mode of determination, if such it can be called, has been adopted in the case of greenstone and basalt, or rocks of such indistinct mineralogical composition as trap and aphanite. With reference to locality it has principally occasioned special names, such as syenite, dunite and andesite, or caused varieties of certain other species to be indicated by such terms as banatite, sievite, lherzolite, &c. From these considerations it would appear that, generally speaking, origin has been allowed to determine the various divisions and sub-divisions among rocks; that the majority of the generic names have reference to texture, while mineralogical composition and locality have had the greatest share in originating the special names of rocks.

In striving to attend to what has been indicated as desirable and necessary in any attempt at classifying rocks, it has appeared to us most judicious to attach greatest weight to their various characters in the following order: 1, origin; 2, texture; 3, chemical composition; 4, mineralogical composition; and 5, locality. If a system be required at all resembling those of other branches of science, these characters might be allowed respectively to determine the classes, orders, families, species, and varities of rocks.

II.—CLASSES OF ROCKS.

If we, at the present day, look around us, and ascertain, from actual experience, what the methods are which nature employs in producing rocks, we find that they result from the operation of two very distinct agencies. On the one hand we may see in different countries widely separated from each other, streams of melted matter issuing from volcanoes and solidifying to rocks on their sides, or at their feet, while on the other hand we may observe, on every sea beach or river delta, sand and clay, teh

debris of pre-existing crystalline masses or fragmentary strata being gradually consolidated to new rocks. Exactly parallel to these operations of nature are certain artificial processes at work around us, the products of which are entirely analagous to the two classes of rocks just indicated. We may stand before an iron furnace and watch the steady stream of slag flowing from the hearth into a large iron wagon, and there solidifying to a mass of solid, sometimes crystalline rock; and we may also visit a stamp mill where valuable metallic particles are being extracted from poor vein-stones, and find, in the slime-pits of the establishment, banded layers of half solidified strata, requiring but a little time to effect their perfect consolidation.

These two means employed by nature in producing rocks have been steadily recognized by the majority of geologists, and the two classes which result have been indicated by a superabundance of names. Unstratified and stratified; igneous and aqueous; eruptive and sedimentary; exotic and indigenous; primary and secondary; (protogene and deuterogene;) crystalline and clastic; massive and fragmentary; original and derivate, are all terms which have been used for distinguishing these two great classes, and the least objectionable among them would appear to be the two last mentioned. The first of these, original (Ursprüngliche,) was first adopted by Zirkel* for denoting igneous or eruptive rocks, while the term derivate was first suggested by David Forbes† as equivalent to secondary or sedimentary rocks. The latter term we have ventured to modify, and in the following pages we shall use the names original and derived for indicating the two great classes. These names would seem to deserve the preference, for the following reasons. It is admitted by geologists, on all hands, that the material which constitutes the various sedimentary formations, consisting of limestone, hardened clay, or consolidated sand, although it may have been immediately derived from pre-existing rocks of a detrital nature, originally came from the decomposition and disintegration of crystalline rocks, of such as are known to constitute the oldest formations of the earth's crust or to have broken through and deposited themselves on the

* Petrographie I., p 173.

† The Microscope in Geology, p 6.

outside of it. It is further an accepted theorem, universally acknowledged by scientific men, that our globe was originally in a state of igneous fusion, and that all the material which constitutes the rocks of our day existed in the form of a melted zone encircling the central part of the globe. It is evident that, before the conditions for the formation of sedimentary rocks could exist, the liquid globe must have become, to some extent, solid; a crust at least, must have been formed upon it, from the disintegration of which the material of such sedimentary rocks could have been derived, and upon which that material could have been deposited. This crust, and the rocks which from time to time after its solidification penetrated or were erupted through it, must consequently, have been the first rocks, and they must have yielded the material for all those subsequently formed by aqueous agencies. It would, therefore, appear legitimate to name the former class original and the latter, derived rocks.

Where, as in the case of the volcanic and sedimentary rocks which are being formed at the present day, we can observe the process of their formation, no doubt can arise as to their origin. These rocks, however, form but a very minute fraction of those which build up the earth's crust, and it becomes necessary, in order properly to discriminate among the latter, to point out the distinguishing characters of original and derived rocks. The further we go back in geological time, and the older the rocks are which we are called on to classify, the greater is the difficulty of doing so, and the more divergent the opinions of geologists become as to their origin. The stratigraphical relations of rocks are most effective in determining this, but it will be necessary at present to confine ourselves to considerations of a more purely petrological nature. This is the more easily done, since the lithological characters afford abundant means of recognizing original and derived rocks, and distinguishing them from each other.

Original rocks are made up of crystalline particles of one or more minerals, principally silicates. These are seldom perfect in crystalline form, are frequently more or less irregular or distorted, and are intimately bound together to a compact whole, without the intervention of any foreign substance as a cementing material. They are thus mutually interlocked to a crystalline mass, which, however, possesses at the same time an average mineralogical and

chemical composition. This would seem to indicate that the mass must have been originally liquid, and, to some extent, in the same condition during crystallization, otherwise it would have been impossible for the various chemical constituents to move toward the points where the minerals were being formed into whose composition they enter. On the other hand, this liquidity must have been somewhat limited in degree, for the minerals seem to have pressed against each other, so as to have mutually interfered with their crystalline development, and so as also to have fitted perfectly into each other on complete solidification. The size of the crystalline particles varies from a foot or more in diameter down to that of microscopical minuteness. It is even the case that they become so minute as to occasion a perfectly vitreous structure which even the microscope is incapable of resolving into distinct minerals. In all such cases, although the rock can scarcely be termed crystalline, it remains, what its mode of occurrence plainly shows, an original rock.

Derived rocks are made up of the disintegrated fragments or particles, and the chemical constituents of previously existing rocks, abraded or dissolved away by water or other agents. These fragments or particles are sometimes angular, sometimes rounded off, and always bound together by means of an intervening cement, which is independent of, and may be altogether different in nature from, the enclosed fragments. They vary in their dimensions even more widely than the constituents of original rocks. There are sometimes found in them blocks of several cubic feet contents; and, on the other hand, they are frequently composed of the finest particles of dust. The cement which unites these particles is subject to great differences, both as regards its quantity and its nature. Sometimes it consists of the material of a newly erupted original rock which has happened to envelope and bind together fragments of a pre-existing crystalline or sedimentary rock. Sometimes it consists of the finely divided detritus of the rock of which the larger fragments are composed. Somtimes the finely comminuted cement is from a different rock than the fragments. Sometimes it is of an infiltrated crystalline nature. In some cases the fragments, and in others the cement predominates. Apart from the finely divided sandstone or clay which sometimes fills the interstices between the fragments,

carbonate of lime, silica and iron oxide are the substances which, more frequently than any others, form the cementing material in these fragmentary rocks.

Recent investigations regarding the chemical composition of rocks have rendered the distinction between the original and derived classes still more marked, and made it possible to point out another essential point of difference between them. Original rocks possess a chemical composition in which a definite relation exists between the quantity of silica and that of the various bases which they contain. In derived rocks this definite relation is not to be observed. This peculiarity of chemical composition possessed by original rocks was first pointed out by Bunsen, and has been quite recently insisted upon as a feature distinguishing them from derived rocks by Von Richthofen in his "Communications from the West Coast of North America." *

These two great divisions do not, however, exhaust all the classes into which rocks have been divided. It has long been supposed, and more recently the belief has gained ground, that many of the rocks belonging to the divisions above indicated have experienced, since their solidification or deposition, certain changes in their chemical and mineralogical composition, and in their physical characters, whereby they have been rendered quite unlike their originals, and this without their having been disintegrated or displaced. The influences to which these changes have been ascribed are various. Heat, water holding different substances in solution, gases, atmospheric agencies acting separately or combined, have all played an important part in effecting these changes. The rocks thus modified have been called metamorphic, altered or hypogenous rocks, without very marked reference to the classes from which they have resulted. In the following pages the name altered will be applied only to those original rocks, and the term metamorphic only to those derived rocks which have experienced, *in situ*, such changes as those here indicated. It is not, however, proposed in the present paper to discuss the relations of derived and metamorphic rocks, but, in endeavouring to classify those of the original class, the altered rocks sometimes resulting from them will be noticed.

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* Zeitschrift der Deutschen Geologischen Gesellschaft, vols. xix and xx.

III.—TEXTURE OF ORIGINAL ROCKS.

In adverting to the origin of rocks, those which have been called original were described as analogous in nature to furnace scoriæ. This may seem a forced comparison, and it may be supposed that crystalline rocks are not likely to be influenced by heat; but the truth is that nearly every one of them have been shewn, experimentally, by Hall, Bischof, Delesse, and Sorby, to be fusible, and to be reduced by a high temperature to the same condition as furnace scoriæ. But while the latter generally exhibit, on cooling, a homogeneous mass, original or compound crystalline rocks are most frequently seen to be composed of various and different minerals. While the furnace slags, in rapid cooling, had no time during which their chemical constituents could arrange themselves into different compounds, the greater number of original rocks, having solidified in enormous masses, and, doubtless, during long periods of time, their constituents had opportunity for arranging themselves in such a manner as their chemical affinities suggested. The minerals, which were the result of this re-arrangement of the chemical elements, are not, however, always readily recognized in rocks. The latter have in some rare cases solidified so hurriedly that they present merely the appearance of natural glass. Others have had time to lay aside the vitreous character and assume a stony appearance, but they appear so homogeneous and fine-grained that their compound nature would scarcely be suspected. This is, for instance, the case with basalt, which, on this account, was, at one time, regarded as a simple mineral. On grinding it to powder and washing it, however, Cordier found it to consist of several minerals with distinct physical characters. A good many other rocks are seen, on examination, to be distinctly compound, but their constituent minerals are developed in such minute grains that their determination becomes a matter of very great difficulty. It is only in the coarser and large grained rocks that the constituent minerals can be readily recognized by the student, and their physical and chemical properties easily tested.

These variations in the size of the constituent minerals are accompanied by differences in their form and position, and, both together, give rise to what is called the texture of crystalline rocks,—differences in which may easily and at once be detected by the student. Coarse and fine grained, schistose and slaty,

vitreous, porous, and other such names, are used for characterizing peculiarities of texture, which are not at all to be regarded as merely trifling accidents in the history of rocks, but which really possess a deeper meaning than we are inclined at first to imagine. Although neither the furnace nor the volcano can give us any conception of the magnitude of the scale upon which the earlier original, or, as they have been named, the plutonic rocks, were erupted, still, they furnish us with hints which we cannot afford to neglect. To the metallurgist, it is an every day occurrence to observe that the same scoriæ yields either a vitreous slag or a stony mass, accordingly as it has been quickly or slowly cooled. Slag cakes, a few inches in diameter, are found to be impalpable or glassy on the outside, while on breaking them, the interior is found to be porcelain-like or crystalline. Bischof made some interesting experiments on this matter at the iron-works of Mägdesprung in the Hartz. He allowed common iron furnace slag to run into cold water, where it disengaged sulphuretted hydrogen, and yielded a white, easily friable pumice stone. He next allowed the slag to solidify upon cold, somewhat moist, sand. This gave a harder pumice, still retaining some of the original color of the slag. In the next experiment the slag was allowed to cool on a completely dry bottom of sand, and the result was a brownish-green transparent glass. Under a protecting cover of dry sand, the solidified slag was found to contain crystalline quadratic prisms in considerable numbers, and between them lay spherical concretions, consisting of regular radiating fibres, extending from the middle point in every direction. In the last experiment the slag was exposed to slow cooling in a basin lined with a warm mixture of charcoal powder and clay. When broken, after cooling, it did not exhibit a trace of vitreous substance nor any quadratic prisms, but a fine radiated texture had spread itself equally throughout the whole mass. The experiments of Sir James Hall have often been mentioned in connection with this subject. Nearly seventy years ago he applied experiment, for the first time, to the elucidation of geological phenomena. It occurred to him to melt a small piece of basalt, and the result was a dark vitreous substance. But on fusing a much larger quantity, and allowing it to cool slowly, he obtained a crystalline mass. Since that time geologists gradually became accustomed to look upon the original rocks of a glassy appearance, which occur in nature, as the products of rapid, and those of a

granular texture as the products of slow cooling. Nor are there wanting instances to show that other physical causes have influenced the structure of such artificial silicates as slags. At the Eglinton iron-works in Scotland, and those of Bethlehem, Pennsylvania, the writer observed that there is frequently developed in the slags, as they flow from the furnace, streaked bands of different colors, not at all unlike those developed in many slate rocks. Then again, when the workmen, at the establishment first named, tap off the iron and cool the small amount of scoriæ which follows after it with a plentiful supply of water, the slag froths up and solidifies to a porous cellular substance, the exact parallel of which is to be found in the pumice stone of volcanoes. In observing the slags of copper furnaces, nothing is more common than to see those which are allowed to flow over damp ground rise up into porous scoriæ, while those which run over wet portions of the smelting-house floor, boil up into loose pieces, or throw themselves about in the form of little volcanic bombs and lapilli. Similar phenomena are observed in the lava streams of active and extinct volcanoes. Those of Alta Vista, in Teneriffe, consist, on the surface, of glittering, transparent bottle-glass-like obsidian, which, towards the interior, changes into a less glittering pitchstone-like mass, which is so filled with crystals as to resemble a crystalline rock. These instances have been given in order to show that, in studying the varying textures of original rocks, it is well to bear in mind that such textures are, in all likelihood, the result of the influence of the physical conditions under which their respective rocks solidified, and of the temperature and plasticity of the mass from which they were produced.

The following modifications in the texture of original rocks may here be distinguished:—

1st. The constituent minerals are of a comparatively large size, ranging from several inches to one eighth of an inch in diameter, generally large enough to be easily tested as to hardness, cleavage, and other physical characters. The mode of their arrangement is altogether irregular, and, although the individual minerals may sometimes have a greater length than thickness, no parallelism of their larger axes can be noticed. Granite, syenite, and diorite are examples of this order of texture, which may be called the *coarse and small grained.*

2nd. The constituent minerals are of a size varying from the smallest individuals to those of an inch in diameter. One or

more of them have their longest axes arranged in the same direction and parallel with each other, there being thus developed a fibrous or laminated texture. This may be called the *schistose* order, to which gneiss and hornblende schist belong.

3rd. The constituent minerals are finer grained than in the preceding order, and more difficult of determination. A similar parallel structure, however, is visible, which occasions an easier fracture of the rock along a particular plane, or what is called a slaty cleavage. Common roofing slate may be regarded as the type of this *slaty* order of texture.

4th. The next order of texture to be distinguished is the *porphyritic*. Large individuals, or crystals of one or several minerals, are enclosed in a fine-grained or impalpable matrix. Augitic, syenitic and felsitic porphyry are examples of this order of texture, the rocks of which are distinguished from each other as well by variations in the nature of their matrices, as in the compositions of the crystals developed in these.

5th. The next order may be called the *variolitic*, and regarded as incipient porphyritic texture. In a fine-grained matrix, small rounded concretions are developed, without, however, being sharply separated from it. These concretions sometimes possess a fibrous structure in the interior, the fibres radiating from the centre, and their existence is frequently betrayed on the weathering of the rock.

6th. The minerals are here of a much smaller size than in the coarse-grained order, so as to be in most cases difficult of determination. This texture is the same as that often possessed by the matrices of porphyries, and, being destitute of parallel structure, bears the same relation to the coarsely granular which the slaty does to the schistose texture. Trap and felsite belong to this order, which may be called the *fine-grained*.

7th. This order may be denominated the *trachytic*, and, although its rocks have frequently a porphyritic development, they are distinguished from those of that class, in having a rough, porous, sometimes even cellular, matrix, and felspar crystals developed in it of a vitreous appearance and full of small fissures. The same rough uneven surface and fracture is developed in those trachytic rocks which contain no largely developed crystals, and even in many of a much more basic composition than what are usually termed trachytes. Rhyolite, andesite and dolerite are examples of this order.

8th. In this order of texture the porous appearance above referred to is developed to such a degree that a scoriaceous or cavernous structure results. This structure is peculiar to volcanic rocks, which also afford examples of purely vitreous texture, in which no "grain" nor any mineralogical constituents are observable, but an impalpable glassy appearance predominates. This order may be called the *volcanic texture*, and lava, pumice-stone, and obsidian, mentioned as examples of it.

It is not to be supposed that these varieties of texture are at all sharply separated from each other. On the contrary, rocks the most varied in their structure are found to be connected with each other by insensible gradations. Thus, vitreous rocks are gradually found to assume an impalpable and then stony character. Then again, they frequently become porous and cellular, and graduate into scoriaceous lavas. Rocks of the latter order have very often well-defined minerals developed in them, and when also the cellular texture becomes more subdued, trachytic rocks result. These, when they gradually become more compact or their felspars gradually lose their vitreous and fissured appearance, become indistinguishable from felsites and porphyries. Farther, when the matrices of the last mentioned rocks gradually become coarser grained and their crystals reduced in size, they pass into thoroughly granular rocks. When, on the contrary, the well-developed crystals of porphyries gradually disappear, fine-grained rocks are the product. Nothing is more common than to find the latter gradually assuming a slaty structure or gradually becoming coarser in the grain, and so giving rise to schistose or granular rocks. And nothing is more common than to find the constituents of granular rocks, little by little, arranging themselves in a given direction, and so producing coarsely schistose structure.

But with all the frequency of gradation between original rocks of various textures, it is to be remarked that those which differ widely from each other in structure, do not exhibit sudden transitions the one into the other. Cavernous and coarsely granular rocks are never found to constitute part of one and the same mass, or to pass into each other, without gradually assuming the characters of intermediate impalpable and fine-grained rocks. Nor is it ever the case that coarsely schistose rocks become trachytes all at once. A certain consistency or method is recognisable in all these transitions, and it is only those orders which are more

nearly related to each other as regards texture, or are more intimately associated, geologically, that graduate into each other in the manner above described. In the description of the various species of texture given above, those have been placed nearest to each other which are most prone to pass into each other by modifications of texture.

To account satisfactorily for these variations of texture among original rocks is no easy matter; but if the facts already given, as regards the solidification of artificial silicates, have any value as applied to lithology, they would lead us to suppose that the coarsely schistose rocks solidified very slowly during the lapse of great intervals of time and under the influence of widely extended movements of the crystalline, but still fluid mass; that the coarsely granular rocks solidified very slowly, but in comparative rest; that porphyritic and small-grained rocks cooled more quickly than coarse granites, although crystallisation evidently took place while they were in a plastic condition; that fine-grained schistose rocks solidified while in motion, but are the products of comparatively rapid cooling; that porous trachytes cooled rapidly, but in comparative rest; that very cavernous rocks came into contact with water during cooling, and we may suppose that, where that element was present in great quantity, many original rocks underwent disintegration while their solidification was in process, giving rise to the tufaceous series of derived rocks. Many of those generalisations are supported by observations recently made on the microscopic structure of rocks to which, however, it is impossible here to refer.

IV.—CHEMICAL COMPOSITION.

Crystalline or original rocks have been hitherto regarded and described as aggregates of minerals. No doubt the larger number of them may be correctly enough thus characterised, but it is doubtful whether the description applies to all the original rocks. For instance, obsidian has always been classed among these, and, on all hands, it is admitted that no minerals are discernable in it, that it is perfectly vitreous, as much so as bottle or window glass. A similar vitreous substance, unresolvable by the microscope, forms, according to Vogelgesang, part of the matrix of all true porphyries. Then we have many instances of rocks, almost impalpable in texture, belonging to various families, in which the microscope certainly reveals the presence

of separate minerals, but, frequently, leaves their nature and, always, their composition undetermined. Besides the uncertainty which thus very frequently surrounds our knowledge of the mineralogical constitution of fine-grained rocks, there are other considerations which tend to shew that the composition of a rock is not ascertained even after its constituent minerals have been determined. In the first place, the relative quantities of these present cannot be ascertained, and, secondly, even when this is done approximatively, the uncertain composition of the mineral species renders the chemical composition of the rock almost as doubtful as before. It would therefore appear simpler and tend to a juster view of the nature of original rocks, to regard them not so much as aggregates of minerals, as mixtures of their chemical components, alkaline and earthy silicates, which, during crystallisation, arranged themselves into compounds of more definite atomic composition, namely, into minerals.

As has been already remarked, the primary source of all original rocks must have been the original fluid globe, and also that part of it, which, until the present day, has remained in a state of igneous fluidity. The elements which originally composed the fluid-globe must have been the same as those which enter into the composition of the earth at the present day. If, however, we leave out of consideration those volatile and gaseous elements which, from their nature, must have gone to form the primitive atmosphere, and also the greater bulk of the metals, which, from their gravity, must have accumulated at the centre of the earth, we have the following list of substances, which in all likelihood, constituted the upper zone of the original fluid-globe:—Silicic, boracic, phosphoric, stannic, titanic, niobic, tungstic, and tantalic acids: among bases, potash, soda, lithia, lime, magnesia, alumina, ferric oxide, zirconia, manganic oxide, manganous oxide, ferrous oxide, glucina, ceria, yttria, oxides of zinc, lanthanum and uranium. All of these substances make their appearance in original rocks, many of them however in comparatively minute quantity and entering only into the composition of their so-called accessorial constituents. If we, for the sake of clearness, leave these rarer substances aside for the present, we have the following, which may be regarded as the essential chemical constituents of original rocks:

Silicic Acid, ...Alumina,.....Protoxide of Iron,
Magnesia,.....Lime,.....Soda,.....Potash.

These substances, we may suppose, were, in the original fluid magmas from which original rocks crystallised, present in the same manner in which we see them combined together in furnace slags or glass. Each of these constituents, the alkalies excepted, is of a most refractory nature by itself, but, when several of the earths unite with the silica, compounds result of various degrees of fusibility. In this there is merely a repetition of the well-known phenomena of chemical combination, where elements the most antagonistic combine to form a substance innocent of any of the properties of its constituents. The silica or quartz infusible and chemically indifferent as it may appear under ordinary circumstances, acts in this case as an acid, and, with the aid of heat, combines with the equally refractory bases, forming readily fusible compounds. The simple silicates, formed by the union of silica or silicic acid with one base, are not always fusible. Those of the alkalies and iron oxides are, but the silicates of alumina (clay), magnesia (serpentine), and lime (wollastonite), are almost or completely infusible. Nevertheless, the three latter combined form the scoriæ of most frequent occurrence in the arts, namely, those of iron furnaces. In these slags the proportion of silica present often mounts as high as 75 per cent., while those from puddling furnaces do not contain more than 35. The former are termed very acid or siliceous, and the latter very basic slags. Such variations in the silica contents of these compounds are accompanied by corresponding changes in their chemical and physical properties. Basic slags are more easily fused than siliceous slags, although the latter do not solidify as rapidly as the former.

The same variations in the quantity of silica which occur in furnace slags are also to be found in original rocks, and just as furnace scoria have been ranged under different chemical formulæ, so, likewise, it has become possible to classify original rocks in a similar manner. When the student of chemistry has gradually added an acid to an alkali, or other base, until the mixture neither reddens litmus nor browns turmeric paper, he has formed a neutral salt consisting of one atom of base to one of acid, such as sulphate of iron ($FeO\ S.O_3$) and nitrate of potash ($KO\ N.O_5$). The salts of the peroxides, although frequently possessing acid properties, are, nevertheless, also regarded as neutral or normal, and contain, for every atom of base, three of acid, such as persulphate of iron ($Fe_2\ O_3\ 3\ SO_3$) or tersulphate of alumina ($A_2\ O_3\ 3\ SO_3$). Similarly in mineralogy those silicates are regarded as

neutral which contain one atom of monoxide combined with one of silica acid or silica, or one atom of sesquioxide combined with three of silica. Thus the mineral leucite, which consists of one atom of potash, one of alumina, and four of silicic acid, may be regarded as the type of a neutral mineral. Its formula is KO. $Al_2 O_3$ 4 Si. O_2 and it will be observed that its bases contain four while its acid contains eight equivalents of oxygen. Neutral or monosilicates, therefore, are those in which the proportion of oxygen in the bases, to that in the acid, is as 1 is to 2. If we search among crystalline rocks for those in which this oxygen ratio exists, we shall find them to be well-defined rock species which are not usually considered from a chemical point of view at all. These rock species are syenite, melaphyre and andesite, which respectively represent the neutral development of the granular, porphyritic, and trachytic orders of original rocks. If, from among the syenites, melaphyres and andesites which have been subjected to analysis, we select those whose oxygen ratio best corresponds to neutrality, we have the following:—

	Oxygen of bases.	Oxygen of acid.	Quantity of Silica in 100 parts rock.
I. Syenite from the Steilen Stiege, in the Hartz,—Fuchs.....	1	1·818	56·36
II. Syenite from Monte Margola, near Predazzo,—Kjerulf.....	1	2·229	58·05
III. Syenite from the Schönberger Thal in the Bergstrasse,—G. Bischof.....	1	2·051	58·90
IV. Syenite from Plauenschen Grund, near Dresden,—Zirkel.	1	2·288	59·83
Average.....	1	2·104	58·28
I. Melaphyre from Schneidmüllersberg, in Ilmenthal, near Ilmenau,—Von Richthofen...	1	1·938	55·54
II. Rhombic porphyry of Vettakollen, classed with the melaphyres, by Naumann, Delesse Kjerulf.....	1	2·017	56·—
III. Melaphyre from Bahrethal, near Ilfeld,—Streng.....	1	2·011	56·22
IV. Melaphyre from Leuchtburg, in the Thüringian Forest,—Söchting.....	1	2·133	59·18
Average.....	1	2·024	56·73

II. Augitic andesite from Löwenburg, in Siebengebirge,—Kjerulf	1	1·858	55 68
II. Hornblendic Andesite, from Merapi, in Java,—Prüss.....	1	1·975	57·60
III. Hornblendic Andesite from Stary Swiethan,—Tschermak.	1	2·091	58·92
IV. Hornblendic Andesite, from Stonzelberg, in Siebengebirge, —Rammelsberg	1	2·332	59·92
Average.....	1	2·066	57·85

It would seem therefore from these figures, that those rocks which, in composition, are neutral or monosilicates, contain an amount of silica averaging 57.62 per cent.

As in chemistry we have acid salts, in which one atom of base is combined with more than one atom of acid, so in lithology we have rocks in which the silica is present in much larger quantity than is required for monosilicates. A very well defined series of rocks is known in which the silica is present in such excess as to give them the composition of bi-silicates, in which two atoms of silica are present for every one of mon-oxide, and six for every two of sesqui-oxide, or in which the oxygen ratio between bases and acid is as one to four. The granular, porphyritic and trachytic developements of those rocks are respectively represented by granite, felsitic porphyry and rhyolite. Proceeding in the same manner as with the neutral rocks we find the following among this series to approach most closely in composition to bi-silicates:

	O RATIO.		Quantity of Silica in 100 parts rock.
	Bases.	Silica.	
I. Granite from Heidelberg,—Streng	1	3 893	72 11
II. Granite from Doochary Bridge, Donegal,—Houghton	1	3.760	72.24
III. Granite of Fox Rock, near Dublin,—Houghton...	1	4.077	73
IV. Granite of Striegau near Silesia, —Streng.....	1	4.361	73.13
V. Granite of Blackstairs Mountian, Wexford,—Houghton ...	1	3.953	73.20
Average.....	1	4 009	72.73
I. Felsitic porphyry from Mühlberg near Halle,—Laspeyres	1	4 051	72 24
I. Quartzose trachyte from Hohenburg, near Berkum, opposite the Siebengebirge, Bischof ..	1	3.824	72.26
II. Quartzose trachyte from the Island of Ponza,—Abich	1	4.152	73.46
Average.....	1	3.988	72.86

It appears, therefore, that the oxygen ratio 1 to 4 corresponds to an average silica percentage of 72.61, and to such bi-silicate rocks the name silicic might be applied.

But besides this silicic series of rocks there is found another series of very different chemical constitution, and in which the bases, and not the silica, preponderate. It is only, however, in rare instances among these rocks that the silica disappears to such an extent as to form a disilicate, *i.e.*, a compound of one equivalent of silica with two of base, or in which the quantities of oxygen contained in acid and base are equal. A very well marked series of basic rocks may, however, be pointed out in which two equivalents of silica are combined with three of base, and in which the oxygen ratio is as $1\frac{1}{3}$ to 1. The rocks which represent this basic development of the porphyritic and trachytic textures, are, respectively, augitic porphyry and nephelinite. The following are instance of these rocks in which the oxygen ratio most closely approaches 1·333=1 :—

	OXYGEN RATIO.		Quantity of Silica in 100 parts rock.
	Bases.	Silica.	
Augitic porphyry from Fassathal in Tyrol	1	1·391	45·05
Nephelinite from Wickenstein in Lower Silesia,—Lowe	1	1·317	41·87

The number of analyses of these basic rocks being somewhat limited, it is not possible to arrive at their average silica contents so closely as in the case of the neutral and silicic rocks. These instances, however, shew that the oxygen ratio 1·333:1 corresponds to a percentage of about 43.46 silica. Rocks thus constituted being two-third silicates, might be conveniently called sub-silicates, and, in contradistinction to the silicic series, might be termed the basic rocks.

Between the basic and neutral rocks, on the one hand, and the latter and the silicic rocks on the other, there exist many other rocks of intermediate composition and forming gradual transitions between each of the series, which have been more minutely referred to in the foregoing. It thus becomes possible to point out a series of rocks passing gradually from the basic extreme to that of acidity in composition, not only for each of the granular porphyritic and trachytic order of rocks, but also for every variety of texture specified in the preceding chapter. The following Table gives an arrangement of these various series of rocks and an exhibition of the distinctive characters as to texture and

chemical composition possessed by each. In constructing this table, it has been found that by limiting the variations in silica contents of each family to 7 per cent. very correct lines of separation may be drawn betwixt them:—

TABLE I,

Showing the General Chemical Composition of the Families of Original Rocks.

Order of Texture.	Basic Rocks, (subsilicates), containing less than 49 per cent. Silica.	Basous Rocks containing from 49 to 55 per cent. Silica	Neutral Rocks, (monosilicates) containing from 56 to 63 per cent Silica.	Siliceous Rocks, containing from 63 to 70 per cent. Silica	Silicic Rocks, containing more than 70 per cent. Silica
I Coarse and small-grained.....	Anorthosite.	Greenstone.	Syenite.	Granitite.	Granite.
II Schistose	Basic schst.	Hornblende schist.	Syenite schist.	Gneiss.	Gneissite.
III. Slaty.....	.....	Greenstone slate.	Clay slate.	Siliceous slate.	Silicic slate.
IV Porphyritic	Augitic porphry.	Greenstone porphyry.	Melaphyre.	Porphyrite.	Felsitic porphyry.
V Variolitic.....	.....	Variolite.	Var. basaltite	.....	Sphärolite.
VI. Fine-grained	Basal.	Trap.	Basaltite.	Eurite.	Felsite.
VII. Trachytic.....	Nephelinite.	Dolerite.	Andesite.	Trachyte.	Rhyolite.
VIII Volcanic.....	Nephelinite lava.	Dolerite lava	Andesite lava.	Trachytic lava.	Obsidian.

Before proceeding to explain the foregoing table, it may be mentioned that no new names have been used in its construction; that names to which definite ideas as to mineralogical constitution are attached, have been, as much as possible, excluded. Such names as trap, greenstone, and melaphyre, which have been, in the early history of the science, much abused and misapplied, and more recently condemned as useless for the purpose of indicating any special rock, are introduced into our table, and advantageously used in designating the families of rocks to which they were originally applied. If it were made a rule in the science to exclude from it all names which have been at one time or other misused, very few petrological terms would escape obliteration; and the fact that the names above mentioned, in spite of their condemnation by some lithologists, continue in common use, sufficiently proves that they possess a certain degree of usefulness and applicability.

It will be observed that in the table the terms basic and basous, silicic and siliceous, are used in a manner analogous to that in which the stronger and weaker bases and the stronger and weaker acids are indicated in chemical nomenclature. A bas*ic* slate always contains a larger percentage of bases than a bas*ous* one, and a sili*cic* porphyry in the same way contains more silica than a silic*eous* one. It will next be observed that we have in the table

eight different horizontal series of rocks, or rather rock families, corresponding to the eight different varieties of texture which have been before particularized. On passing in each of these series from left to right we pass from the basic to the siliceous extremes, through rock families gradually increasing in silica contents, as the figures at the head of the vertical columns shew. With this increase in the amount of silica a corresponding change in the nature of the bases with which it is combined takes place. Towards the basic extreme these are principally magnesia, lime, and protoxide of iron; but as the silica increases these bases diminish, and alumina with the alkalies increase until, at the silicic extreme, alumina and potash become the preponderating bases. We have also in the table five different vertical series, among which the neutral, basic and silicic groups already referred to, occupy places in the middle and at the sides, while the intermediate groups, which were also mentioned above, and which have been called the basous and silic ous rocks, occupy positions immediately to the left and right of the central column. The rock families of each of these vertical series, although they may differ widely as regards their texture, all possess a similar chemical composition. The chemical nature, texture, and affinities of any original rock or rock family are seen from this table at a glance. Thus, porphyrite appears as the porphyritic developement of the siliceous group of rocks; as less siliceous than felsitic porphyry, and more so than melaphyre. Basalt is seen to be the most basic member of the fine-grained order, and to contain less than forty-nine per cent. of silica. The affinities of any rock may be ascertained by observing the names of the rocks placed next to it, for in almost every case it is into these that it is most prone to graduate.

There are other of the general relations among original rocks visible from this table than those which refer to their composition texture and affinities. Not only do the rock families mentioned in each vertical column resemble each other in chemical composition, but they also exhibit similar coincidences as regards their general colour, hardness and fusibility, and gradual transitions in each of these respects are found to exist from rock to rock along each horizontal series. The basic rocks are generally darker coloured, less hard, and more readily fusible than the rocks which correspond to them in texture but differ from them in containing a larger percentage of silica. On the other hand

the more siliceous a rock is, the lighter it will generally be found to be in colour, the harder and more difficult to penetrate or excavate, and the more refractory on exposure to high temperatures.

There is yet another physical property belonging to those original rocks, in which they show a similar correspondence with their chemical composition. Still speaking generally, the more siliceous a rock the lighter it is, not only in colour, but in weight; the more basic the rock, the heavier it becomes. Thus it is the case that, in each order of texture on passing from the siliceous to the basic rocks, a gradual increase of density takes place, and on the other hand, the transition from the basic rocks to the more siliceous exhibits a gradual diminution of specific gravity. So constant is this relation that it may be taken advantage of in determining the general composition of a rock. To take as an instance the coarsely granular series of rock families the general range of their specific gravities may be said to be as follows:—

Granite - - - - -	2.65 and under.
Granitite - - - - -	2.65 to 2.8.
Syenite - - - - -	2.8 to 2.875.
Greenstone - - - -	2.875 to 3.—

This part of the subject is one of very great interest, but it would be premature at present to discuss it minutely.

V.—MINERALOGICAL CONSTITUTION.

Having, in the foregoing, adverted to the texture and chemical composition of original rocks, it now becomes necessary to refer more particularly to their mineralogical constitution. In order to continue the analogy which has been shown to exist between furnace slags and original rocks, it will be well here to refer to those instances which have been observed of the formation of well developed crystals in the cooling of artificial silicates. The rapid manner in which furnace slags are commonly allowed to cool is of course detrimental to the formation of any mineral-like aggregations, but it is sometimes possible to observe in copper furnace slags, that when they have been allowed to solidify in large blocks or cakes, they show an actynolitic structure in their mass, often closely resemble hornblende rock, and very commonly contain cavities lined with the most beautiful crystals. The formation of pyroxene in slags from iron furnaces has been frequently observed and well authenticated. Nöggerath described

augite crystals from the slags of the iron furnace of Olsberg, near Bigge, in Westphalia; Montefiori Levi analysed augites taken from the slags of the iron furnace at Ougreé, near Liege. Richter described and examined similar crystals from the iron works of Rufskberg in the Banat; Von Leonhard mentions acicular augite crystals in the iron furnace slags of Skis-hytta in Sweden. F. Sandberger describes similar occurrences, and numerous others might here be mentioned. Mitscherlich and Berthier obtained by melting silica, lime, and magnesia together, in a charcoal crucible placed in a porcelain furnace, a mass possessing cleavage corresponding to the faces of augite, and the hollow cavities in which were crowded with the most beautiful crystals of that mineral. These are also of very common occurrence in the lava streams, not only of extinct but of active volcanoes, and well developed augite crystals have not unfrequently been ejected from their craters. Olivine has been observed in the slags of iron furnaces quite as frequently at augite, and it, as well as magnetite is one of the commonest minerals in streams of basaltic lava. So is leucite, although it has not yet been produced artificially. Mitscherlich observed transparent six-sided tabular crystals of mica, and laminæ of it several inches broad, in the cavities of old copper furnace slags near Garpenberg, in Dalecarlia. Gurlt also mentions artificially formed mica, and it appears frequently in ancient and modern lava streams. With regard to felspar, Hausmann makes mention as early as 1810, of felspar crystals which had been formed in one of the Mansfield furnaces. In 1834, Heine found similar crystals in the copper furnace of Sangershausen after it had been blown out, and in the iron furnace of Josephshütte, in the Hartz, they were also detected. In 1810 the formation of felspar crystals in glass works was first observed, and in 1848 Prechtl gave an account of their occurring in a mass of glass weighing 133⅓ lbs. which had been melted in the plate glass factory at Neuhaus. They were of various sizes, some an inch in length, with perfectly sharp edges. The formation of sanidine and other varieties of felspar, in lavas of recent age, is a matter of common occurrence. No instance is known of the production of quartz from artificial silicates, nor do those lavas of the present day which are highly siliceous, develope it in cooling. These solidify as vitreous uncrystalline masses, but many lavas of extinc volcanoes in the Andes and the Siebengebirge contain it in well

formed crystals, showing that it must have crystallised out from the mass of the rock.

The number of minerals which enter into the constitution of rocks is very small compared with the number of the mineral species which are found described in the various treatises on mineralogy. Of the latter there are upwards of six hundred, but the great majority of these are rare minerals, occurring in veins or cavities and not entering into the constitution of the rocks themselves. The number of minerals which are found in original rocks is still more limited, and if from it we deduct the sparingly occurring, or so-called accessorial constituents, the number is reduced to ~~twenty~~ minerals which may be called the essential constituents of original rocks. The following table gives their names and the silica contents of the extreme acid and basic varieties :—

Mineral.	*Per centage of Silica.*
Quartz	100·00 — 00·00
Orthoclase	69·00 — 62·75
Oligoclase	64·26 — 59·28
Labradorite	55·83 — 50·31
Anorthite	47·63 — 42·01
Leucite	58·10 — 53·50
Nepheline	45·31 — 43·50
Potash mica	51·73 — 43·47
Magnesia mica	44·63 — 36·17
Hornblende	60·60 — 37·84
Pyroxene	57·40 — 38·58
Hypersthene	54·35
Enstatite	56·91
Diallage	53·71 — 49·12
Olivine	44·67 — 36·30
Magnetite	00·00

The separation of the minerals occuring in rocks into essential and accessorial constituents, originated with German lithologists and may perhaps be regarded as arbitrary. In characterizing the sixteen minerals just mentioned as *essential* constituents we have, however, to some extent, been guided by their chemical constitution. In the preceding chapter silicic acid, alumina, peroxide of iron, protoxide of iron, magnesia, lime, soda and potash were indicated as the essential chemical constituents of rocks, and only such minerals as contain these substances, and no others as *essential ingredients* have been admitted into the table. This mode of selection may perhaps be considered as arbitrary as any other, for it causes the exclusion of the mineral tourmaline which sometimes appears to deserve the rank of an essential

constituent. Tourmaline, however, contains, besides some of the subtances just mentioned, boracic acid and fluorine, and, in its mode of occurrence, resembles such accessorial or accidental minerals as zircon, apatite, titanite and others. Garnet, corundum, epidote, cordierite and scapolite are rock minerals, containing no other chemical constituents than those above mentioned, but they have been excluded from our list because they resemble the accessorial constituents in the manner of their occurrence.

With regard to these essential minerals it is first to be remarked that the analyses which have been made of them are not, in every case, of such specimens as have actually formed part and portion of some rock species. To obtain pure specimens of the minerals of rocks is often a matter of great difficulty, and well-developed crystals from veins or geodes have been preferred for analysis to the generally amorphous particles of the same species which enter into the constitution of rocks. The composition of these minerals cannot, like that of well-crystallised artificial chemical compounds, be unequivocally expressed by chemical formulæ. Attempts, the most painstaking and persevering, have been made in this direction by mineralogists, and the result has only been to shew that, in the majority of cases, each analysis of the same species demands a different formula for expressing its composition in chemical equivalents. The composition of micas, augites and hornblendes is especially variable, and even with regard to the felspars it has been maintained that those of our list are not distinct or independent species but are mixtures of one with the other or with other supposed species, such as krablite, albite or adularia. It has therefore been considered best here to neglect their various assumed chemical formula and to regard principally their average chemical composition.

Certain differences in the composition of these minerals cause their subdivision into two different classes. The minerals of the first class are mostly silicates of alumina, lime, potash and soda, and *it may be called the felspathic class.* It includes, however, leucite and nepheline, which can scarcely be called felspars, and quartz, which, although of very different composition, nevertheless possesses lithological affinities connecting it closely with the acid felspars. The minerals of the second class also contain lime, but alumina and the alkalies are less frequent or absent altogether, being replaced by magnesia and protoxide of iron. They are generally of a more basic nature than the felspathic class, and the

purely basic mineral magnetite may be placed, as lithologically related, along with them. The minerals of this class may therefore be called the basic essential constituents of rocks. We have thus the following classification of these essential rock minerals.

Class 1st.—Felspathic—Quartz, Orthoclase, Oligoclase, Labradorite, Anorthite, Leucite, Nepheline.

Class 2nd.—Basic—Potash mica, Magnesia mica, Hornblende, Pyroxene, Diallage, Enstatite, Hypersthene, Olivine, Magnetite.

The extent to which these minerals enter into the constitution of original rocks will be best seen by repeating here the general view given of the families of rocks, placing at the head of each column the names of the principal constituents.

Table II.

General View of the Mineralogical Constitution of the families of Original Rocks.

	Basic Rocks.	*Basous Rocks*	*Neutral Rocks*	*Siliceous R'ks*	*Silicic Rocks.*
Felspathic Min'ls	Anorthite.... Nepheline ...	Oligoclase. Labradorite. Anorthite. Nepheline.	Orthoclase. Oligoclase.	Quartz Orthoclase. Oligoclase.	Quartz. Orthoclase.
Basic Minerals ..	Pyroxene .... Olivine ..... Magnetite ...	Mag: mica. Hornblende. Pyroxene. Olivine.	Mag: mica. Hornblende.	Mag: mica.	Pot: mica.
I. Coarse and small-grained .	Anorthosite..	Greenstone.	Syenite.	Granitite.	Granite.
II. Schistose	Basic schist..	Greenstone schist.	Syenitic schist.	Gneiss.	Gneissite.
III. Slaty	.....	Greenstone slate.	Clay slate.	Siliceous slate.	Silicic Slate.
IV. Porphyritic..	Augitic porphry.	Greenstone porphry.	Melaphyre.	Porphyrite.	Porphyry.
V. Variolitic	.....	Variolite.	Var. basaltite	.....	Spherulyte.
VI. Fine grained	Anhydrous basalt.	Trap.	Basaltite.	Eurite.	Felsite.
VII. Trachytic..	Nephelinite.	Dolerite.	Andesite.	Trachyte.	Rhyolite.
VIII. Volcanic..	Nephelinite lava.	Doleritic lava	Andesitic.	Trachytic lava.	Obsidian.

It will be observed from this table that a certain degree of consistency is observed by the essential minerals in entering into the constitution of original rocks. Such acid minerals as quartz and orthoclase never occur in the basic rocks; nor, on the other hand, do we find augite or labradorite entering into the composition of siliceous granites or trachytes. Towards the basic extreme of chemical composition in rocks, the siliceous minerals diminish or disappear, and, towards the acid extreme, basic minerals act in the same way. This behaviour alone is sufficient to shew that the mineralogical constitution of a rock is not the result of accident, but mainly the consequence of the chemical nature of the plastic magma from which it resulted, an inference which is borne out by the varying composition of the minerals themselves.

It will be seen that at the heads of the columns the minerals have been arranged according to the classification already given. Now it would appear, with regard to the members of each of the classes which we have distinguished, that not only do they resemble each other in chemical composition but they seem to replace each other when they enter into the composition of original rocks. That is to say, the increase, in quantity, of one of them in a rock is generally accompanied by a decrease on the part of another member of the class, and generally of that member which most closely approaches the first in chemical composition. This appears to be well borne out by the table, and numerous examples of such substitutions might be cited. Thus hornblende replaces mica in granitite forming syenite; oligoclase replaces orthoclase in the passage from syenite to diorite; and diallage replaces pyroxene in that species of greenstone called gabbro. There are thus formed gradual transitions from one rock species to another in mineralogical constitution as well as chemical composition. In the subjoined table (III) the nature and manner of these transitions are exhibited. It will be seen that the distinctions already made as to the orders and families of rocks are kept steadily in view while at the same time an attempt is made to give a systematic arrangement of the different species of original rocks and their mutual relations.

III.—Table showing the Constitution of the various Species of

Description of Texture and names of Essential Basic Constituents.	*Basic Non-felspathic Rocks.*	*Basic Rocks (Subsilicates.)* Under 49 p. c. Silica.	*Basous R* 49 to 56 Silica
		Saussurite. Anorthite. Nepheline.	Oligoclase. Labradorite
I. Coarse and small-grained; with no basic constituents	.....	.....	Noryte.
" " with Mica	.....	.....	Micaceous
" " " Hornblende	Amphibolyte.	Corsyte.	Diorite.
" " " Pyroxene	Pyroxenyte.	Eukryte.	Diabase.
" " " Diallage or Smaragdite.	Omphazyte.	Emphotide.	Gabbro.
" " " Hypersthene	.....	.....	Hyperyte.
" " " Enstatite	Lherzolyte.	Protobastyte.	
" " " Olivine	Dunyte.		
" " " Magnetite	Magnetyte.		
II. Schistose; with no basic constituents	.....	.....	.....
" " Mica	.....	.....	.....
" " Hornblende	Hornb. schist.	.....	Diorite schi
" " Pyroxene	.....	.....	Diabase sch
III. Slaty	.....	Green slate.	Aphanyte sl
IV. Porphyritic; with no basic constituents developed	.....	.....	.....
" " Mica separated	.....	.....	Kersantone.
" " Hornblende separated	.....	Anorthite porph.	Diorite porp
" " Augite separated	.....	Augitic porph.	Diabase por
V. Variolitic	.....	.....	Variolyte.
VI. Fine-grained; with Minerals indistinct	.....	Basanyte.	Aphanyte.
" " Hornblende perceptible	.....	Teschenyte.	Dioritic aph
" " Augite perceptible	.....	Anamesyte.	Trap.
" " Augite and Olivine	.....	Basalt.	
VII. Trachytic; with no basic constituents	.....	.....	.....
" " Mica and Hornblende	.....	.....	.....
" " Augite and Magnetite	.....	Nephelinyte.	Doleryte.
VIII. Volcanic.			
Vitreous	.....	.....	.....
Cavernous	.....	.....	.....
Scoriaceous	.....	Basaltic lava.	Doleritic la

...sic Rocks. ...bsilicates.)	*Basous Rocks.*	*Neutral Rocks. (Monosilicates.)*	*Siliceous Rocks.*	*Silicic Rocks. (Bisilicates.)*	*Silicic Non-felspathic Rocks containing Quartz.*
...der 49 p. c. Silica.	49 to 56 p. c. Silica.	56 to 63 p. c. Silica.	63 to 70 p. c. Silica.	Over 70 p. c. Silica.	
		Essential Felspathic Constituents.			
...surite. ...rthite. ...heline.	Oligoclase. Labradorite.	Orthoclase. Oligoclase.	Quartz. Orthoclase. Oligoclase.	Quartz. Orthoclase.	
....yte. ...ryte. ...notide. ....bastyte.	Noryte. Micaceous diorite. Diorite. Diabase. Gabbro. Hyperyte.	..... Miascyte. Syenite.	..... Granityte. Hornb. Granityte.	Granitelle. Granite.	Quartzyte. Greisen.
....	.... Diorite schist. Diabase schist.	.... Syenitic schist.	..... Gneiss. Syenitic gneiss.	Granulite. Gneissyte.	Quartz schist. Mica schist.
...n slate.	Aphanyte slate.	Argillyte.	Siliceous slate.	Felsitic slate.	
....hite porph. ...ic porph.	..... Kersantone. Diorite porphyry. Diabase porphyry.	Melaphyre. Minette. Hornb. Melaphyre. Augitic Melaphyre.	Porphyrite. Mica porphyrite. Hornb. porphyrite.	Felsitic porphyry Mica porphyry.	
.....	Variolyte.	.....	.....	Spherulyte.	
...yte. ...enyte. ...esyte.	Aphanyte. Dioritic aphanyte. Trap.	Basaltyte.	Euryte.	Felsyte.	
....linyte.	.... Doleryte.	..... Andesyte. Augitic Andesyte.	..... Trachyte. Augitic trachyte.	Rhyolyte. Dacyte.	
....ic lava.	.... Doleritic lava.	..... Andesitic pumice. Andesitic lava.	Obsidian. Pumice.	Silicic obsidian.	

In preparing table III, the same care has been taken as with those already given to introduce no new terms, and to use the various names of the species only in the sense which at present is generally attached to them by petrologists. In a few instances, where such names have hitherto borne a too general or a more or less indefinite meaning, an attempt has been made to confine their application to one species. The name rhyolite is for instance used in a somewhat more restricted sense than that given it by its originator, and the very vague, generally condemned, but still much used or misused, name, melaphyre, is, as applied to a particular species, limited to those porphyrite rocks which are neutral in chemical composition and in which crystals of triclinic felspars only are developed. In some other cases, where the same species possessed several synonyms, a slightly different signification has been given to one, and generally the least used of them, in order to make it of use in our system. For instance, eurite and felsite have hitherto been synonymous. In our table the latter term is made to indicate the more silicic species of fine grained rocks. Such names of rocks as have been derived from those of minerals have their terminations, in accordance with Dana's suggestion, altered from *ite* to *yte*.

It will be observed that, in table III, the minerals of the felspathic class only are placed at the head of the vertical columns, while the other essential minerals have been placed under each variety of texture on the left hand side. The cause of this arrangement may here be stated. The felspars, being of very constant occurrence in original rocks, and being frequently difficult to determine, have not been much made use of in distinguishing species until quite recently. For instance, oligoclase very often can only be distinguished from orthoclase by an experienced mineralogist, and only an experienced chemist after a minute analysis, can distinguish between oligoclase, labradorite and anorthite in a compound rock. On the other hand the minerals of the other class possess very well marked physical characters, and the presence of one or other of them was readily detected by the earlier petrologists and made use of by them for characterising different rocks. Thus, mica, hornblende and olivine are very widely apart both as regards form, colour, hardness and fusibility. The only two minerals of the second and third classes which are difficult to distinguish from each other are hornblende and augite, and this is only the

case in fine grained compound rocks. By giving prominence to each of these non-felspathic minerals and placing their names on the horizontal lines of our table, it becomes possible to shew at a glance the rocks which they form with the felspathic minerals named at the heads of the vertical columns, and the manner in which, by gradually replacing each other, they form the different species of original rocks. Thus it will be observed that among the schistose rocks the most basic is diabase schist; that the latter becomes diorite schist when hornblende replaces pyroxene; that the diorite schist, as its oligoclase is replaced by orthoclase, becomes syenite schist, and, as quartz makes its appearence and increases, syenitic gneiss is produced. At the next step in a silicic direction, mica replaces the hornblende, producing common gneiss, then when the mica disappears, granulite results. If, instead of the mica, the orthoclase disappears, mica schist is developed, and when from the latter rock the mica in greater part is withdrawn, it becomes quartz schist. The other varieties of texture, such as the porphyritic and trachytic, each exhibit a similar series of transitions, the most fully developed being the granular order. In the latter it becomes possible, by means of the peculiar arrangement of our table, to shew the mineralogical nature of each of the species of the complicated family of the greenstones. Diorite, gabbro, hyperyte, diabase and protobastyte rock are shewn to be respectively characterised by hornblende, diallage, hypersthene, pyroxene and enstatite in combination with various felspars. The great majority of original rocks contain some variety of felspar, but there are a few species in which that mineral is absent and which are called non-felspathic rocks. In order as far as possible to shew these also in our table, two columns have been added to it, one at each side. The right hand one shews the silicic, and the left hand the basic rocks void of felspar.

VI.—ACCESSORIAL CONSTITUENTS.

Besides the minerals mentioned in the foregoing chapter as the essential constituents of crystalline rocks, there are others of less frequent and only accidental occurrence, which have been called by German lithologists the accessorial constituents. Among these such minerals are not included as are only found in the veins, cavities, or even joints enclosed in rocks. Only those which are found in intimate mechanical union with the essential constituents in the body of the rock itself are regarded as accessorial consti-

tuents. They are sometimes made up of the same common chemical components as the essential rock constituents, but much more frequently other and rarer elements enter into their composition. It is indeed almost exclusively from these accessorial minerals that many of the rare simple elements have been derived with which chemists alone have any intimate acquaintance. Thus glucinum, cerium, yttrium, lanthanium, columbium, tantalum, tungsten and zirconium are only found as components of accessorial rock constituents, while other elements, such as sulphur, phosphorus, boron, fluorine, chlorine, tin, copper, lead, chromium and titanium are frequently found in them, which but rarely occur in essential rock constituents. The following is a catalogue of the accessorial constituents of rocks, arranged according to Dana's system, which at the same time indicates briefly their chemical nature.

I. *Native elements.*

Gold.
Silver.
Mercury.
Iron.
Diamond.
Graphite.

II. *Sulphides, &c.*

Molybdenite.
Galena.
Blende.
Magnetic pyrites.
Iron pyrites.
Copper pyrites.
Skuterdite.
Cobaltite.
Leucopyrite.
Mispickel.

III. *Fluorides.*

Fluorite.
Fluocerite.

IV. *Anhydrous Oxides.*

Corundum.
Hematite.
Ilmenite.
Perofskite.
Spinelle.
Gahnite.
Chromite.
Chrysoberyl.
Tinstone.
Rutile.

V. *Anhydrous Silicates.*

1. Bi silicates.
Aegirite.
Acmite.
Spodumene.
Crocidolite.
Beryll.
Eudialite.

2. Uni silicates.
Leucophanite.
Wohlerite.
Phenakite.
Helvine.
Zircon.
Vesuvianite.
Melilite.
Epidote.
Saussurite.
Allanite.
Gadolinite.

Mosandrite.
Lievrite.
Cordierite.
Lepidolite.
Scapolite.
Meionite.
Dipyre.
Sodalite.
Haüyn.
Nobean.
Leucite.

3. Subsilicates.
Tourmaline.
Andalusite.
Cyanite.
Topaz.
Titanite.
Staurolite.

VI. *Tantalates, Columbates and Tungstates.*

Pyrochlore.
Tantalite.
Columbite.
Yttrotantalite.
Aeschinite.
Polycrase.
Polymignite.
Mengite.
Wolframite.

VII. *Phosphates.*

Apatite.
Monazite.
Tryphllite.

From this list it will be seen that the accidentally-occurring minerals in crystalline rocks are five times as numerous as the essential minerals. It is scarcely possible to take a general view of the list without noting not only the number of rare elements which are found among their components, but also the preponderance of bases in their composition. The number of subsilicates and unisilicates largely exceeds that of the bisilicates. The rare tantalates, columbates, &c., are exceedingly basic, while no less than ten consist exclusively of anhydrous oxides. Another peculiarity in the composition of the silicates among them is the presence of sesqui-oxides in large quantity. Epidote, lievrite and others are silicates of alumina and peroxide of iron, while andalusite, cyanite, topaz and many others contain the former base in great abundance.

With regard to their distribution among original rocks, it is to be remarked that by far the greater number are native to the coarse-grained and schistose series, and occur in largest quantity in their neutral or siliceous families. Granites and syenites are especially rich in them, a remarkable instance being the zircon syenite of Fredericksvaern in Norway, in which no less than fifty different minerals are found, among whose components there are nine rare elements. These accessorial minerals become less frequent in the porphyritic and trachytic rocks, until among modern lavas very few of them are to be found.

The following statement shews the distribution of the accessorial minerals among the various orders of original rocks:

In coarse and small-grained rocks.

Aegirite.
Aeschinite.
Acmite.
Allanite.
Analcime.
Andalusite
Apatite.
Apophyllite.
Beryll.
Blende.
Calespar.
Cataplciite.
Columbite.
Copper pyrites.
Cordierite.
Corundum.
Crocidolite.
Chrysoberyll.
Cyanite.
Diamond.
Epidote.
Eudnophite.
Eukolite.
Fluocerite.
Fluorite.
Gadolinite.
Gahnite.
Galena.
Gold.
Graphite.
Hematite.
Hypostilbite.
Ilmenite.
Iron pyrites.
Lepidolite.
Leucophane.
Magnetic pyrites.
Mengite.
Mercury.
Molybdenite.
Monazite.
Mosandrite
Phenakite.
Pinite.
Polycrase.
Polymignite.
Prehnite.
Pyrochlore.
Rutile.
Saponite.
Saussurite.
Scapolite.
Silver.
Sodalite.
Spodumene.
Tantalite.
Thorite.
Tinstone.
Titanite.
Tourmaline.
Triphylite.
Tritonite.
Vesuvianite.
Wolframite.
Wohlerite.
Yttrotantalite.
Zircon.

In Schistose rocks.

Andalusite.
Apatite.
Beryll.
Calcspar.
Cordierite.
Corundum.
Cyanite.
Dolomite.
Fluorite.
Graphite.
Hematite.
Iron pyrites.
Lepidolite.
Molybdenite.
Rutile.
Spinelle.
Staurolite.
Titanite.
Tourmaline.
Zircon.

In Slaty rocks.

Chiastolite.
Chloritoid.
Damourite.
Dipyre.
Fahlunite.
Ottrelite.
Paragonite.
Sericite.
Staurolite.

In Porphyritic rocks.

Apatite.
Calcspar.
Crocidolite.
Delessite.
Epidote.
Fluorite.
Gieseckite.
Halloyside.
Iron pyrites.
Liebenerite.
Titanite.
Tourmaline.

In Impalpable rocks.

Hauynite.
Ilmenite.
Iron.
Iron pyrites.
Magnetic pyrites.
Nepheline.
Noscan.
Sapphire.
Titanite.
Zircon.

In Trachytic Rocks.

Apatite.	Melilite.
Faujasite.	Nepheline.
Hauynite.	Nosean.
Hematite.	Sapphire.
Iron pyrites.	Titanite.
Leucite.	Zircon.

With regard to the origin of these accessorial minerals it may be maintained that by far the greater number of those just mentioned have been developed during the solidification of the rocks containing them, and somewhat in advance of the essential constituents among which they are found. The evidence of this statement will, however, be given in the following chapter.

VII.—ON THE ORDER IN WHICH THE CONSTITUENTS OF ORIGINAL ROCKS WERE DEVELOPED.

It cannot be assumed that, in the slow crystallisation of a rock from igneous fusion, its minerals were all developed at one and the same instant. On the contrary, many of them are found under circumstances which prove that, even after their formation, the mother magna still possessed some degree of plasticity, and many of the constituents of rocks are so associated and surrounded as fairly to lead to the conclusion that a certain order was maintained in their gradual developement.

The well-known phenomena of fractured crystals in original rocks first deserves mention in this connection. Felspar crystals are frequently found in granites, broken in two pieces, these fragments being displaced, and the space between them filled up with

granitic substance. This is the case with the orthoclase crystals of the porphyry of Elba and of the quartz porphyry of Ilmenau; with the sanidine in the trachyte of Drachenfels, and with the tourmaline of the granite of Winkelsdorf in Moravia. These phenomena serve to prove that the solidification of original rocks took place very gradually, and that their crystallisation was in progress long before they became completely consolidated.

Very many of the facts recorded regarding the occurrence of accessorial minerals in rocks go to prove that they were the first to separate from the fluid magna and assume their characteristic forms. Blum has observed that the long tourmaline crystals which occur in the chloritic schists and granites of Aschoffenburg and of Winkelsdorf in Moravia, and which are frequently found fractured, have their separated fragments frequently bent out of their proper direction and cemented together by mica. The proof here seems plain as to the formation of the tourmaline prior to that of the mica.* In the large grained granite of Bergstiege, near Ruhla in Thuringia, Senft has observed that the quartz partly surrounds the tourmaline and wholly surrounds the mica plates, and regards this occurrence as proving that the formation both of the tourmaline and of the mica preceded that of the quartz.† Very many instances have been observed which go to prove the formation of tourmaline prior to quartz, and not a few from which it may reasonably be inferred that it crystallised before both mica and felspar. In connection with the ore deposits of Scandinavia, mention is made of the occurrence of iron pyrites completely enclosed in a crystal of tourmaline. A similar relation has been observed in the case of garnet, which very frequently encloses in its crystals a kernel of magnetite. Garnet is, however, noted for enclosing many other minerals, quartz, mica, iron glance, vesuvian, epidote, copper pyrites, iron pyrites, galena, blende, and especially hornblende varieties, having been found in the interior of its crystals. According to Blum the orthoclase crystals of the porphyrite of the Baraneo des las Angustias, on the Island of

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* Zirkel, Petrographie I, 63.

† Die Krystallinische Felsgemengtheile, p. 512.

Palma, contain radiating particles of epidote which gradually merge into the mass of the orthoclase. This and similar instances can scarcely be explained otherwise than on the supposition that the formation of the epidote preceded that of the orthoclase. Other facts concerning the occurrence of epidote in syenitic rocks would seem to indicate that the formation of the hornblende preceded or took place contemporaneously with that of the epidote. Senft has observed, near Brotterode, staurolite crystals enclosed in transparent plates of mica, and G. Rose describes both staurolite and cyanite columns as occurring in a similar manner. According to Senft, tourmaline, garnet, staurolite and cyanite are very constant companions of potash mica in crystalline rocks, and most frequently occur bedded in it as well developed crystals, and when separated from the surrounding mass of mica, leave in it an accurately bounded, smooth sided and sharp angled impression of their several forms.*

The order of the formation of the minerals of granite has been a matter of frequent discussion, and the impression prevails that the mica preceded the formation of at least the quartz in that rock. Senft thus gives the result of his observations on this matter: "Potash mica shews itself most frequently associated "with amorphous quartz and with orthoclase; with the first "usually so that it lies imbedded in its mass, which would in- "dicate a later formation for the quartz; with the orthoclase, on "the contrary, frequently so that it appears to sit upon it, so "that one must regard the mica as the newest mineral. How- "ever, there are not wanting examples of the occurrence of mica "sitting upon the quartz, nor of others in which it appears so "evenly intermixed with fresh orthoclase that one must ascribe "to them a contemporaneous origin." †

Senft has also the following remark on the mutual relations of oligoclase and hornblende: "Where oligoclase occurs in very "distinct intermixture with crystals of hornblende, it, for the "most part, surrounds them, and, indeed, often completely encloses "them in its mass. This relation plainly indicates that although "both minerals were produced in one and the same original "magma, nevertheless, the hornblende was the first born, and the "oligoclase was obliged to produce itself out of that part of the "magma remaining after the formation of the hornblende."

* Felsgemengtheile, p. 707. † Felsgemengtheile, p. 707.

The study of the manner and order of the formation of crystalline minerals in coarse-grained, compound crystalline rocks, has not, on the whole, had that attention which it deserves. On the other hand many of the results obtained in the microscopical examination of fine-grained original rocks have an important bearing upon this subject. Vogelsang* has described with the most painstaking accuracy his observations on the mutual relations of the minerals of many pitchstones, trachytes and porphyries. Mention must first be made of a very interesting phenomenon which he has detected in the microscopical structure of many trachytic and porphyritic rocks. This is called Fluidal-structure, and seems to have been discovered somewhat earlier and independently by E. Weiss.† This term is to be understood to denote such a position of the constituents of a rock relatively to each other, as to allow of the inference being drawn that a movement of the mass either as a whole or in its smallest parts, had taken place while the process of crystallisation or solidification was going on. Eight different illustrations of this phenomenon are given in the beautifully coloured plates accompanying Vogelsang's work. One of these shews a trachytic pitchstone from the Euganean hills magnified 100 times. In a brownish perfectly vitreous matrix there are found yellowish grains of glassy felspar, needles of hornblende and microscopical crystals of magnetite. The whole of the vitreous matrix is, besides, filled with small prismatic crystals which are sharply distinguishable from the dark ground. These, Vogelsang hesitates to declare to be felspars, and in the meantime, for convenience sake, terms them "microlites." These little crystals are quite frequent in many rocks, and it is possible to distinguish light and dark coloured microlites, the former being in all likelihood scapolites or felspars, the latter augites or hornblendes. The figure shews the position of these little crystals in relation to the larger ones above named, and it is easily observed that the former lie with their longest axes parallel to each other except in the neighbourhood of the larger crystals of felspar, hornblende and magnetite, around certain sides of which they crowd more closely than elsewhere. The drawing shews the effect of the

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* Beiträge zur Kemetniss der Feldspath bildung, Haarlem, 1866.

† Vogelsang—Philosophie der Geologie und Microscopische Gesteins-studien—Bonn, 1867.

last movement of the mass at the moment of its final solidification. The observer can plainly see that this movement proceeded from right to left, crowded the microlites against the right sides of the larger previously formed crystals, and then carried them past these in the direction of the flow, namely, towards the left. The figure further shews that one large dark coloured crystal of hornblende had been broken into two pieces, and that the smallest of these, after the fracture, had been caused by the motion of the mass to assume a new position against the end of the larger piece. There can be no doubt, says Vogelsang, as to this fact, for each piece possesses a crystalline and a fractured end, and at the latter, in the larger piece, a crystal of magnetite is seen which corresponds exactly to a space visible in the broken end of the smaller piece. The crystal has evidently been broken at this weak place, and the pieces afterwards turned and pressed against each other. Sometimes the felspar crystals in this rock shew a light brown edge round the clear central mass of the crystal. When more strongly magnified, it becomes plain that the brown vitreous matrix has penetrated the crystal in innumerable places by the cleavage planes. In some crystals this only takes place to a certain depth; others are penetrated through and through by the matrix. Fluidal-structure, sometimes closely resembling that just described and sometimes considerably modified, has been observed by Vogelsang in the basalts of Unkel and Obercassel, in the lava of the island of Ischia, in the diabase of Weilburg on the Sahn, in the quartzose trachyte of Campiglia, in the black pitchstone of Zwickau, and in the quartzose porphyry of Wurtzen in Saxony. Another figure gives a representation of a part of the last named rock magnified 200 times. In this example the Fluidal-structure is not indicated by the position of crystals previously developed, but by a varied colouring which corresponds to differences of densities in the vitreous matrix. A similar appearance is frequently visible in window glass when its substance has not been rendered perfectly homogeneous in the manufacture. Through the whole of the matrix of this rock there are scattered very fine black points, but these are found much less frequently in the dark than in the light-coloured portions of the matrix.

Many of the facts observed by the naked eye, concerning the order of the formation of rock minerals, are confirmed by Vogelsang's researches with the microscope. Especially

decided is the result as regards magnetite, which is invariably observed to be the oldest formed mineral in the more recent eruptive rocks, all the crystalline constituents of which enclose it. The felspars contained in trachytes, basalts, dolerites, and melaphyres, and the augites and hornblendes of the same rocks, all found the magnetite ready formed when their developement began, and enclosed it as their growth progressed. Even leucite and olivine, which are ordinarily free from foreign enclosures, are found to contain magnetite. On the other hand magnetite is seldom enclosed by quartz, but it is to be remembered that rhyolites very seldom carry the former mineral. In the matrices of many basalts, melaphyres and trachytes, which, in an undecomposed condition, present under the microscope a mass of microlites, the magnetite is found inserted between the needles and determining their limits. The andesite of Lowenburg in Siebengebirge shews, under the microscope, many of these phenomena clearly and distinctly.

In considering the observations that have been made on this subject one cannot avoid remarking that magnetite, tourmaline, and other basic accessory minerals, appear to have been the first to separate from the solidifying magma of crystalline rocks. After the very basic minerals the essential constituents seem to have been formed somewhat in the following order: 1st. Mica; 2nd. Hornblende; 3rd. Felspar; 4th. Quartz. It would, therefore, seem possible to recognise the operation of a definite law in the order of the separation of these minerals from their mother magma, namely, that the minerals of original rocks have crystallised out in the order of their basicity. Some facts, in support of the existence of such a law, are observable in connection with the composition of porphyritic rocks. Not unfrequently the felspar crystals found in these, and which we must suppose, in accordance with facts stated above, to have been produced previous to the solidification of their matrices, have a more basic composition than the latter, or, what amounts to the same thing, the composition of the matrices is more siliceous than that of the whole rock including the crystals. Thus, according to Laspeyres, the felsitic porphyry of Mühlberg, near Halle, enclosing colourless sanidine, oligoclase, quartz and a little mica, contains 72.24 p. c. silica, while the dark greyish green matrix contains 74.41 p. c. Again, the porphyrite of Gänse-Schnabel, near Ilfeld, containing triclinic felspar and other crystals has a silica contents

of 64.34 p. c. The homogeneous, nearly infusible matrix of the same rock contains 67.36 p. c. of silica. The labradorite porphyrite of Mühlenthal, near Elbingerode in the Hartz, possesses a black, very fresh and hard matrix, which encloses undecomposed very lustrous crystals of labradorite, and a dark green or black augitic or hornblendic mineral. The labradorite contains 51.11 p. c. silica, while the whole rock, in spite of the presence of the, doubtless more basic, black mineral, contains 57.57 p. c. silica. On the other hand, in many porphyries and rhyolites distinct quartz crystals are developed, which, of course, must be more acid than the enclosing matrix. In spite of this exception, the law above referred to still applies so far as regards the minerals developed in crystalline rocks or separated out from their matrices during solidification.

VIII.—SPECIFIC GRAVITY.

It has been already remarked that in general the specific gravity of original rocks decreases with the increase of silica and increases with the decrease in quantity of the same substance; the most acid rocks are specifically the lightest, the most basic rocks are specifically the heaviest. Abich was the first to call attention to this as exhibited among the volcanic rocks, and to shew the conclusions which might be drawn regarding the silica contents of these rocks from their ascertained specific gravities. Although the same relation has been observed to exist among the granitic and porphyritic rocks, and doubtless runs through all the orders, it has not been found that a certain specific gravity invariably corresponds to a certain degree of silicification or that, for instance, because a syenite containing 59.83 p. c. of silica has a specific gravity of 2,730, a trachyte having the same silica contents will have the same specific gravity. On the contrary we find decided differences as to specific gravity in rocks of similar composition, but belonging to different orders of texture. The following table shews the average specific gravity of the various families of granular, porphyritic and trachytic rocks:

	GRANULAR.	PORPHYRITIC.	TRACHYTIC.
Hypersilicic rocks with over 77 p. c. silica.	Pegmatites below 2.6	Quartz porph. below 2.6	Q. trachyte below 2.57
Silicic... 70 to 77 p. c. silica	Granites.. 2.65 to 2.6	Porphyry... 2.65 to 2.6	Rhyolite ... 2.62 to 2.57
Siliceous 63 to 70 "	Granitites 2.72 to 2.65	Porphyrite.. 2.75 to 2.65	Trachyte ... 2.7 to 2.62
Neutral. 56 to 63 "	Syenites.. 2.8 to 2.72	Melaphyre.. 2.8 to 2.75	Andesite ... 2.8 to 2.7
Basous.. 49 to 56 "	Gr'nstones 3.0 to 2.8	Gr. porphyry 2.9 to 2.8	Dolerite.... 2.86 to 2.8
Basic ... 42 to 49 "	Anorthosyte 2.9 to 3.	Aug. porphyry 2.7 to 2.9	Nephelinite. 2.6 to 2.86

It will be observed from this table that the specific gravity of granular rocks is generally greater than that of the trachytic rocks which correspond with them in degree of acidity; granites are heavier than rhyolites, and greenstones than dolerites. (The rule does not hold good when applied to the basic rocks, but this may be owing to the facility with which they become d composed and absorb water, which causes a material diminution of gravity.) The porphyritic rocks seem to occupy a position between the other two series, being neither so dense, relatively, as the granular nor so light as the trachytic rocks. This would seem to indicate that the coarsely granular rocks crystallised more slowly and perfectly than the porphyries and the latter more than the trachytes. This difference in density between rocks having the same percentage of silica is even more observable between trachytic and vitreous rocks. Obsidian has invariably a much less specific gravity than a quartzose trachyte which possesses the same percentage of silica. Thus we have the specific gravity of

Rhyolite from Palmarola	with 74·54 p. c.	Si. O_2	= 2·529
Obsidian from Lipari	with 74·05	"	= 2.370
Quartz trachyte from Besobdal, Asia Minor,	with 76.56	"	= 2.656
Obsidian from Little Ararat	with 77.27	"	= 2.394

The cause of the difference seems merely to be that while the rhyolites cooled slowly and shrank together to a denser mass, the obsidians are quickly cooled unannealed natural glasses. It is well known that garnet, vesuvianite, orthoclase, labradorite, augite, and olivine have their densities much decreased by being fused and quickly cooled, and the same thing has been remarked with regard to rocks. St. Claire Deville, and Delesse experimented on several rocks, and found that their specific gravities were diminished after fusion. St. Claire Deville's results were as follows:

	Specific Gravities before fusion.	Specific Gravities after fusion.
Vitreous lava from the Peak of Teneriffe.....	2.570	2.464
Trachyte from Chahorra	2.727	2.617
Basaltic lava from the Peak of los Majorquines	2.945	2.825
Basalt from Pic de Foga, Cape of Good Hope..	2.971	2.879
Granite from Andoux.....	2.662	2.360

Delesse found the loss to be less with fine-grained and semi-vitreous rocks than with those of a distinctly crystalline character. According to his results, if the rocks experimented on be arranged according to the degree of diminution which their specific gravities undergo in fusion, beginning with those which experience greatest

loss, those rocks will be found at the head of the list which are commonly considered to be the oldest in age. Delesse found the following per centages of diminution, the specific gravity of the various rocks before fusion being regarded as = 100.

Granite, granulite and quartz porphyry	9—11	p. c.
Syenitic granite, and syenite	8— 9	"
Porphyry with orthoclase and oligoclase, with and without quartz	8—10	"
Diorite and diorite porphyry	6— 8	"
Melaphyre	5— 7	"
Basalt, trachyte, and old volcanic rocks	3— 5	"
Lavas and volcanic rocks	0— 4	"

As early as 1841, Gustav Bischof made observations on the comparative volumes of Basalt, Trachyte and Granite in their crystalline, melted, and vitreous conditions, with the following results :

	Volume in vitreous condition.	in crystalline.
Basalt	1	0.9298
Trachyte	1	0.9214
Granite	1	0 8420

	Volume in a fluid state.	in crystalline.
Basalt	1	0.8960
Trachyte	1	0.8187
Granite	1	0.7431

Nothing can be more obvious from these data and experiments than that original rocks in cooling, solidifying and crystallising, underwent contraction, increasing thereby their density, and that the amount of contraction was the greater the more thoroughly and coarsely crystalline the rock, and the earlier the dates of its eruption in the geological history of the earth. It is not customary in treating of eruptive rocks usually to entertain any very definite ideas as to their age, but it ought not to be forgotten that the geological experience of Europe has shewn that they made their appearance on the earth's surface somewhat in the same order as they occupy in Table III. It would therefore seem that those rocks which have experienced most perfect crystallisation and the greatest amount of contraction or increase of density during that process are the oldest in geological age, that those which have crystallised imperfectly and experienced but a moderate amount of contraction, belong to the middle age of geological history, and that those which have solidified quickly to a semi-vitreous condition, and have experienced in so doing scarcely any contraction, are exactly those which are the most recent, and have been denominated volcanic rocks. Such results ought not to surprise us, but ought rather to be anticipated if

the theory of the original igneous fluidity of the globe be well founded. The enormous degree of heat, which only could have occasioned such a condition, could not have disappeared suddenly. A gradual decrease of temperature must have taken place from the time when the solidification of the earth began down to recent geological periods. It follows that this gradually decreasing temperature must have had more or less influence upon the cooling of the various rocks protruded through the earth's crust during different geological ages. Those which appeared in earlier periods must have cooled when the earth's temperature was very high, and must therefore have enjoyed the most favorable conditions for slow and perfect crystallization and great contraction of volume, while on the other hand, those which were erupted in later ages must have appeared at a time when the temperature had much diminished, and consequently they must have solidified much more rapidly, crystallised much more imperfectly, and experienced less increase of density than their predecessors. Thus there can be distinctly traced a very decided connection between the universally accepted theory of the earth's original fluid condition and many of the facts which have been here stated with regard to the density of original rocks.

But although, generally, definite relations can be shewn to exist between the age and texture of rocks, it is not to be supposed that this is invariably the case, that there are no exceptions to the rule. It is not to be forgotten that other conditions besides the temperature of the earth's surface may have exerted their influence. Thus it is frequently the case that veins or dykes of diorite have in the centre a distinctly compound texture, while toward the sides they become almost impalpable. Then again beds of basaltite are often seen to be in the upper part and at the bottom fine-grained and compact, while in the middle they are small-grained and variolitic in texture. It is also frequently to be observed that masses of granite distinctly granular in the centre, assume towards the periphery a schistose texture, the direction of which is most generally parallel to the line of junction with the neighbouring rock. Thus it appears that in the solidification of a rock, the space which it occupied, the pressure to which it was exposed, the temperature of the enclosing rocks at the time of eruption, and the circumstances under which it was erupted, whether, for instance, on land or under water, must have influenced more or less its resulting density as well as its texture.

IX.—STRUCTURE.

At a certain stage in the process of the solidification of original rocks and probably after their constituent minerals had assumed shape and position, a certain further consolidation seems to have taken place accompanied by a contraction or diminution in the volume of the rock, during which the space originally occupied by its mass remained the same. The amount of contraction in the most of cases was very small but nevertheless sufficient to diminish the cohesion of the rock along certain planes or curved surfaces. No actual fissure or open space would seem to have been developed at the time this contraction took place, but merely weak places, planes of least resistance, which by the action of atmospheric forces were subsequently revealed as joints of separation (Absonderungs klüften.) The word structure would seem to be a convenient term whereby to designate the incipient jointing caused by the contraction of original rocks. The joints thus formed occur at varying intervals and run in various directions and by such variations cause the separation of the affected rock into blocks of very different shapes and sizes. According to the form of the resulting fragments the following different sorts of separation or structure have been distinguished.

Cubical structure is caused by the occurrence of three sets of joints which each occur at somewhat regular distances and intersect each other almost at right angles, so that the rock becomes separated into large masses of a more or less cubical shape. Granite shews this structure in the most marked degree, and when, after desintegration, the blocks have their corners and edges weathered off, they somewhat resemble cotton bales built up into huge piles. This phenomenon is observable around the Brocken in the Hartz, at Louisenburg in the Fichtelgebirge, near Liskeard in Cornwall and on the north shore of Lake Superior between Michipicoten and Michipicoten Island. A modification of cubical structure is occasioned by one of the three series of joints (those lying horizontally) occurring at shorter intervals and causing the formation of blocks having their length and breadth almost equal but a lesser thickness. Granites and syenites sometimes shew this form of separation.

Polyhedric structure results when the sets of joints intersect the rock in several irregular directions, and divide it into angular blocks of the most irregular shapes. This form of structure is

common among granites, porphyries and greenstone. It is also frequent among greenstone schists and other slaty rocks.

Flaggy structure has the same three sets of joints as in the case of cubical structure, but those lying horizontally are at very short distances from each other and the rock becomes split up into thin blocks or flags. Phonolite yields the best examples of this form of structure. At Mont D'or in the Auvergne thin flags of phonolite are used for roofing. Porphyries, trachytes and basalts often shew the same sort of seperation.

Curved structure is caused by the surfaces of the flags being bent and appearing hollowed out in a saucer-like form. Of this there are some good examples among the melaphyres of the south shore of Michipicoten Island.

Globular or Spheroidal structure gives rise on disintegration to the developement of rounded pieces of the rock varying from an inch or less to several feet in diameter. Sometimes the pieces are perfectly spherical and at others flattened or oblong. They sometimes occur singly and perfectly round in the mass of the rock which does not then exhibit any other forms of seperation. When however they increase in numbers, and crowd together, their round shape becomes masked and polyhedric forms are produced. Most frequently these globes or balls consist of concentric rings with a hard kernel in the centre and the constituents grouped round it in a peculiar manner.* The following rocks exhibit this structure: the greenstones of Nassau and the Fichtelgebirge, basalts; the trachyte of Chiajo di Luna on the Island of Ponza; the trachyte of Altenau in the Eifel. Even porphyry and granite occasionally exhibit this structure. Portions of the diorites and eorsites which occur in dykes between Pigeon River and Point Porphyry, Lade Superior, are frequently broken up into heaps of little rough balls from half an inch to an inch in diameter.

Columnar structure is, of all the varieties, the one which has attracted most attention. It causes the seperation of the rock into pillars having from three to nine but generally six sides. The length of these pillars is variable but remains tolerably equable at each particular locality. Those of Ailsa Craig in the Firth of Clyde are 400 feet, and those of the Palisades in the Hudson 200 feet high. Just as variable is the thickness. The elegant trachyte pillars of Baula in Iceland sometimes sink to

* Zirkel—Petrographie I. 99.

the thickness of a finger, those of the Mendeberg on the Rhine are often only 4 inches thick, while some are known to possess a diameter of from 10 to 15 feet. The position of these pillars varies from being pesfectly vertical to perfectly horizontal; sometimes they lie parallel with each other, sometimes they diverge in a radiating form. At one place they are straight, at others bent and sometimes even S-shaped. The longer pillars are frequently intersected at various intervals throughout their length by cross joints generally running at right angles to the direction of the column. The ends of the members thus formed have mostly even surfaces, but they are often concave and converse the latter shape fitting into the former. A modificotion of columnar structure is occasionally met with in which cylindrical columns, consisting of concentric zones, are found sometimes alone inside of angular pillars. These are found in the andesite of the Henzelberg in Siebengebirge and in the trachyte at Kelberg in the Eifel. In whatever positions the columns stand, or are grouped, they are invariably placed at right angles to the surface at which the coolhg began. If the rock has solidified in the form of a horizontal layer or covering, the pillars stand vertical; if it has filled out vertical fissures the columns lie horizontal, like cord wood. Granites, Greenstones, porphyries and trachytes all occassionally exhibit columnar structure, but basalt and anamesite shew it almost invariably, and in the most magnificent examples as for instance at Giant's Causeway, Staffa, the Faroe Islands, and in Iceland.

The degree of distinctness with which these different structures are developed seems in general to depend upon the degree of rapidity with which they cooled. The quicker the cooling the more decided the jointing, and this would derive confirmation from the fact that those eruptive rocks which are very much broken up by jointing are less distinctly crystallized.

It would appear however that the more regular of these forms of structure have not in all cases been occasioned by contraction, but that the influences which governed the mineralogical grouping were also active in producing it. The following circumstances seem to indicate this. Globular structure is frequently accompanied by a globular arrangement of the rock constituents, and by their forming concentric rings around a middle point. In some rocks, crystals of their constituents are much larger, more frequent and more perfectly crystallized near the joints than in

the centre of the blocks. The peculiar fracture of certain rocks seems also to stand in connection with their structure. Many thoroughly granular rocks are more easily split in one direction than another and this direction is frequently parallel with the horizontal joints occurring in the rock. In the north of England this property is called the grain by the quarry-men there, and filo mastro (filone maestro) by the workmen of Baveno.

X.—THE ALTERATION OF ORIGINAL ROCKS.

The greater part of our globe is surrounded by a liquid envelope, the ocean, and this, as well as all the dry land, is completely enclosed by a gaseous envelope, the atmosphere. Both of these envelopes by means of their own properties, or those of certain ingredients which they contain, exert, and have, in bye-past geological ages exerted, a powerful influence upon the original rocks to which our attention has been directed in the foregoing pages. These rocks after consolidation occupied very different positions both as regards their geological relations and their situation with respect to the sea level. According to their position they became exposed to the disturbing influences of the atmosphere and its contents, or to the attacks of the ocean and the substances it held in solution. These disturbing influences were in both cases of a twofold nature; they were both chemical and mechanical, both decomposing and disintegrating, but, in general, chemical decomposition preceded and aided mechanical disintegration; the superficial parts, at least, of rocks became weathered and altered before the deluging rain began its work of denudation.

But, besides the superficial influences of atmosphere and ocean, other less ostentatious agents have been at work penetrating a greater distance into various original rocks and altering them in some cases far more profoundly. Water or aqueous solutions of various substances have been flowing through their joints and fissures or penetrating their minutest pores producing effects which we are yet very far from comprehending, and, in very many cases, removing ingredients which have no doubt contributed materially to the formation of derived rocks. Whatever their mode of operation the whole of these agents, atmosphere, ocean and subterraneous solutions have exerted their twofold influence upon original rocks. They have in the first place decomposed them producing altered rocks, and they have removed

material from them producing derived rocks. On this occasion we have to consider their chemical action only and the manner in which the weathering and alteration of original rocks is effected, between which two processes we must always be careful to distinguish.

The effect of the atmospheric agents, aided by the heat of the sun and changes of temperature as exhibited to us in our own experience, is the comparatively superficial decomposition which we call the weathering of rocks. This shews itself in bleaching or discolouring, in softening or loosening them or their particles. It begins at the surface, then penetrates through the joints and crevices of the rock inwards, and in the course of time can extend to considerable depths and over very large areas.* This weathering is accomplished by the action of the watery vapour, oxygen and carbonic acid of the atmosphere upon the minerals or chemical components of which the rock is made up. Of these atmospheric agencies, water is without doubt the most important. Without its aid oxygen and carbonic acid would have very little influence upon rocks and no removal of chemical components from them could take place. Ever present in ever varying form in the atmosphere and ever enveloping in one form or other the surfaces of original rocks or penetrating the pores and cleavage planes of their minerals, it is at all times ready to act as the vehicle for introducing the decomposing agencies or removing the products of decomposition. But, besides operating in this manner, and besides exerting its powerful disintegrating action, water enters into chemical combination with the decomposing and decomposed silicates and with the substances resulting from their alteration, forming with them a series of hydrated minerals which enter extensively into the constitution of the weathered and altered rock-masses of the earths crust. Next to water in importance comes carbonic acid which, although but slightly soluble in water at ordinary pressures, is sufficiently so to obtain access to the interior of rock minerals, and begin the attack upon them by combining with their bases. After it has combined with a small quantity of lime or alkali it forms a solution of a carbonate, which, being capable of absorbing a further quantity of carbonic acid, giving rise to a bicarbonate, becomes a much more powerful agent in decomposing silicates than the carbonic

* Naumann; Geognosie I. 442.

acid alone. As regards oxygen its action in decomposing silicates is mostly confined to bringing to a higher state of oxidation the protoxides of the heavy metals which they contain and especially the protoxide of iron.

The chemical components of original rocks are principally silicates of alumina, protoxide of iron, lime, magnesia, potash and soda. The manner in which these are chemically acted on by the atmospheric agencies in the process of weathering is as follows. The carbonic acid contained in the humidity which almost continually moistens rocks, first decomposes a small quantity of the silicate of protoxide of iron forming a carbonate of the latter base, which however is almost instantaneously converted into peroxide of iron by oxygen, the carbonic acid being set free to attack fresh portions of silicates. The silicates of lime and magnesia are next decomposed by it, carbonates of lime and magnesia being produced, dissolved in the water as bi-carbonates and either gradually removed, or, owing to the evaporation of carbonic acid, redeposited. The same thing takes place with the silicates of potash and soda, but part of these alkalis dissolve away part of the silica of the silicate of alumina and remove it in the form of silicate of potash or soda. Of all the bases alumina alone remains undissolved by the carbonic acid, and, it, combined with a certain amount of silica and water and sometimes with part of the other bases, is the principal product of the weathering process, and in the form of an impure clay forms the weathered crust of the rock.

But original rocks with weathered surfaces are not by any means altered rocks. The latter result from a much more thorough change in the former. The process of alteration differs from that of weathering in being much more deep seated and in having taken place out of contact with air or atmospheric oxygen. The latter seems to have been retained in the superficial portions of the rock and only the carbonic acid and water appear to have penetrated to greater depths. These have had the same decomposing effect upon silicates as in the upper regions, but the resulting bi-carbonates together with the alkaline silicates and perhaps aluminates were retained for sometime in these greater depths, none of them decomposed by atmospheric oxygen and many of them causing further alteration among the rock components, or forming and depositing new products in the interior of the rock. Here the steadiness of their action must have been uninfluenced

by changes of temperature and uninterrupted by the evaporation of the carbonic acid, the action of which seems to have been entirely different under the new circumstances. Probably the alkaline silicates were the first to be decomposed, then the silicate of lime seems to have been attacked, afterwards the silicate of protoxide of iron and lastly the silicate of magnesia. The order of the solution and removal of the alumina and silica was doubtless dependant upon the quantities of the alkalies present. Where the texture of the rock or the occurrence of veins and cavities in it afforded the necessary space, the dissolved products re-arranged and deposited themselves as new minerals generally as carbonates or hydrous silicates, while, in the spaces occupied by the original minerals are found their lixiviated residues consisting of similar minerals and frequently possessing the forms of their originals. Only those rocks in which this more thorough alteration has taken place to very great depths are to be understood as included in our class of altered rocks.

In some cases the results of such altering processes are so thorough and extend to such considerable depths beneath the surface that the atmospheric agencies above mentioned would appear to be altogether incapable of producing them. It must not however be forgotten that, in earlier geological ages, the atmosphere must have been differently constituted from that of our day, and must have contained not only an immensely larger amount of carbonic acid but also large quantities of sulphurous, sulphuric and hydrochloric acids, the action of which upon the original rocks then existing must have been incomparably more energetic than that of the agencies now at work. These rocks must at that time have been deluged with showers of acid rain or submerged beneath a strongly acid and saline sea.

Besides being subject to weathering and alteration, some original rocks simply absorb water one or more of their constituents becoming converted into zeolites or other hydrated minerals. By this process of hydration phonolytes and hydrous basalts become formed from fine grained, and perlyte and pitchstone from impalpable rocks.

Although these processes of weathering alteration and hydration have not unfrequently affected original rocks it is nevertheless to be remembered that the latter are not invariably or even generally subject to them. Those which allow themselves to be acted on by such decomposing processes seem to do so more or less

reluctantly and the degree of the decomposition effected differs with their varying composition. Original rocks, as has been already shewn, are for the most part made up of silicates and, having been formed under circumstances which admitted of a very perfect union of their various elements into crystalline minerals, their decomposition is no easy matter. Even when exposed in the state of fine powder to the action of concentaated acids very few of them are completely decomposed. The same chemical rule applies to rocks as to artificial and natural silicates, namely, the more acid they are, that is to say, the higher the percentage of silica which they contain, the more effectually do they resist the action of acids. In a similar manner we find, generally speaking, that the more siliceous a rock is, or its minerals are, the less liable it is to be acted on by atmospheric agencies. These cannot of course be compared in energy of action with concentrated mineral acids but their want of power is compensated for by their quantity and the unlimited time at their disposal. Their decomposing effect is however as in the case of the mineral acids the greater, the larger the quantity of bases contained in the rock upon which they act. It is on this account that we frequently find silicic granite to have remained unattacked while basic diorites, gabbros and diabases have experienced more or less alteration; granulite and gneiss, porphyrytes and silicic porphyry, trachyte and rhyolyte remain comparatively unchanged while the corresponding basic rocks, diabase schist, augitic porphyry and basalt are frequently found more or less decomposed. The capacity of an original rock for alteration depends also upon its texture and the state of aggregation of its minerals. Many of the coarsely granular granites and syenites belonging to a primitive geological age have to this day remained unaltered by atmospheric influences because of their dense, highly crystalline state. It is only some of the more recent granites and porphyries that are found in such a state of decomposition as to be the source of much of the kaolin of commerce. Those of the mines of Scandinavia and Saxony which occur in primitive rocks never require elaborated timbering the latter being very little given to weathering, while those on the Comstock Lode in Nevada expend enormous sums for timbering on account of the breaking up or "slaking," which the much more modern enclosing rocks (propylite and doleritic trachyte) undergo after the vein is opened up. A fine grained or almost vitreous texture seems to

be no security against the access to the interior of a rock of decomposing solutions, for many rocks with this texture such as basalt, phonolite, and pitchstone have experienced hydration and partial decomposition throughout their mass. A slaty texture seems especially adapted for assisting atmospheric influences to penetrate rocks and induce their decomposition. Indeed the greatest number of altered rocks will, in our system, be found among those of a schistose or slaty texture and comprise the most of the semi-crystalline schists and slates which have been by many geologists termed metamorphic rocks. It has already been sufficiently well explained why a schistose or even slaty structure is not to be considered as indicating a sedimentary origin, and gneiss and granulite have therefore been classed unhesitatingly with other crystalline original rocks. The great mass of schists and slates which occupy a geological position betwixt such gneissoid rocks and those of an evidently detrital nature would appear to have the same original origin as the former but to have acquired their semi-crystalline habitus from the action of processes of alteration subsequent to their solidification. As is well-known the formation of these rocks, mica schist, argillaceous mica schist, talc and chlorite schists, has heretofore been explained in an opposite manner. It is impossible to describe here the various agencies which are usually supposed to have caused the alteration, or the manner in which they have operated, so diverse are the many metamorphic theories. They all however agree in assuming that the schistose rocks in question were originally sedimentary; stratified clays and sandstones. In this paper, on the other hand, they have been regarded as products of igneous fusion. There are many reasons why schistose and slaty rocks solidified from igneous fusion should have been more accessible than other original rocks to altering influences. Their fine slaty grain is peculiarly fitted for the introduction of altering solutions into the minutest pores and around the minutest particles. Then they have almost invariably a highly inclined position and consequently present their edges to the atmosphere in such a manner as to cause the formation of little reservoirs of water all over their outcrops, from which the grain of the rock leads the moisture directly into the interior. It is also highly probable that these slaty strata occupied this position at the time when the acid atmosphere and ocean existed on the earth and were therefore much more exposed to alteration than those original rocks which only made their appearance at later periods.

XI.—TEXTURE OF ALTERED ROCKS.

As a general rule altered rocks retain the texture of their originals. This is very plain in the case of the granular rocks which have suffered change. However much their minerals may have been affected their texture remains intact. Schilleryte, chloritic syenite and protogine remain granular like the protobastyte, syenite and granite from which they resulted. Even with those altered rocks, whose originals it is somewhat difficult to point out, we are justified in supposing that no change in the texture has taken place.

The following varieties of texture exist among altered rocks. 1. Granular; 2. Schistose; 3. Slaty; 4. Amygdaloidal; 5. Fine grained; 6. Impalpable. The nature of these different sorts of texture was explained in referring to original rocks, the amygdaloidal only excepted, which may be thus characterised. In a small or fine grained matrix rounded cavities occur partly or wholly filled up with various minerals. These cavities sometimes possess the long drawn and flattened shape of the almond; hence the name. This texture is generally supposed to have the same origin as the cavernous structure of lavas. The erupted rock came in contact with water developing steam and causing the formation of cavities containing it, many of which were retained within its mass as the rock solidified. Thereafter the rock, on account of its cellular structure, readily permitted the entrance of water with various agents dissolved in it, which accomplished a very thorough alteration or leaching of the matrix, and caused the decomposition of new minerals in the cavities, thus forming so called geodes. In the majority of cases and especially when the cavities possessing the almond, pear, or tube shapes, have their flat sides lying parallel or their longer axes with a similar direction, this method of accounting for amygdaloidal texture is doubtless correct. Nor can much doubt hang over their origin if the interior of the cavities, after they have been weathered out, appear viirified like porous lavas. In some instances however the cavity is said to have been originally occupied by porphyritic crystals of minerals, from the lixiviation and alteration of which the new minerals resulted. This view of their origin is maintained by Kjerulf for the amygdaloid of Holmestrand in Norway, by Jensch for the cavities of the phonolyte of Bohemia, by Tschermak for the amygdules of dolerite, diabase and augitic porphyry, and by Hegmann even for the

agate geodes of many melaphyres. One or other of these modes of accounting for amygdaloidal texture would seem to be applicable for explaining the origin of the globular texture so minutely described by Delesse,* and which is prone to occur in silicic rocks of vitreous texture such as pearlyte, pitchstone and obsidian.

XII.—MINERALOGICAL CONSTITUTION OF ALTERED ROCKS.

In order satisfactorily to explain the origin of the minerals of altered rocks it now becomes necessary to advert more particularly to the changes which the atmospheric agencies are capable of affecting in the essential minerals of original rocks. Quartz is unquestionably the one which is most indifferent to their chemical action. Hence it is that in such porphyritic rocks as contain the silicic feldspar, orthoclase, dull and decomposed to the core, the quartz is found undiminished in lustre and hardness.

As regards the feldspars the rule applies that the more basic they are the more readily they are decomposed, and it may be added, the more lime and soda they contain the more rapid is their alteration. Orthoclase being moresiliceous than the others, most stubbornly resists weathering influences. Even to this day there are to be seen among the gneissoid rocks of Lake Superior those whose surfaces shew the orthoclose as firm and fresh as in newly exposed fractures. But on the other hand, in other rocks the same mineral is found thoroughly decomposed. The reason of this difference probably lies in the more or less perfect crystallisation and it has also been observed that the presence of small quantities of lime, magnesia, protoxide of iron or soda induces decomposition. The species adularia, colourless and quite transparent, longest retains its fresh appearance and normal composition. It contains neither magnesia nor protoxide of iron, and lime and soda in but very small percentages. When orthoclase, containing protoxide of iron, is long exposed ro the atmosphere it loses its lustre and its degree of transparency and changes its colour. White orthoclase becomes yellowish and reddish, the flesh coloured varieties change to ochre yellow and reddish brown. Observed with a magnifying glass the previously smooth and lustrous surfaces are now seen to be penetrated by numberless cracks produced by continuously recurring changes of temperature. The weathering proper now begins by these cracks

* Memoires de la Soc. Geol. de France (2) IV, 2 partie, 1852.

absorbing, like so many capillary tubes, atmospheric water, vapour, rain or dew, impregnated with carbonic acid and oxygen. A loosening and hydration of the moistened parts of the feldspar next takes place; then an oxidation of the protoxide of iron in the hydrated mass to peroxide occasioning the change of colour already mentioned. The decomposition of the silicate of potash by the carbonic acid next begins, the resulting carbonate of potash as also silicate of potash is removed and an earthy weathered crust is formed on the orthoclase, consisting of kaoline, peroxide of iron and some acid silicate of potash, and possessing a yellowish white to an ochre yellow colour. This clayey crust greedily absorbs atmospheric humidity, with its oxygen and carbonic acid and conducts its underneath to attack the still undecomposed orthoclase and in this way the latter becomes more and more decomposed from the outside to its centre always more crumbling, softer and lighter, until its whole mass appears altered to kaoline or clay.* According to Forchhammer Quadro silicate of potash (K O, 4 Si O_2) is in this manner removed from the orthoclase ($Al_2 O_3$ 3 Si O_2 + K O, 3 Si O_2) and two equivalents of water (2 H O.) absorbed by it the result being Kaoline ($Al_2 O_3$ 2 Si O_2 + 2 H O.) On account of its invariably containing lime, oligoclase weathers more easily than orthoclase, and the more lime it contains the more rapidly it decomposes. Water saturated with carbonic acid dissolves out the lime as bi-carbonate and also the alkalies in combination with silica, so that there remains, as in the case of orthoclase, kaoline, generally, however, more impure and containing earthly carbonates. According to Senft (Felsgemengtheile p. 592,) it is only the layers first formed of the weathering crust which are free from carbonate of lime. After decomposition has penetrated to the mass of the crystal the crust very frequently consists of a mechanical mixture of kaoline with silica and carbonate of lime, and sometimes even carbonate of magnesia. Senft accounts for this phenomenon by supposing that the later formed kaoline crust retains the water containing the carbonate of lime and silica from the underlying decomposing oligoclase so long as to cause the loss of the carbonic acid which held these substances in solution, where upon, they become deposited and mechanically combined with the kaoline. Labradorite being more basic and richer in lime

* Senft; Felsgemengtheile p. 577.

than oligoclase is even more prone to decomposition. Its weathering begins as usual with a hydration of the mass of the Labradorite, then progresses with carbonating and leaching out first the lime and a part of the silica, afterwards of the magnesia and soda, and ends with the formation of a white clayey substance, or, if iron oxide is present, of ochre yellow clay. The porcelain earth of Passau is the product of the alteration of a mass of so-called passauite or porcelain spar which, according to Senft (Felogemengtheile p. 600), resembles, in composition, labradorite in which the process of alteration has already begun. Amorphous silica, in the form of opal and chalcedony, are also products of its alteration. With regard to anorthite its history as a rock constituent is very modern and very few observations have as yet been made regarding the manner of its weathering. Senft mentions an anorthitic rock from Thuringia the small crystals of which become dull, white and effervesce with acids in weathering. The large crystals of the anorthite porphyry of Thunder Cape, Lake Superior, become opaque and bleached on weathering, but the thin weathered surfaces do not effervesce with acids. In general therefore it may be stated that the products of the alteration of the feldspars are kaolinite sometimes contaminated with silica, iron oxide or carbonate of lime; soluble silicates of the alkalies and carbonate of lime in greater part removed; and hydrated silica. The formation of the latter seems especially prone to occur with feldspars deficient in the alkalies which are necessary for its solution and removal.

Among the basic essential rock minerals, potash mica resists decomposition most stubbornly. Indeed were it not for its foliated structure it might be regarded as indestructible. Its normal formula is three atoms mono-silicate of alumina and one ter-silicate of potash ($3\ Al_2\ O_3\ Si\ O_2 + K\ O\ 3\ Si\ O_2$) but it very seldom occurs so pure and simple in composition as this. Small quantities of iron oxide, magnesia, soda and lime frequently occur in it and, like the feldspars, the more it contains of these substances the more prone it is to decomposition. If its position is such that water can readily penetrate between its leaves, a loosening of its mass and an opening of its leaves may be observed which, when frost cooperates, gradually results in their complete disintegration and the formation of a loose mass of small scales. And this is all the alteration that atmospheric agents can effect when the mica contains very little or no protoxide of iron or

magnesia. But when these, and perhaps also lime, are present, oxidation of the iron to peroxide by the oxygen contained in the water which penetrates between its leaves causes the formation on them of faint violet and green circular figures, which gradually become broader and impure greenish brown in colour, until an ochre yellow film is developed which decreases the transparency but not the lustre of the plates which it covers and lends them often a bronzed or gilded appearance. If this skin is dissolved away by muriatic acid, the pure transparent mica reappears. In the ordinary weathering however this skin becomes thicker and thicker and at last the mica loses its transparency, lustre and coherence. If water containing carbonic acid now has access to it, it gradually dissolves out from it its alkalies and alkaline earths until there remains an impure clay coloured yellow by iron oxide and filled with innumerable scales of undecomposed mica often microscopically small. Magnesia mica differs from potash mica in containing less silica, the quantity of which seldom exceeds 40 per cent, and in containing less potash, usually about 5 and seldom reaching 10 per cent. It contains further from 15 to 30 per cent magnesia, and sometimes as much as 25 per cent of protoxide and peroxide of iron. Its percentage of alumina varies from 16 to 20 and besides these principal constituents there are present 0·5 to 4 per cent fluorine, 0·5 to 3 per cent water, 0·5 to 5 per cent soda and sometimes about 2 per cent lime. In a similar manner to potash mica, but with less difficulty, it undergoes alteration to a reddish brown earthy mass consisting, to a large extent, of undecomposed scales of mica, with traces of carbonates of lime and magnesia in a ferruginous clay (Senft. Felsgemengtheile p. 714.) It thus appears that the weathering of mica does not result in the formation of a new hydrated mineral retaining the place of the original but contributes chiefly to its disintegration and prepares it for subsequent removal by mechanical means. Sometimes when oxygen is excluded mica appears to be subject to alteration to chlorite and talc but the proofs of this are not very distinct.

Hornblende has an extremely variable chemical composition, which can scarcely be reduced to any general formula applicable to all its varieties. Its components are principally silica, alumina, protoxide of iron, magnesia and lime. The light coloured varieties such as tremolite, actynolite and anthophyllite contain little or no alumina; but they seldom occur as rock constituents.

The black, greenish black or brownish black varieties are mostly aluminous, and invariably so when they enter into the constitution of original rocks. In the latter case the quantities of their components oscillate between the following limits.

Silica	50,04 to	39,62	per cent.
Alumina	26,00 to	8,85	"
Peroxide of Iron	10,28 to	0,00	"
Protoxide of Iron	22,22 to	4,55	"
Magnesia	21,12 to	2,00	"
Lime	12,65 to	8,00	"
Soda	2,24 to	0,00	"
Potash	2,18 to	0,00	"

The weathering of hornblende resembles in rationale that of the feldspars. The silicate of protoxide of iron is, in an early stage, decomposed by carbonic acid, the resulting carbonate being at once decomposed by atmospheric oxygen, and the peroxides of iron deposited as ochre yellow hydrate on the surface of the hornblende. Sometimes a shining violet coating of ferroso ferric oxide is first produced, which however gradually changes to peroxide. This process then progresses accompanied by a decomposition of the silicates of lime and magnesia also, the lime and then the magnesia being removed as carbonates. The alkalies in combination with silica and carbonic acid also disappear leaving at last a leather yellow ferruginous clay. Quite a different product results however when atmospheric oxygen is excluded and water, containing carbonic acid, alone has access to the hornblende, which is the case when it is contained in deeper lying portions of the rock. In this case the whole of the lime is removed as carbonate, together with the alkalies and part of the silica and chlorite is produced. Some of the magnesia and protoxide of iron may likewise be removed by the carbonic acid, chlorite still being the result. In the decomposition of very ferruginous hornblende, containing little magnesia, the product is often ferruginous chlorite or delessite. When however the greater part of the bases disappear, a sort of Fullers earth (smectite) is produced, while, at the same time, quartz, iron spar, dolomite, brown spar, and calcspar become deposited in the minute cracks of the rock. (Senft Felsgemengtheile p. 681.) This decomposition of hornblende with exclusion of oxygen is, as before explained, alteration, whilst the common decomposition in contact with air is understood by the term weathering.

Pyroxene much resembles hornblende in chemical composition. The components are the same and their quantities equally as much subject to alteration. Alumina is frequently present but

in smaller quantity, the silicates of lime, magnesia and protoxide of iron preponderate, the alkalies are entirely absent, as are also fluorine and titanic acid which are occasionally found in the hornblendes. Aluminous and non-aluminous pyroxenes are usually distinguished, as in the case of hornblende, and those which enter into the composition of rocks are mostly aluminous, possessing dark green, brown and black colours. Common augite weathers somewhat more quickly than hornblende but, at the same time, more slowly than the feldspathic minerals usually associated with it. When weathering once begins, peculiarly shining violet coloured points and spots may be observed on its surface, which gradually become yellowish green and ochre yellow, a proof that the protoxide of iron becomes seperated out as hydrated peroxide. As the weathering progresses it is remarked that the yellow spots effervesce with acids, and even under the peroxide a white coating may be detected which effervesces with acids. The spots have now an earthy appearance, have an argillaceous smell and allow themselves to be washed away by rain, exposing small depressions on the surfaces of the crystal. These spots, dissolved in muriatic acid, yield a solution containing peroxide of iron, silica, alumina and carbonate of lime with traces of magnesia. In this manner the augite gradually loses its iron, lime and magnesia and is converted into a ferruginous clay containing carbonate of lime and often silicate of magnesia. (Senft. Felsgemengtheile p. 653.) Rammelsberg and Von Hauer have analysed weathered crystals of augite, from Bilin in Bohemia, and their results abundantly shew the correctness of the above explanation of their manner of decomposition.

	According to Rammelsberg.	According to Von Hauer.
Silica	60.63	54.24
Alumina	23.08	25.02
Peroxide of iron	4.21	5.22
Lime	1.27	0.87
Magnesia	0.91	0-56
Water	9.12	14.37
	99.22	100.28

The yellowish brown weathered crust found on augite crystals from Cernosin had the following composition.

Silica	35.5
Alumina, Peroxide of iron	37.7
Lime	6.5
Magnesia	4 1
Water	18.0
	101.8

When decomposition takes place under circumstances which exclude the presence of air, augite seems to undergo an alteration similar in nature to that experienced by hornblende; water is absorbed and one or more of the monoxides are removed while hydrous augite, pyrallolite, chlorite or delessite result. Senft mentions its alteration to green earth in the augitic porphyry of Fassathal. He accounts for the presence of the alkalies, which seem to have replaced the magnesia, as having been derived from the decomposition of the oligoclase which occurs in the matrix of the rock; Kjerulf has observed similar alterations in the augite porphyry of Holmestrand, Norway. This rock graduates into an amygdaloid, calespar, surrounded by green earth taking the place of the spaces previously occupied by augite crystals. The calespar amygdules frequently indicate by their form that of the original augite. All the stages of this alteration may be observed in the rocks of Holmestrand from the undecomposed augite to the half decomposed with calespar in the interior, and ultimately to those which have been entirely altered into calespar and green earth.* The writer has had opportunity of making similar observations among the amygdaloids of Lake Superior, the results of the alteration being, however, generally calespar and delessite. According to Blum a weathered doleritic amygdaloid of Lutzelberg contains augites changed in a similar manner into steatite (Senft Felsgemengtheile p. 660.)

Diallage, a silicate of protoxide of iron, magnesia and lime; hypersthene, silicate of iron and magnesia; and enstatite, principally silicate of magnesia, seem all to be somewhat less subject to weathering than hornblendes and augites. They have been called by Senft serpentine producers because of the frequency of their alteration to that mineral by hydration and removal of their lime and iron and part of their silica. In the case of diallage this alteration has very frequently been remarked in gabbros. Hypersthene yields frequently steatite as well as serpentine, while the alteration of enstatite to the latter mineral has been shewn, by Streng, to effect the alteration of protobastite rock to Schiller rock and ophiolyte.

Olivine, a silicate of magnesia and protoxide of iron, yields in weathering an ochre yellow mass owing to the oxidation of its iron. Out of contact with air and exposed to the action of water, containing carbonic acid, it absorbs water, loses its protoxide of iron and part of its magnesia and is converted into serpentine.

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* Zirkel, Petrographie I, 91.

There is reason for supposing that the basic feldspars by their alteration frequently give rise to the formation of zeolites which are sometimes deposited in the mass of the rock as well as in its cavities. Nepheline is even more subject to this sort of change and gives rise to the formation of natrolite which often occurs as a constituent among altered rocks.

From what has been said it will be apparent that the essential minerals of original rocks, although all subject to alteration, differ in the degree of resistance which they offer to decomposing agencies. It therefore sometimes happens that one or more of the minerals of an original rock become altered while the others remain in their original conditions. On this account the essential minerals of derived rocks include those of original rocks as well as those resulting from their decomposition. We have seen how variable the original minerals are, in composition, and it need scarcely be remarked that the altered minerals are even more so. The latter are given in the following list, in the order as arranged by Dana.

HYDROUS SILICATES.

Zeolites.

UNISILICATE

of Alumina and Soda,	Natrolite.

Magarophyllites.

BISILICATES

of Magnesia,	Talc.
of Alumina,	Pyrophyllite.
of Alumina, ferrous oxide and potash.	Glauconite. (Green earth.)

UNISILICATES

of Magnesia,	Serpentine.
of Alumina; Kaolinite,	Saponite,
Halloysite,	Damourite,
Paragonite.	

SUBSILICATES

of Alumina, iron oxide and magnesia,	Penninite. Delessite.
of Alumina and magnesia,	Ripidolite. (Chlorite.)
of Alumina and ferrous oxide,	Chloritoid. Ottrelite.

CARBONATES

of Lime,	Calcite.
of Lime and magnesia,	Dolomite.

The following table gives a general view of the species of altered rocks and of their chemical and mineralogical nature.

IV.—Table showing the Constitution of the Species of Altered Rocks.

Description of texture and Basic Constituents.	*Non-felspathic Rocks.*	*Basic Rocks under 49 p. c. Silica with Anorthite.*	*Basous Rocks 49 to 56 p. c. Silica with Felspar.*	*Neutral Rocks 56 to 63 p. c. Silica with Felspar.*	*Siliceous Rocks 63 to 70 p. c. Silica with Quartz and Felspar.*	*Silicic Rocks 70 p. c. Silica and upwards with Quartz and Felspar.*
I. Coarse and small grained						
with talc or chlorite	Steatyte.		Chloritic diorite	Chloritic granityte.	Protogine.	
" Serpentine	Ophiolyte.	Schilleryte.				
II. Schistose and slaty						
with hydrous mica			Paragonite slate	Damourite slate	Nacreous slate	Sericite slate.
" indistinct micaceous and chloritic minerals			Green slate	Argillaceous mica slate	Phyllyte.	Silicic slate.
" talc or chlorite	Potstone.	Chlorite Schist	Talcose schist	Talc schist	Protogine gneiss.	
" porphyritic minerals		Chloritoid Schist	Ottrelite slate	Cornubianyte.		
" Aluminous silicates		Kaolinyte	Parophite schist	Pinitoid schist	Pyrophyllite schist.	
III. Amygdaloidal and spheralitic		Basic amygdaloid.	Spilyte	Amygdaloidal melaphyre.	Amygdaloidal porphyrite	Pearlyte.
IV. Impalpable			Hydrous Tachylyte	Melaphyre pitchstone	Trachytic pitchstone.	Felsitic pitchstone.
V. Fine grained		Hydrous basalt.	Nosean phonolyte.	Phonolyte.		

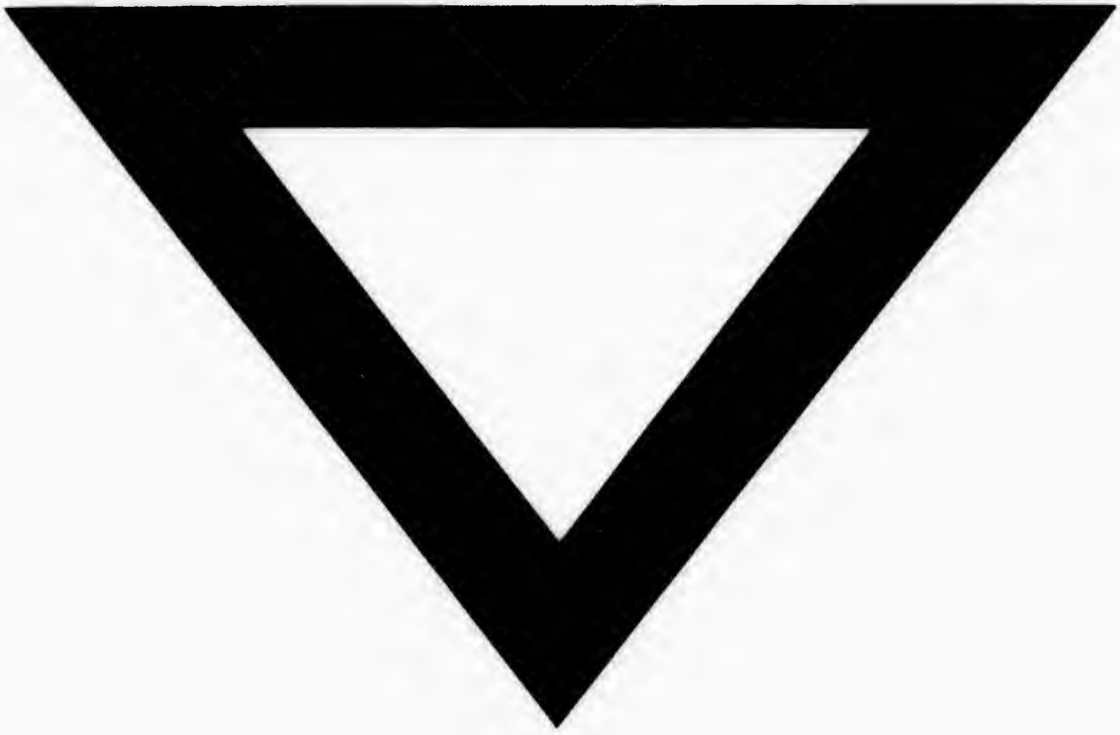
The foregoing table being constructed on the same principle as No. III requires but little explanation. It has been our object to include and arrange in it all the altered rocks and even some of somewhat doubtful character. As in former tables no new names have been invented, and only in the case of argillaceous mica slate and phyllite have synonyms been so applied as to indicate two different rocks. The former of these terms is applied to the siliceous and the latter to the silicic rocks of the series of slates to which they belong.

The principal accessorial constituents of original rocks appear to be but very slightly subject either to weathering or alteration. Topaz, tourmaline, crysoberyll, beryll, corundum, chromite, ilmenite, zircon, diamond, gadolinite, perofskite, gahnite, spinelle tinstone, rutile and many others are, chemically, almost indestructible minerals. Many of them possess a hardness equal to and sometimes exceeding quartz, resist chemical decomposition as well as it, and are found accompanying it among the ruins of rocks in the sands of rivers and sea shores. Most of this indifference is attributable to their extremely dense and crystalline nature, and perhaps also to their peculiar chemical composition, for, although many of them are basic, their components are such as are but little influenced by atmospheric agencies. Many of these accessorial minerals which seldom exhibit decomposed surfaces, such as garnet, epidote and tourmaline, are nevertheless said to give rise to the formation of other minerals by their alteration. This is owing to the occurrence of the latter in forms belonging to the former minerals, but in some cases it may be doubted whether the proof of alteration is sufficient. The gradual change of the garnet or tourmaline into the supposed new mineral is not always traceable, and the latter being frequently very crystalline and anhydrous, bears very little resemblance to an altered mineral. These remarks apply to the alleged change of beryll to mica, tourmaline to chlorite, leucite to sanidine, garnet to specular iron ore, epidote to potash mica and others recorded by Senft. On the other hand allanite, kacite, haüynite, sodalite and others, have been found on analysis to contain water and to have undergone hydration and other changes. Cordierite and scapolite are the principal occasional minerals of original rocks which have been very thoroughly altered. The number of new minerals to which they are said to have given rise is very remarkable. Senft mentions praseolite, esmarkite, aspasiolite, bonsdorffite, fahlunite, weissite, gigantolite, pinite and potash mica as pro-

ducts of the alteration of cordierite, the first four by its absorbing water and losing silica, the next four by absorbing water and losing magnesia, and the last by again losing its water and appropriating potash. (Felsgemengtheile p. 551). These alterations with the exception of the one said to yield mica are well authenticated. It is however worthy of remark that Senft failed to discover cordierite in any granite containing pinite. It is unnecessary here to specify the numerous minerals regarded as altered scapolite as it is very seldom that they are found in altered rocks.

None of the auxiliary minerals of original rocks yield so readily as the sulphurets to the decomposing influences of the atmosphere, in the process of weathering, but they seem to have entirely escaped the more subterraneous process of alteration. Iron pyrites, markasite, magnetic pyrites, copper pyrites and galena which are frequently found in fine particles impregnating rocks readily decompose in contact with the atmosphere and weather in a very noticeable manner. At greater depths in similar rocks they appear entirely unchanged although in close contact with thoroughly altered minerals. This is owing to the exclusion of atmospheric oxygen in the process of alteration. That element is very potent in the weathering process and readily oxidises these sulphurets, but the water containing carbonic acid which alone penetrates to greater depths is altogether without action on them.

XIII.—CONCLUSION.

We have endeavoured in the foregoing pages to set forth some of the more interesting relations which exist among the various families of original and altered rocks, and have also attempted to make use of these for their better classification. Whether or not the system advanced be regarded as satisfactory, it will perhaps be admitted, at any rate, that Petrology as at present developed is not the very confused department of Geology which some have represented. This could be rendered even more evident by describing singly each rock species, and showing more minutely its various relationships. This would however carry us much beyond our proposed limits, and go far towards making our paper a regular treatise on petrology. It is hoped, however, that the preceding pages will be found to contribute a little towards a better understanding of the subject, in which case our object in writing them will have been accomplished.

Acton Vale, P.Q., May, 1872.