

CONTRIBUTIONS TO LITHOLOGY.

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- I. THEORETICAL NOTIONS.
 - II. CLASSIFICATION AND NOMENCLATURE.
 - III. ON SOME ERUPTIVE ROCKS.
 - IV. LOCAL METAMORPHISM.
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BY

T. STERRY HUNT, M.A., F.R.S.,

OF THE GEOLOGICAL SURVEY OF CANADA.

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INTRODUCTION.

In a recent paper on *The Chemical and Mineralogical Relations of Metamorphic Rocks* (Silliman's Journal [2], xxxvi, 214),* an attempt was made to define the principles which have presided over the formation of sedimentary rocks, and to explain the nature and conditions of their alteration or metamorphism. That paper may be considered as to a certain extent introductory to the present one, which will contain, in the first part, some theoretical considerations which it is conceived should serve as a basis to lithological studies. In the second part will be given a few definitions which may serve to render more intelligible the classification and nomenclature of crystalline rocks; while a third part will contain the results of the chemical and mineralogical examination of some of the eruptive rocks of Canada; and a fourth, some examples of local metamorphism. The most of the results appear in the recent published Geology of Canada.

I. THEORETICAL NOTIONS.

I have already, in other places, expressed the opinion that the various eruptive rocks have had no other origin than the softening and displacement of sedimentary deposits; and have thus their source within the lower portions of the earth's stratified covering, and not beneath it. The theory which conceives them to have been derived from a portion of the interior of the earth still retaining its supposed primitive condition of igneous fluidity, is in my

* *Canadian Naturalist*, vol. viii, page 195.

opinion untenable. It is not here the place to discuss the more, or less ingenious speculations of Phillips, Durocher, and Bunsen as to the constitution of this supposed fluid centre, nor the more elaborate hypothesis of Sartorius von Waltershausen as to the composition and arrangement of the matters in this imaginary reservoir of plutonic rocks. The immense variety presented in the composition of eruptive masses presents a strong argument against the notion that they are derived, as these writers, have supposed, from two or more zones of molten matters differing in composition and density, and lying everywhere beneath the solid crust of the earth; which, in opposition to the views of many modern mathematicians and physicists, the school of geologists just referred to regard as a shell of very limited thickness.

The view which I adopt is one the merit of which belongs, I believe, to Christian Keferstein, who, in his *Naturgeschichte des Erdkörpers*, published in 1834, maintained that all the unstratified rocks, from granite to lava, are products of the transformation of sedimentary strata, in part very recent; and that there is no well-defined line to be drawn between neptunian and volcanic rocks, since they pass into each other (vol. i, p. 109.) This view was subsequently, and it would seem, independently brought forward in 1836 by Sir John Herschel, who sought to explain the origin of metamorphism and of volcanic phenomena by the action of the internal heat of the earth upon deeply buried sediments impregnated with water. (Proc. Geol. Soc. of London, vol. ii, pp. 548, 596.) See also my papers in the Canadian Journal, 1858, p. 206; Quar. Jour. Geol. Soc. 1859, p. 488; Can. Naturalist, Dec. 1859; and Silliman's Journal [2], vol. xxx, p. 135.

The presence of water in igneous rocks, and the part which it may play in giving liquidity to all volcanic and plutonic rocks, was insisted upon by Poulett Scrope, so long ago as 1824, in his *Considerations on Volcanoes*. (See also Quar. Jour. Geol. Soc. London, xii, 341.) This view has since been ably supported by Scheerer in his discussion with Durocher. (Bul. Soc. Geol. France [2], iv, 468, 1018; vi, 644; vii, 276; viii, 500.) See also Elie de Beaumont, *ibid.*, iv, 1312. The admirable investigations of Sorby on the microscopic structure of crystals (Quar. Jour. Geol. Soc., xiv, 453) have since demonstrated that water has intervened in the crystallization of almost all plutonic rocks. He has shown that the quartz

both of granites and crystalline schists contains great numbers of small cavities partially filled with water, or with concentrated aqueous solutions of chlorids and sulphates of potassium, sodium, calcium, and magnesium, sometimes with free hydrochloric acid. Similar fluid-cavities were found by him in most crystals artificially formed in aqueous solutions; and were also observed in the minerals from the limestones of Vesuvius, where they occur in nepheline, idocrase, hornblende, and feldspar; the liquid in the latter crystals containing, besides chlorids and sulphates, alkaline carbonates. Mr. Sorby has also described the cavities filled with vitreous and with stony matters which he has observed in quartz, in the feldspar of pitchstones, in augite, leucite, and nepheline; and which are sometimes found associated with fluid-cavities in the same mineral. As these fluid-cavities enclosed the liquid at an elevated temperature, its subsequent cooling has produced a partial vacuum, which is again filled on heating the crystal; so that the temperature of the crystals at the time of their formation may be approximatively determined. Mr. Sorby concludes that every peculiarity in the structure of the quartz of the veins in Cornwall, "may be most completely explained by supposing that this mineral was deposited from water holding various salts and acids in solution, at temperatures varying from 200° C. to a dull red heat visible in the dark" (about 340° C.). At this highest temperature he conceives that other minerals, such as mica, feldspar, and tinstone were deposited; the latter mineral containing numerous small fluid-cavities. In like manner, he deduces from the fluid-cavities in the Vesuvian minerals just noticed, a temperature of from 360° to 380° C. The presence at the same time of bubbles or vapor-cavities, and of glass and stone cavities in these crystals shows them to have been formed "at a dull red heat under a pressure equal to several thousand feet of rock, when water containing a large quantity of alkaline salts in solution was present, along with melted rock, and various gases and vapors. * * * I therefore think that we must conclude provisionally, that at a great depth from the surface, at the foci of volcanic activity, liquid water is present along with the melted rocks, and that it produces results which would not otherwise occur." (Loc. cit., p. 483.)

Mr. Sorby has, as we have just seen, determined the temperature requisite to expand the liquid so as to fill the fluid-cavities, provided they were formed under a pressure not greater than the elas-

tic force of the vapor. This of course represents the lowest temperature at which the consolidation could have taken place, and varies from 340° to 380° in the Vesuvian minerals, and 356° in the quartz of the trachyte of Ponza, to a mean of 216° in the Cornish granites, to 99° in those of the Scottish Highlands, and even descends to 89° in some parts of the granite of Aberdeen. But this low temperature is improbable, and inasmuch as water and aqueous solutions are compressible, their volume would be considerably reduced under a great pressure of superincumbent rock. Mr. Sorby has therefore calculated the pressure in feet of rock which would be required to compress the liquid so much that it would just fill the cavities at 360° C. The numbers thus obtained will therefore represent the actual pressure, provided the rock was in each case consolidated at that temperature. It would thus appear that the trachyte of Ponza was solidified near the surface, or beneath a pressure of only 4000 feet of rock; while for the Aberdeen granite the pressure was equal to not less than 78,000 feet, and for the mean of the Highland granites 76,000. The Cornish granites vary from 32,400 to 63,600, and give as a mean 50,000 feet of pressure. In this connection Mr. Sorby remarks that from Mr. Robert Hunt's observations on the mean increase of temperature in the mines of Cornwall, a heat of 360° C. would be attained at a depth of 53,500 feet.

The observations upon the metamorphic crystalline schists in the vicinity of these various granites show that their constituent minerals must have crystallized at about the same temperature as the granite itself; affording, as Mr. Sorby observes, "a strong argument in favor of the supposition that the temperature concerned in the normal metamorphism of gneissoid rocks was due to their having been at a sufficiently great depth beneath superincumbent strata"; and he concludes that with regard to rocks and minerals formed at high temperatures, we have "at one end of the chain erupted lavas, indicating as perfect and complete fusion as the slags of furnaces, and at the other end simple quartz-veins, having a structure precisely analogous to that of crystals deposited from water. Between these there is every connecting link, and the central link is granite." When the water, which at great depths was associated with the melted rock, was given off as vapor while the mass remained fused, slag-like lavas resulted. If however the water could not escape in vapor, it remained, as we

have seen, to take its part in the crystallization, in some cases forming hydrated minerals; and the excess of it, as Mr. Sorby suggests, passed up as a highly heated liquid, holding dissolved materials, which would afterwards be deposited in the form of mineral veins in the fissures of superincumbent rocks.

I have thought it well to give at some length the remarkable results and conclusions by Mr. Sorby, because I conceive that they have not as yet received the full degree of consideration to which they are entitled, and are perhaps little known to some of my readers.* The temperature deduced by him from the examination of the crystals of hornblende and feldspar from Vesuvius is curiously supported by the experiments of Daubr e; who obtained crystallized pyroxene, feldspar, and quartz, in presence of alkaline solutions, at a temperature of low redness; while De Senarmont crystallized quartz, fluor-spar, and sulphate of barytes in presence of water, at temperatures between 200° and 300° C. At the same time the deposits from the thermal waters at Plombi eres show that crystalline hydrous silicates, such as apophyllite, harmotome, and chabazite, have formed at temperatures but little above 80° C.

We conceive that the deeply buried sedimentary strata, under the combined action of heat and water, have, according to their composition, been rendered more or less plastic, and in many cases have lost to a greater or less degree the marks of their sedimentary origin, although still retaining their original stratigraphical position. In other cases they have been displaced, and by pressure forced among disrupted strata, thus assuming the form of eruptive rocks; which, becoming consolidated under a sufficient pressure, retain the same mineral characters as in the parent beds. It is only those rocks which, like lavas, have solidified at or near the surface of the earth, and consequently under feeble pressure, which present mineralogical characters dissimilar to those of the undisturbed crystalline sediments. With this exception, the only distinction which can be drawn between stratified and unstratified masses must in most cases be based upon their attitude, and their relation to the adjacent rocks.

In view of these considerations I have, in previous papers, adopted for geological purposes a division of crystalline rocks into

* See further the late observations of Zirkel confirming those of Sorby Proc. Imp. Acad. Vienna, March 12, 1863; in abstract in Quar. Jour. Geol. Soc., vol. xix.

indigenous rocks, or sediments altered *in situ*, and exotic rocks, or sediments displaced and translated, forming eruptive and intrusive masses. Under the head of exotic rocks is however to be included another class of crystalline aggregates, which are for the most part distinguished by their structure from injected or intrusive masses. I refer to the accumulations which fill mineral veins, and which doubtless have been deposited from aqueous solutions. While their peculiar arrangement, with the predominance of quartz and non-silicated species, generally serves to distinguish the contents of these veins from those of injected plutonic rocks, there are not wanting cases in which the predominance of feldspar and mica gives rise to aggregates which have a certain resemblance to dykes of intrusive granite. From these however, true veins are generally distinguished by the presence of minerals containing boron, fluorine, phosphorus, cæsium, rubidium, lithium, glucinum, zirconium, tin, columbium, etc.; elements which are rare, or found only in minute quantities in the great mass of sediments, but are here accumulated by deposition from waters, which have removed these elements from the sedimentary rocks, and deposited them subsequently in fissures.

No one at the present day will probably be found to deny the plutonic origin of most non-stratified rocks, so that the once vexed questions of the neptunists and plutonists may be regarded as settled. If however we go back but a few years in the history of geology, it will be found that an eruptive origin was then claimed for many rocks which are now admitted to be indigenous. It is scarcely necessary to refer to the views of those who have maintained the exotic character of many quartzites and crystalline limestones, when a majority of writers, even to the present day, class serpentines, euphotides, and hyperites among eruptive rocks; although the experience of every field-geologist is accumulating, from year to year, a great mass of evidence in favor of the indigenous nature of all these rocks. The sedimentary and indigenous character of very many granites, syenites, and diorites will now no longer be questioned. Thus we find, for example, that the melaphyres of the Tyrol, which, in Von Buch's too-famous theory of dolomitization, were supposed to have been erupted together with magnesian vapors which effected the alteration of the adjacent limestones, have been shown by Fournet to be sediments of Carboniferous age, metamorphosed *in situ*,—indigenous

rocks, which were altered before the Jurassic dolomites were deposited. (Bul. Soc. Geol. France [2], vi, 506-516). In like manner we find Scipion Gras concluding from his researches on the anthracitic rocks of the Alps, that the serpentines, euphotides, porphyries, and spilites, which are there found associated with crystalline schists, are all of sedimentary origin, but have been so profoundly altered *in situ* as to have lost nearly all traces of sedimentary origin. (Ann. des Mines [5], v, 475.) We might add that the tendency of recent investigations has been to show that the protogines, or granites of the summit of the Alps, are Tertiary strata altered in place; thus confirming the bold assertion made by Keferstein in 1834, that these granites are altered strata of *flysch*. (This Journal [2], xxix, 123, 124.) Lesley's recent investigations of the granites of the White Mountains of New Hampshire, show them to be clearly stratified sedimentary deposits in nearly horizontal layers. (American Mining Journal, 1861, page 99; Silliman's Journal [2], xxxi, 403.) The ophites (amphibolites) of the Pyrenees, which by Dufrenoy and other French geologists have been regarded as eruptive, and were by the former imagined to be in some mysterious manner related to the rock-salt and gypsum of the region, which he supposed to be, like the ophites, of posterior origin to the enclosing strata (Explic. de la Carte Geol. de France, i, 95), are according to a recent note by Virlet, not eruptive, but altered indigenous rocks; belonging, together with the associated gypsum and saliferous strata, to the Triassic series. (Comptes Rendus de l'Acad., Aug. 1863, p. 232).

It would be easy to multiply examples of this kind, which show that a careful study of very many of the crystalline rocks hitherto regarded as eruptive, leads to the conclusion that they are really indigenous rocks. At the same time, many of these indigenous rocks appear to have been at one time in a soft semi-fluid condition, which permitted movements obliterating the marks of sedimentary origin, and producing other results which show the passage into eruptive rocks. Thus the crystalline limestones of the Laurentian series in Canada are frequently interstratified with thin beds of gneiss and quartzite, both of which are often found broken, contorted, and even twisted spirally, in a manner which indicates great flexibility of the silicious layers, as well as violent movements in the calcareous rock. The latter is in some cases found in the form of thin seams or considerable dykes among the

adjacent broken silicious strata ; thus assuming for small distances, the characters of an intrusive rock. For some figures and descriptions illustrating these broken and distorted strata, see *Geology of Canada*, pp. 27, 28. We may also allude in this connection to the observations of Dr. Hitchcock among the altered strata of the Green Mountains, which seem to show that the pebbles of gneiss and of quartz in certain conglomerate beds have been so softened as to have been flattened, laminated, and bent around each other. (*Silliman's Journal* [2], xxxi, 372.) Hence, while the tendency of the various observations above cited is in favor of the indigenous character of many rocks hitherto regarded as eruptive, we have at the same time evidence that these rocks are occasionally displaced. We should not therefore on *a-priori* grounds reject the assertion that any metamorphic sediment may sometimes occur in an exotic or intrusive form. A given rock, like limestone or diorite, may occur both as an indigenous and exotic rock ; and different portions of the same mass may be seen by different observers under such unlike conditions that one may regard it as indigenous, and the other, with equal reason, may set it down as intrusive. It is evident then that to the lithologist, who examines rocks without reference to their geological relations, the question of the exotic or indigenous character of a given rock is, in most cases, one altogether foreign ; and one which can frequently be decided only by the geologist in the field. Hence, although generally made a fundamental distinction in classification, it will be disregarded in the following sketch of the nomenclature of crystalline rocks.

I may here allude to a fact which I have already noticed, and tried to explain, (*Silliman's Journal* [2], xxxi, 414, and xxxvi, 220, *note*,) that throughout the great metamorphic belt which constitutes the Appalachian chain, exotic rocks are comparatively rare (at least in New England and Canada) ; but abound, on the contrary, among the unaltered strata on either side. Illustrations of this are seen in the valley of Lake Champlain, and in its northward continuation toward Montreal, in those of the Hudson and Connecticut, and in the northeastward continuation of the latter valley by Lake Memphramagog to the Bay of Chaleurs, which is marked throughout by intrusive granites. In accordance with the reasons already assigned for this distribution of exotic rocks, it is probable that a similar condition of things will be found to exist in other regions ; and that eruptive rocks will, as a general rule, be found among

unaltered, rather than among metamorphic strata. It is of course possible that a crystallization of the sediments may in some cases take place subsequent to the eruption of foreign rocks into their midst. The rarity of intrusive rocks among crystalline strata, not less than the unaltered condition of sediments which are traversed by abundant intrusive masses, is a strong proof of the fallacy of the still generally received notion which connects metamorphism with the contiguity of eruptive rocks.

II. CLASSIFICATION AND NOMENCLATURE.

It is proposed in this second part, to describe briefly the composition, structure, and nomenclature of the various crystalline silicated rocks, considered without reference to the distinction between indigenous and intrusive masses. Comparatively few of these rocks are homogeneous, or consist of a single mineral species and the names which have been applied to varying mixtures of different species are of course arbitrary; and as they have often been given without any previous mineralogical study, it sometimes happens, that, as in the case of the rocks composed of anorthic feldspars and pyroxene, different names have been proposed for varieties very closely related, or differing from one another only in texture or in structure.

The minerals essential to the composition of the rocks under consideration are few in number, and are as follows: quartz, orthoclase; a triclinic feldspar which may be albite, oligoclase, andesine, labradorite, or anorthite; scapolite, leucite, nepheline sodalite; natrolite, or some allied zeolite; iolite, garnet, epidote, wollastonite, hornblende, pyroxene, olivine, chloritoid, serpentine, diallage; muscovite, phlogopite, and some other micas; chlorite, and talc. To these may be added as accidental ingredients, the carbonates of lime, magnesia, and protoxyd of iron, together with magnetite, ilmenite, and sphene. The silicates which, like tourmaline, beryl, zircon, spodumene, and lepidolite, contain considerable portions of the rarer elements, and often occur with quartz and feldspar in granitic veins, whose origin has already been alluded to, enter at most in very small quantity into great rock-masses.

The varieties of structure in crystalline rocks are the more deserving of notice as they have led to a great multiplication of names. We may note first the granitoid structure, in which the mineral elements are distinctly crystalline, as in granite. From

this, there is a gradual passage through granular into compact varieties of rock. Most of these are simply finely granular, and are rightly entitled to the distinction of crypto-crystalline; but others, like the pitchstones, obsidians, and lavas, are apparently amorphous, and are natural glasses. In some cases the constituent minerals may be so arranged as to give a schistose or a gneissoid form to a rock. This arrangement is generally to be looked upon as an evidence of stratification; but something similar is occasionally observed in eruptive masses. In the latter case it generally seems to arise from the arrangement of crystals during the movement of the half-liquid crystalline mass; but it may in some instances arise from the subsequent formation of crystals arranged in parallel planes.

See on this point Naumann *On the Probable Eruptive Origin of Several Kinds of Gneiss, etc.*; Leonhard and Bronn, *Neues Jahrbuch* for 1847, and Poulett Scrope, *Geol. Journal*, xii, 345. I consider however that their views are to be adopted with great reserve, and admitted only in a very few cases. The ribbanded structure of some porphyries and clinkstones, as noticed by Scrope, is undoubtedly the result of movements in the liquid mass, and the same is true of some of the granitoid dolerites to be described in the third part of this paper; but the eruptive origin assumed by Darwin, Naumann, and some others for great areas of gneiss and gneissoid granite, seems to a student of the crystalline rocks of this continent utterly untenable. As has been already remarked, the progress of each year's investigation restores to the category of indigenous rocks many of those previously regarded as eruptive, and will, I am convinced, confirm the principle which I have laid down of the comparative rarity of exotic rocks in crystalline and in metamorphic regions.

Occasionally the crystallization of a rock takes place around certain centres, giving rise to rounded masses which have a radiated or a concentric structure, and constitute the so-called globular or orbicular rocks. Distinct crystals of some mineral, generally feldspar, augite, or olivine, are often found imbedded in rocks having a compact base. To such rocks the name of porphyry is given, and by analogy a rock with a granular base enclosing distinct crystals is designated as porphyritic or porphyroid. Amorphous or vitreous rocks, as pitchstones, are in like manner sometimes porphyritic. The name of porphyry, at first given to a peculiar type of feld-

spathic rocks, has now become so extended that it is to be regarded as only indicating an accident of structure. The title of amygdaloid is given to various rocks having rounded cavities which are wholly or partially filled with various crystalline minerals. The base of these rocks is generally granular or crypto-crystalline; but is sometimes amorphous, resembling a scoria or vesicular lava, the cavities of which have been filled by infiltration. Such is doubtless the origin of some amygdaloids. In more cases however these cavities have probably been formed like those often found in dolomites, and in some other rocks, by a contraction during solidification. Porphyroid rocks, in which quartz, orthoclase, and other minerals are arranged in orbicular masses, are also sometimes designated as amygdaloids, and may be confounded with the two previous classes in which the imbedded minerals are the result of subsequent infiltration. Allied in structure and origin to the last are what are named variolites or variolitic rocks. (See Geology of Canada, pp. 606, 607.)

The masses into which some aluminous minerals enter as a prominent element constitute by far the greater part of the rocks now under consideration. These are naturally divided into two classes, whose origin we have pointed out in a recent paper already referred to. (Silliman's Journal [2], xxxvi, 218.) The first of these is characterized by containing an excess of silica, with a portion of alumina, much potash, and small portions only of lime, magnesia, and oxyd of iron. The second class contains a smaller amount of silica, and larger proportions of alumina, lime, magnesia, and oxyd of iron, with soda, and but little potash. These chemical differences are made apparent in the more coarsely crystalline rocks, by the nature of the constituent minerals; and in the compact varieties, by differences in color, specific gravity, and hardness. Thus in the rocks of the first class the predominant mineral is orthoclase, generally associated with quartz, and the composite rocks of this class seldom have a density much above that of these species; or from 2.6 to 2.7. In the second class, the characteristic mineral is a triclinic feldspar, with pyroxene or hornblende, the feldspar sometimes predominant; while in other cases the pyroxene or hornblende makes up the principal part of the rock. The presence of these latter minerals generally gives to the fine-grained rocks of this class a dark color, a hardness somewhat inferior to the more silicious class, and a density which may vary from 2.7 to more than 3.0. It will

however be found that the line between the two classes cannot always be distinctly drawn; inasmuch as rocks containing orthoclase and quartz often include triclinic feldspars such as albite and oligoclase, and by an admixture of hornblende offer a transition to rocks of the second class. On the other hand, quartz is sometimes found with triclinic feldspars and hornblende in the rocks of the second class. Besides these two feldspathic classes, there is a third small but interesting group, in which an aluminous silicate of high specific gravity, such as garnet, epidote, or zoisite replaces the feldspar wholly or in part. These minerals being basic silicates rich in alumina, the relations of this group are naturally with those of the second class, although varieties of these species are found in rocks which belong to the first class.

The silico-aluminous crystalline rocks may thus be conveniently divided into three families. The first of these includes those rocks in which the aluminous mineral is orthoclase (orthose), from which they may be conveniently designated by the name of the *orthosite* family. The second includes those in which the aluminous element is an anorthic or triclinic feldspar, and may be designated as the *anorthosite* family: chemically related to this are those rocks holding as one of their elements nepheline, leucite or scapolite. The third family includes those rocks which contain an aluminous silicate of high density, as epidote, zoisite, garnet, andalusite, or kyanite, in place of a feldspathide. Iolite or dichroite, which enters into the composition of some orthosite rocks, appears from its atomic volume to be related to the feldspars, and should take its place along-side of anorthite and scapolite as a magnesian feldspathide, while beryl in like manner appears to be a glucinic feldspathide.

It is worthy of notice, that some feldspars having the crystallization and density of orthoclase, nevertheless contain large proportions of soda. The loxoclase of Breithaupt appears from the analyses of Smith and Brush to be a true soda-orthoclase (Silliman's Journal [2], xvi, 43); while the sanidine or glassy feldspar of many trachytes contains potash and soda in nearly equal proportions. The name of potash-albite has been given to some feldspars of this composition; but the trachytic rocks hereafter to be described contain feldspars, which, without being glassy, have the composition of sanidine, together with a cleavage

and specific gravity which show them to belong to orthoclase, rather than to albite. The anorthic feldspars offer in their composition such gradations from albite to anorthite, that the various intermediate species which have been distinguished seem to pass into each other. (Silliman's Journal [2], xviii, 270, Phil. Mag. [4], ix, 262.)

Next to the feldspars in lithological importance are the two species, pyroxene and hornblende. These are sometimes found associated in the same rock, and the varieties of pyroxene known as diallage and smaragdite are frequently surrounded or penetrated by hornblende. This association of the two species should be kept in mind, inasmuch as the substitution of pyroxene for hornblende in anorthosites, has been made the basis of a subdivision in classification. (Silliman's Journal [2], xvii, 339.) Among the micas found in silicated rocks, besides muscovite and a magnesian mica (phlogopite or biotite), are to be included the hydrated micas observed by Haughton in many of the Irish granites. Of these the one is margarodite, and the other a uniaxial black mica, also hydrated, which he has referred to lepidomelane. (Trans. Royal Irish Acad., xxiii, 593.) The presence of from four to six hundredths of water in the micas of these granites is important in connection with the evidence already given of the intervention of water in the formation of granitic rocks. These two hydrous micas were often found by Haughton to be united in the same crystal; and Rose has remarked a similar association of potash-mica and magnesian mica in certain granites. (Senft, die Felsarten, p. 206.)

A scientific nomenclature for compound rocks presents such great difficulties that we must be content for the most part with trivial names which have from time to time imposed. In the case of simple rocks, the terms quartzite, pyroxenite, anorthosite, and orthoclasite are sufficiently definite, or they may be farther characterized as normal orthoclasite, etc.; while quartzose, micaceous, and quartzo-micaceo-hornblendic orthoclasite would designate various compound rocks of which orthoclase is the base. Such names, however descriptive, will never replace the older terms granite, syenite, etc., which are employed to designate certain forms of orthosite rocks. The frequent association of a triclinic feldspar (oligoclase) with orthoclase in granite rocks, and the partial or total replacement of the micas generally present in these, by hornblende, by chlorite, or by talc, giving rise in the latter case to what is called protogine, are well known. Nepheline (elæo-

lite), natrolite, iolite, and magnetite are sometimes found as elements in granitic, gneissic, and syenitic rocks. The name of miascite is given to a granitic mixture of orthoclase and black mica with elæolite, sometimes with hornblende, albite, and quartz.

The structure of these orthosite rocks gives rise also to a great variety of names; thus to coarsely lamellar granites the name of pegmatite is sometimes given, while fine-grained mixtures of orthoclase and quartz have received the names of granulite, leptinite, and eurite, or when apparently homogeneous and crypto-crystalline are called petrosilex. These latter forms often become porphyritic from the presence of crystals of orthoclase, giving rise to orthoclase-porphyr, or orthophyre. In some of these porphyries, as in those of Grenville, to be described in the third part of this paper quartz is also present in distinct grains or crystals; while in some of the red antique porphyries the feldspathic base contains no excess of silica, and occasionally encloses crystals of oligoclase or of hornblende. In many cases the granites, syenites, orthophyres, and other orthosite rocks just mentioned are intrusive; while in other instances, rocks lithologically indistinguishable from these are indigenous, and becoming schistose pass into gneiss and mica-schist.

The rocks to which the name of trachyte has been given are generally composed in great part of orthoclase (sanidine). The typical varieties of these rocks are white or of pale colors, granular or finely crystalline, and frequently porous or cellular. They appear to consist of grains, crystals, or lamellæ of orthoclase, aggregated without any cementing medium, and to this seems to be due that roughness to which the rock owes its name. Oligoclase, quartz, hornblende, and mica are also met with in this rock, which becoming coarsely granular, passes into granite. Such is the case with the trachytes of the Sierra of Carthagena in Spain, described by Fournet as passing from a dull rough grayish feldspathic mass, into a highly crystalline aggregate of feldspar and mica, with or without hyaline quartz, enclosing hornblende, red garnet, and fine blue iolite. (*Comptes Rendus*, xlv, p. 1834.)

The trachytic texture is not confined to orthosite rocks. Abich has described under the name of trachy-dolerites a group of trachytoid anorthosites (dolerites). The cone of the Soufrière of Guadalupe is described by Deville as a rough granular rock having the external characters of trachyte, from which it is dis-

tinguished by its somewhat greater density (2.75). It consists essentially of labradorite, with a little quartz, pyroxene, olivine, and magnetite. (Bul. Soc. Geol. de France [2], viii, 425.) Humboldt designates the trachy-dolerites of Etna and of the Peak of Teneriffe as trachytes (Comptes Rendus, xlv, 1067); so that this word, like porphyry, comes to indicate nothing more than a peculiarity of structure, which may be assumed by various feldspathic rocks. The trachytic orthosites, as we have seen, pass into granites, from which they do not differ in chemical composition; and their differences in texture probably depend upon the fact that the one was solidified under great pressure, and the other near the surface, trachytes passing in fact into lavas. The observations of Sorby on the fluid-cavities in the crystals of granites and of trachytes are in point.

Among the intrusive rocks of Canada to be described are granitoid, compact, and earthy varieties of trachytic orthosites, besides trachytic porphyries. These rocks often contain disseminated earthy carbonates, sometimes in considerable amount; as Deville had already shown for some of the trachytes of Hungary, and as I have also observed for those of the Siebengebirge on the Rhine. Trachytes also hold in some cases disseminated portions of a zeolite, apparently natrolite; and through this mixture pass into phonolites, of which a characteristic variety will be noticed in this paper. Obsidian and pumice-stone, which are often associated with orthoclase trachytes, are related to them in composition; and pitchstone and perlite are similar rocks, differing however in containing some combined water. Rocks resembling pitchstone, and sometimes porphyritic from the presence of distinct crystals of feldspar, occur in the south side of Michipicoten Island, Lake Superior, but have not yet been examined. (Analyses by Jackson and by Whitney of the pitchstones of Isle Royale will be found in Silliman's Journal [2], xi, 401; xvii, 128.)

The presence of an anorthic feldspar, generally oligoclase, in many granites and trachytes, not less than the admixture of orthoclase crystals in some of the trachytic dolerites of Etna, serves to connect the orthosite with the anorthosite family. Great masses of indigenous rock in the Labrador series in Canada, are made up of almost pure granular labradorite, or related triclinic feldspars, and might be termed normal anorthosites. (Silliman's Journal [2], xxxvi. 224; Geol. of Canada, 588.) In most cases however, these feld-

spars are intermingled with some other mineral, commonly hornblende or pyroxene.

The name of diorite is by good authorities restricted to rocks whose predominant elements are triclinic feldspars with hornblende; while the names of diabase and dolerite distinguish those rocks in which pyroxene takes the place of hornblende. In some anorthosite rocks however, pyroxene and hornblende are intimately associated, so that a passage is established from diorite to diabase. The feldspar of diorites varies in composition from albite to anorthite, and is occasionally accompanied by quartz. This, though most frequent with the more silicious feldspars, is sometimes met with in diorites which contain feldspars approaching to anorthite in composition. Sometimes the two constituent minerals are distinct and well crystallized, constituting a granitoid rock: fine examples of this, hereafter to be described, occur in the intrusive hills of Yamaska and Mount Johnson. At other times the diorite is finely granular or compact, when its color is generally of a green more or less dark from the disseminated hornblende, and it takes the name of greenstone. The greenstones of the Huronian series are in part at least diorites, and probably indigenous; but a great number of the so-called green-tone-traps are pyroxenic, and belong to the class of diabase or dolerite. Diorite not unfrequently contains a mica, which is generally brown or black in color. Chlorite, magnetite, ilmenite, and sphene often occur as disseminated minerals, as also carbonates of lime, magnesia, and oxyd of iron. The finer-grained diorites are frequently porphyritic from the presence of crystals of feldspar or of hornblende. Occasionally this rock is concretionary in its structure, as in the orbicular diorite or napoleonite of Corsica; which contains a feldspar allied to anorthite, with hornblende, and some quartz. The norite from Sweden is a granular mixture of a similar kind, containing also mica; and the ophite of some writers is a diorite in which hornblende greatly predominates.

The rocks which are essentially composed of anorthic feldspar and pyroxene, present still greater diversities than the diorites, and have received various names based upon differences in texture and in the form of the pyroxenic element. It is here proposed to restrict the name of dolerite to such of these rocks as contain the black augitic variety of pyroxene, and to include the mixtures of triclinic feldspars with all the other varieties of this species under

the head of diabase. The finer-grained and impalpable varieties of diabase have received the name of aphanite; which is often indistinguishable from the corresponding forms of diorite, and like these may become porphyritic, giving rise to the augite-porphry of some authors. Different varieties of this porphyry have received the name of labradophyre, oligophyre, and albitophyre, according to the composition of the imbedded feldspar crystals. These are sometimes accompanied by crystals of augite, or are altogether replaced by them.

The name of hyperite or hypersthenite has been given to those varieties of diabase which contain hypersthene or diallage. These rocks occur abundantly in the Labrador series, where the hypersthene in them sometimes takes the form of a green diallage, or passes into a finely granular pyroxene, and is associated with red garnet; ilmenite, and a little brown mica; in addition to which epidote is said to occur in the hyperites of the same series in New York, and olivine is mentioned as being found in the hyperites of Sweden, and of the Island of Skye. Hornblende is also in some localities associated with the hypersthene. The hyperites, although indigenous rocks in the Labrador series in Canada, are described as forming in other regions intrusive masses.

Those varieties of diabase or hyperite which contain diallage, have, by the Italian lithologists been called granitone, but by Rose and others have been described under the name of gabbro. This rock sometimes contains hornblende, mica, and an admixture of epidote. A compact white or greenish-white epidote, or zoisite, which has the hardness of quartz and a density of 3.3 to 3.4, is the mineral named saussurite. This with smaragdite, which is an emerald-green pyroxene, often minged with hornblende, and passing into diallage, forms the euphotide of Haüy. Compact varieties of labradorite and of other triclinic feldspars have by most of the modern lithologists been confounded with saussurite, and hence the name of euphotide is frequently given to the so-called granitone or gabbro, which is only a diallagic variety of diabase. The true euphotide often contains a portion of talc, and sometimes encloses crystals of a triclinic feldspar, apparently labradorite, thus offering a transition to diabase. See farther my researches on euphotide and saussurite; *Silliman's Journal* [2] **xxvii**, 330, and **xxxvii**, 426.

Under the name of dolerite, as already remarked, it is proposed

to class such anorthosite rocks as contain a black ferruginous pyroxene or augite. These rocks, which are sometimes coarsely granular or granitoid in their structure, pass into fine-grained or compact varieties, which are distinguished by the names of anamesite and basalt. To these latter varieties belong a great part of the greenstone-traps, although in rocks of this texture it is often impossible to determine whether it is hornblende or pyroxene which is mingled with the feldspar. Olivine in grains or crystals frequently occurs both in the fine-grained basaltic dolerites and the granitoid varieties, giving rise by its predominance to what is called peridotite. Some fine-grained dolerites are porphyritic from the presence of black cleavable augite crystals, forming an augite-porphiry. Finely disseminated carbonates of lime and oxyd of iron are occasionally present in these rocks to the extent of twenty per cent., and even more. In like manner, magnetite and ilmenite, which are often associated, may constitute several hundredths of the mass. Many fine-grained greenstones contain, like phonolite, large portions of some zeolitic mineral, and they often abound in chlorite. The pyroxene in these rocks is sometimes replaced by a highly basic silicate. Some varieties of what has been called diallage may be represented as an aluminiferous pyroxene *plus* a hydrate of magnesia. At other times a mineral approaching in composition to a ferruginous chlorite (frequently amorphous) enters into the composition of these anorthosites, and even in some cases appears to replace altogether the pyroxene or the hornblende, constituting an aberrant form of diorite or of diabase, which is not uncommon among greenstones, and for which a distinctive name is needed. See on this point *Geology of Canada*, pp. 469, 605, and the remarks on melaphyre below.

The finer-grained dolerites are often cellular, giving rise to amygdaloids, whose cavities are generally filled with calcite, quartz, or some zeolitic minerals. To these amygdaloids the name of spilite is sometimes given. Earthy varieties of basalt, which are frequently the result of partial decomposition, constitute the wacke of some writers. It is doubtful how far many of these spilites and wackes have a claim to be considered as crystalline rocks, inasmuch as they appear in very many cases to be nothing more than aqueous sediments accumulated under ordinary conditions, or perhaps in some cases derived from volcanic ash or volcanic mud. As the other extreme of this series of rocks we may notice that dole-

rites often assume a trachytic form,—the trachy-dolerites already mentioned,—or constitute the lavas from modern volcanoes.

Among the compound rocks which are related to the preceding group by the presence of augite, may be noticed nepheline-dolerite, in which nepheline replaces the feldspar; and analcinite, a variety into which analcime enters in large amount. Scapolite also in some cases replaces feldspar, and forms with green pyroxene, a peculiar aggregate associated with the Laurentian limestones. Leucite enters as an important element in some dolerites, and even replaces wholly the feldspathic element, giving rise to what has been called leucitophyre or leucilite.

[Leucite is generally regarded as an exclusively volcanic mineral; but according to Fournet, it occurs like other feldspars in mineral veins, forming the gangue of certain auriferous veins in Mexico (*Géologie Lyonnaise*, page 261). According to Scheerer, leucite also occurs in drusy cavities with zeolites and quartz at Arendal in Norway; although it would seem to be rare in this locality since Durocher was not able to detect it. (*Annales des Mines* [4], i, 218). The conditions required for the formation of this feldspathide must be peculiar, since the volcanic rocks which afford it are confined to a few localities; and since while it contains a large amount of potash it is a basic silicate, and found among highly basic rocks, in which potash compounds are generally present only in very small quantities. The agalmatolite rocks, including dyssyntribite and parophite (*Geology of Canada*, page 484), are however basic aluminous silicates in which potash predominates, and might be supposed under certain conditions of metamorphism to yield leucitic rocks.]

The name of melaphyre, which is employed by many writers on lithology requires a notice in this connection. It was proposed by Brongniart as a synonym for black porphyry (*mela-porphyre*), and defined by him in 1827 as a porphyry holding crystals of feldspar in a base "of black petrosilicious hornblende." (*Classif. des Roches*, page 106.) Subsequent researches showed that some of these porphyries were really augitic; and Von Buch employed the name of melaphyre as synonymous with augite-porphyre, in which he was followed by D'Halloy. (*Des Roches*, p. 75.) In consequence of this confusion, and of the vague manner in which the term is used to include rocks which are sometimes diorites and sometimes varieties of dolerite or basalt, Cotta seems disposed to reject the

name of melaphyre as a useless synonym, in which I agree with him. (*Gesteinslehre*, page 48.) More recently however, Senft (*Die Felsarten*, page 263) has endeavored to give a new signification to the term, and defines melaphyre as a reddish-gray or greenish-brown colored rock, passing into black, and containing neither hornblende nor pyroxene. The melaphyres of Thuringia and of the Hartz, according to him, consist of labradorite with iron-chlorite (delessite), carbonates of iron and lime, and a considerable portion of titaniferous magnetic iron. Hornblende and mica are present only as rare and accidental minerals. We have already alluded to this class of anorthosite rocks, as requiring a distinctive name; but from the historical relations of the word melaphyre, it seems to be an unfortunate appellation for rocks which are not black in color, and from which both hornblende and pyroxene are absent.

We now come to consider that third group of silicated rocks, in which the feldspathides are replaced by the denser double silicates of the grenatide family, garnet, epidote, zoisite, and perhaps idocrase. Red garnet enters into many gneissic rocks, and even forms with a little admixture of quartz, rock-masses. In some of these, as in the Laurentian series, there appears an admixture of pyroxene, forming a passage into omphazite or eclogite; which consists of smaragdite (pyroxene) and red garnet, sometimes mixed with mica, quartz, and kyanite, and passes through an increase of the latter into disthenite or kyanite rock. An aggregate of hornblende and red garnet forms beds in the Green Mountains, and an admixture of red garnet with lievrite and a little mica makes up a rock in the Laurentian series. This is evidently related to euly-site, a rock forming strata in gneiss in Sweden, and consisting of garnet, pyroxene, and a mineral having the composition of an olivine in which the greater part of the magnesia is replaced by ferrous and manganous oxyds. Related to this is an apparently undescribed rock from the Tyrol, of which a specimen is before me, consisting of red garnet, green pyroxene, and yellowish-green olivine, the latter greatly predominating; and also a coarsely crystalline rock from Central France, recently described by the name of cameleonite, and composed of olivine, with pyroxene, and enstatite, a magnesian augite; these minerals being accompanied by spinel, sphene, and ilmenite. I have already alluded to the true euphotides, in which a compact zoisite (jade or saussurite) takes

the place of feldspar in a rock the other element of which is pyroxene, and have shown how the occasional presence of a triclinic feldspar connects euphotide with diabase (Silliman's Journal [2], xxvii, 336.) In the same paper are described rocks made up of a white compact garnet with and without hornblende and feldspar, and also an epidosite, composed of epidote and quartz.

By the disappearance of the aluminous silicate from the rocks of the second and third groups, a passage is established to the amphibolites and pyroxenites; and these, through diallage rock, offer a transition to the ophiolites or serpentines. These relations are well exhibited in Eastern Canada, where the diorites or greenstones, which are sometimes highly feldspathic, pass into actinolite rock and hornblende slate on the one hand, and into diallagic diabase and diallagic ophiolite on the other.

These greenstones, which contain a chloritic mineral, and are often epidotic, pass gradually into compact or schistose chloritic rocks, frequently enclosing modules or layers of epidote, either pure or mingled with quartz. The relations between these various rocks are such that after a prolonged study of them I find it difficult to resist the conclusion that the whole series, from diorites, diallages, and serpentines, to chlorites, epidosites, and steatites, has been formed under similar conditions, and that they are all indigenous rocks. (Geology of Canada, pp. 606, 612, 652.) I have elsewhere expressed the opinion that these silicates are probably of chemical origin, and have been deposited from solutions at the earth's surface. The sepiolite or hydrous silicate of magnesia, which occurs in beds in tertiary rocks, the neolite of Scheerer, the silicates of lime, magnesia, and iron-oxide deposited during the evaporation of many natural waters; and the silicates of alumina like halloysite, allophane, and collyrite, and that deposited by the thermal waters of Plombières, all show the formation and deposition at the earth's surface of silicates, whose subsequent alteration has probably given rise to many minerals and rocks. (Silliman's Journal [2], xxxii, 286; and Geology of Canada, pp. 559, 577, 581). At the same time the phenomena of local metamorphism furnish evidences that similar compounds have resulted from the action of heat upon mechanical mixtures in sedimentary deposits. (Ibid., p. 581.) A further consideration of this subject, and of the two-fold origin of many silicious minerals, is reserved for another place.

III. ON SOME ERUPTIVE ROCKS.

In Silliman's Journal for March 1860 (2nd, xxix, 282) there is a short note, pointing out the existence, in the vicinity of Montreal, of several interesting classes of eruptive rocks, including quartziferous porphyries, trachytes, phonolite, dolerites, and diorites. It is proposed in the third part of the present paper to describe the results of some chemical and mineralogical examinations of these rocks, and to give by way of preface a description of their geographical distribution and geological relations. They may be considered geographically as belonging to two groups; of which the first and more important for the number and variety of its rocks may be conveniently described as the Montreal group. It consists of a succession of intrusive masses along a belt running nearly transverse to the undulations of the Notre Dame Mountains, which are the prolongation of the Appalachians into eastern Canada. Commencing at Shefford Mountain, an isolated trachytic mass not far removed from the western base of the Notre Dame range, we find, going westward, the detached hills known as Yamaska, Rougemont, Rouville or Belœil, Montarville or Boucherville, Mount Royal or Montreal, and Rigaud Mountains; the last being distant about ninety miles from Shefford. Brome Mountain, which occupies a large area to the south of Shefford, approaches within two miles of it. In like manner, a few miles to the south of Belœil is another intrusive mass known as Mount Johnson or Monnoir; making in all nine hills of eruptive rock belonging to the Montreal group. Besides these, numerous smaller intrusive masses in the form of dykes are met with around and between the hills. From Mount Royal to Rigaud Mountain, a distance of about thirty miles, a gentle undulation of the strata is observed, which increases to the westward of Rigaud, and finally gives place to a considerable fault. This disturbance has been traced to the Laurentide hills on the Lac des Chats, 140 miles west of Montreal; but to the eastward the strata exhibit no evidence of this transverse undulation, unless the appearance of the intrusive rocks already mentioned be supposed to indicate the prolongation of a fracture without sensible dislocation.

The whole of these eruptive rocks rise through unaltered paleozoic strata, which however, in the immediate vicinity of the intrusive rocks, exhibit a local metamorphism. The hills of Shefford, Brome, and Yamaska break through the strata of the Quebec group, and lie a little to the east of the great line of dislocation

which, in this region, brings up the lower members of the paleozoic series against the superior portion of the Lower Silurian, and divides into two districts the great paleozoic basin. (Geology of Canada, pp. 234, 597.) The other hills all belong to the western division of this basin, and break through various members of the Lower Silurian series from the Potsdam to the Hudson River formation. Among the numerous dykes which traverse not only the sedimentary strata but the intrusive masses, there are some which intersect the conglomerates of St. Helen's Island. These are of uncertain age, but repose unconformably on the Lower Silurian series, and enclose pebbles and masses of Upper Silurian limestone characterized by fossils of the Lower Helderberg period. (Ibid., p. 356.)

This group of intrusive rocks offers very great varieties in composition; thus Shefford and Brome consist of what we shall describe as a granitoid trachyte, while the succeeding mountain, Yamaska, and the most western, Rigaud, both consist in part of a kind of trachyte, and in part of diorite. Monnoir and Belœil also consist of diorites, which however differ from the last two, and from each other; while Rougemont, Montarville, and Mount Royal consist in great part of dolerites, presenting however many varieties in composition, and sometimes passing into pyroxenite. The dolerites of Rougemont and Mount Royal are cut by dykes of trachyte. Similar dykes also traverse the diorite of Yamaska, and may perhaps be connected with the trachytic portion of this mountain. It is probable, judging from some specimens from Rougemont, that the dolerite is there intersected by veins of diorite, some of which resemble that of Belœil, and others that of Monnoir. Dykes both of trachyte, phonolite, and dolerite are also found traversing the Lower Silurian strata in the vicinity of the great eruptive masses; and the conglomerate of St. Helen's mentioned above is traversed by dykes of dolerite, which in their turn are cut by others of trachyte.

A second and smaller group of intrusive rocks occurs to the northwest of Montreal, chiefly in the county of Grenville, where they traverse the gneiss and limestones of the Laurentian system. The principal undulations of these rocks have, like those of the Appalachians, a north and south direction; but there is apparent also a second series of undulations, affecting in a less degree the geographical distribution of the strata, and having, like the Montreal and Rigaud undulation, an east and west direction. Coincident with the latter system of folds is a series of doleritic dykes, which nowhere

attain a great breadth, but have in some cases been traced more than fifty miles in a nearly east and west direction. These dykes are interrupted by a great mass of reddish syenite, passing in some parts into granite, and occupying an area of about thirty-six square miles in the townships of Grenville, Chatham, and Wentworth. Dykes of this syenite extend from the central mass, and traverse the surrounding gneiss and limestone. Numerous dykes of quartziferous porphyry intersect both this syenite and the surrounding gneiss, and are seen in one case to proceed from a considerable nucleus of porphyry, which rises into a small mountain; rendering it probable that numerous other porphyry dykes of the region radiate in like manner from other nuclei of the same rock. Some parts of this porphyry enclose fragments of syenite, dolerite, and gneiss, which vary in size from small grains to several feet in diameter, and often give to the rock the character of a breccia. In one instance a bed of gneiss, upwards of a hundred yards in length, is completely surrounded by the porphyry.

ORTHOPHYRE AND SYENITE.

ORTHOCLASE-PORPHYRY OR ORTHOPHYRE.—Under this head may be noticed a rock which has for its base a compact petrosilex, or intimate mixture of orthoclase and quartz, rendered porphyritic by the presence of grains or crystals of orthoclase, of quartz, or of both of these minerals together. The occurrence of this rock at Grenville, where it forms dykes in the syenite of that region, has just been noticed. The fine-grained petrosilicious base of this rock varies in color from dark green to various shades of red, purple, and black; these differences probably depending upon the degree of oxydation of the contained iron. Throughout this paste are disseminated well-defined crystals of a rose-red or flesh-red feldspar apparently orthoclase, sometimes very abundant; and less frequently small grains of nearly colorless translucent quartz. An analysis was made of a characteristic variety of the rock, the base of which was greenish-black, jasper-like, conchoidal in fracture, and feebly translucent on the edges, with a somewhat waxy lustre. The hardness was nearly equal to that of quartz, and the specific gravity 2.62. A few distinct crystals of red orthoclase, and some grains of quartz, were present. The base, freed as much as possible from these, gave as follows:

	I
Silica.....	72.20
Alumina.....	12.50
Peroxyd of iron.....	3.70
Lime.....	.90
Potash.....	3.88
Soda.....	5.30
Volatile.....	.60
	99.08

The oxygen ratio of the alkalis and alumina is 2.02: 5.84, or nearly 1:3. The alumina requires 43.80 parts of silica to form with the alkalis 65.48 parts of a feldspar having the ratios 1:3:12, which are those of orthoclase and albite. There will then remain 28.4 parts of silica. This, with the exception of a small amount which is probably united with the oxyd of iron and lime, may be regarded as uncombined. The porphyries of this region receive a high polish, and are sometimes very beautiful.

SYENITE.—The syenite of this region consists of orthoclase, usually flesh-red in color, and grayish vitreous quartz, with a small portion of blackish-green hornblende, which is sometimes almost or altogether wanting, and is occasionally accompanied with a little mica. The orthoclase is often nearly compact, but more generally distinctly crystalline and cleavable, and so far as observed, is not associated with any triclinic feldspar. The hornblende is apparently subject to decomposition, becoming soft, earthy, and ferruginous in its aspect, while the feldspar retains its brilliancy. The partial analysis of such a specimen of the syenite gave only 0.56 of lime, and traces of magnesia, with 3.75 per cent. of peroxyd of iron, and of alkalis, potash 4.43, soda 4.35. This large proportion of soda is also to be remarked in the orthophyre just described, and in the red orthoclase-gneiss of this region, a portion of which gave 3.86 per cent of potash and 3.70 of soda; while the red orthoclase from the rocks of this Laurentian series, named perthite by Dr. Thompson, gives in like manner 6.37 of potash to 5.56 of soda. A nearly pure potash-orthoclase, generally white in color, is however found in some of the stratified Laurentian rocks. (Geology of Canada, page 474.)

This syenite of Grenville has in some portions undergone a peculiar decomposition, which has reduced it to a soft greenish matter having the aspect of serpentine, or rather of pyralloite. This change has been remarked only in the vicinity of some remarkable

veins of chert which are here found cutting the syenite, and as described by Sir W. E. Logan, is more or less complete for a distance of two hundred yards on each side of them. In specimens of this altered rock, the quartz remains unchanged; while the feldspar, still preserving its cleavages, has a hardness no greater than carbonate of lime. It is somewhat unctuous to the touch, with a feeble waxy lustre, and its color is occasionally reddish, but more often of a pale green. Such a specimen was selected for analysis, and gave of silica 80.65, alumina 12.60, lime 0.60, soda and a little potash 2.65, volatile 2.10, magnesia and oxyd of iron, traces; = 98.60. From this result it appears that the feldspar of the syenite has lost nearly two thirds of its alkali; the iron and other bases having also for the most part disappeared. This removal of the protoxyd bases would appear from the character of the resulting mineral to be different from that which takes place during the kaolinization of feldspar. The nature of the process requires further investigation, but it was not improbably connected with the deposition of the adjacent chert or hornstone. This substance, according to Sir W. E. Logan, forms two large veins which cut the syenite vertically, and have a breadth of from four to seven feet. It is generally arranged in bands or layers parallel to the walls of the veins, and varying in color from white to yellowish and flesh-red. The mineral has the chemical characters of flint or buhrstone, and like the latter presents numerous irregular cells, the walls of which are sometimes incrustated with crystals of quartz, and in other cases bear the impression of small cubes, perhaps of crystals of fluor-spar, which have themselves disappeared. The relations of these singular veins of silex show that it cannot be of sedimentary origin, and it can scarcely be doubted that it is an aqueous deposit, and results from a similar process to that which on a lesser scale gives rise to agate and chalcedony in various rocks. (Geology of Canada, page 41.)

TRACHYTES.

Under this head we shall describe a class of rocks which are very abundant in Eastern Canada, and present a great variety of aspects. There are many dykes in the vicinity of Montreal which resemble some of the typical trachytic rocks of Auvergne and of the Rhine; while the rocks of the mountains of Brome and Shefford consist almost entirely of distinctly crystalline feldspar. These will

be described as granitoid trachytes, under which head may also be included a somewhat similar rock from Yamaska Mountain.

BROME AND SHEFFORD MOUNTAINS.—The trachytes of Brome and Shefford occupy two considerable areas near to each other, and, as already stated, are the easternmost of the eruptive masses now under description. The larger area covers about twenty square miles in Brome and the western part of the township of Shefford. It consists of several rounded hills, of which the principal are named Brome and Shefford Mountains, and rise boldly about 1,000 feet above the surrounding plain. The rock shows divisional planes, giving it an aspect of stratification, and separates by other joints into rectangular blocks. The second area includes about nine square miles in the township of Shefford, to the northwest of the last, and at the nearest point is only about two miles removed from it. This is known as Shefford Mountain.

The rocks of these two mountainous areas present but very slight differences; being, so far as examined, everywhere made up in great part of a crystalline feldspar, with small portions of brownish-black mica, or of black hornblende, which are sometimes associated. The proportion of these two minerals is never above a few hundredths, and is often less than one hundredth. The other mineral species are small brilliant crystals of yellowish sphene, and others of magnetic iron, amounting together probably to one thousandth of the mass. In some finer-grained varieties a few rare crystals of sodalite and of nepheline are met with. But for the uniform absence of quartz, these rocks might be taken for varieties of granite and syenite. They are very friable, and subject to disintegration, so that the soil for some distance around these mountains is almost entirely made up of the separated crystals of feldspar; which however show but little tendency to decomposition, and retain their lustre. The rock is sometimes rather finely granular in its texture; but is often composed of cleavable masses of orthoclase, which are from one fifth to one half of an inch in breadth, and sometimes nearly an inch in length. The lustre is vitreous, and in the more opaque varieties, pearly; but the crystals never exhibit the eminently glassy lustre nor the fissured appearance that characterizes the feldspars of many European trachytes which are similar to them in composition. The color of the feldspar of these rocks is white, passing into reddish on the one hand, and into pearl-gray or lavender-gray on the other.

Specimens of the rock of Brome Mountain were taken from the side near to the village of West Shefford. It was coarsely crystalline, lavender-gray in color, and contained a little brown mica, sphene, and magnetic iron, but no hornblende. The density of fragments of the rock was found to be 2.632-2.638. Selected grains of the feldspar had a specific gravity of 2.575, and gave by analysis the result II. The analysis of a second specimen from another portion of the hill, is given under III.

The rock from the south side of Shefford Mountain was next examined. In one part it consisted of a coarse-grained grayish-white feldspar with a little black mica, and closely resembled the rock just described from the adjacent mountain. A little lower down the hill however was a variety which, though completely crystalline, was more coherent and finer-grained than that of Brome, the feldspar rarely exhibiting cleavage-planes more than a fourth of an inch in length. Brilliant crystalline grains of black hornblende about the size of grains of rice were sparingly disseminated through the mass, together with very small portions of magnetite and yellowish sphene. Fragments of the rock had a density of 2.607-2.657. The feldspar was yellowish-white and sub-translucent, with a somewhat pearly lustre. By crushing and washing the mass, the grains of feldspar were separated from the heavier minerals, and found to have a specific gravity of 2.561. The result of its analysis, which scarcely differs from that of Brome, is given under IV.

	II.	III.	IV.
Silica	65.70	65.30	65.15
Alumina	20.80	20.70	20.55
Lime .....	.84	.84	.73
Potash	6.43	....	6.39
Soda	6.52	....	6.67
Volatile.....	.50	....	.50
	<hr/>		<hr/>
	100.79		99.99

YAMASKA MOUNTAIN.—About twelve miles to the north of west from Shefford Mountain rises the hill of intrusive rock known as Yamaska Mountain, which has an area of about four square miles, and breaks through the strata of the Quebec group, near the line of the great dislocation which brings these up against the limestones of the Trenton group. The southeastern part of this hill consists of a granitoid diorite hereafter to be noticed; but the greater portion of the mass may be described as a granitoid trachyte, differing in aspect from that of Brome and Shefford, in

being somewhat more micaceous and more fissile. The mica, which is dark brown, is in elongated flakes, and there is neither hornblende nor quartz in the specimens collected, which however hold small portions of magnetite, and minute crystals of amber-yellow sphene. These seem to be contained in veins of segregation, which are of a lighter color than the mass. The cleavable feldspar grains, which make up by far the greater part of the rock, are brilliant, with a vitreous lustre, and are often yellowish or reddish-gray in color. A portion of this feldspar separated by washing from the crushed mass of the rock, had a specific gravity of 2.563, and gave by analysis the result v. Another portion of selected grains of the feldspar gave VI. Both specimens were however somewhat impure.

	v.	VI.
Silica.....	61.10	58.60
Alumina.....	20.10	21.60
Peroxyd of iron.....	2.90	2.88
Lime.....	3.65	5.40
Magnesia.....	.79	1.84
Potash.....	3.54	3.08
Soda.....	5.93	5.51
Volatile.....	.40	.80
	<hr/>	<hr/>
	98.41	99.71

Besides these great trachytic hills, numerous smaller masses of different varieties of trachyte, in the form of dykes and beds, are found along the line of country between Rigaud and Yamaska Mountains. The diorite of the latter is cut into dykes of a white or brownish-gray trachyte, which is often porphyritic, and may be connected the great mass just described.

CHAMBLY.—At Chamby a mass of porphyritic trachyte is intruded in the form of a bed among the strata of the Hudson River formation; and about midway in the Chamby canal a similar trachyte is met with, which contains in drusy cavities, crystals of quartz, calcite, analcime, and chabazite. The base of this rock is of a pale fawn color, and appears at first sight to be micaceous; but on closer examination it is seen to be almost entirely feldspathic. Minute portions of pyrites, and grains of magnetic iron, are rarely met with, and small scales of a dark green micaceous mineral are very sparsely disseminated. The crystals of orthoclase, which are very abundant, are sometimes an inch in length, and one fourth of an inch in thickness: they are

more or less modified, and terminated at both ends. They are easily detached from the rock, and are yellowish and opaque on the exterior, but the inner portions of the large crystals are transparent and vitreous. The composition of the crystals is given under VII. The paste of this porphyry, when carefully freed from crystals, lost by ignition 2.1 per cent. When pulverized and digested with dilute nitric acid, it effervesced slightly, giving off carbonic acid, together with red fumes, arising in part from the oxydation of the pyrites. The portion thus dissolved equalled carbonate of lime 1.76, carbonate of magnesia 0.98, peroxyd of iron with a trace of alumina 2.12 per cent. The residue, dried at 300° F., gave the result VIII.

	VII.	VIII.
Silica	66.15	67.60
Alumina	19.75	18.30
Peroxyd of iron .....	....	1.40
Lime .....	.95	.45
Potash	7.53	5.10
Soda	5.19	5.85
Volatile .....	.55	.25
	<hr/>	<hr/>
	100.12	99.85

The paste of this trachyte thus differs but little from the crystals in composition. It contains only a slight excess of silica, and seems to be made up of lamellæ of orthoclase, mingled with small portions of carbonates of lime and magnesia. A part of the iron also is probably present as carbonate, which, by its decomposition, gives rise to the rusty red color of the weathered surface of the trachyte.

MONTREAL.—The island of Montreal offers a great variety of trachytic rocks, which traverse both the Lower Silurian strata, and the dolerite of Mount Royal. Some of these dykes are finely granular, occasionally crumbling to sand, and frequently are earthy in texture. In some cases they assume a concretionary structure, and they are often porphyritic from the presence of feldspar or hornblende. One variety exhibits large feldspar crystals in a compact purplish or lavender-gray base, with a waxy lustre. This effervesces with acids, from an admixture of earthy carbonates, and closely resembles in its aspect certain trachytes from the Siebengebirge on the Rhine. Other varieties can scarcely be distinguished from the so-called domite, the trachyte of the Puy de Dôme, and exhibit small drusy cavities. The presence of carbonates in tra-

chytic rocks has generally been overlooked; Deville however found seven per cent of carbonate of lime in a trachytic rock from Hungary, and it occurs disseminated in some of the trachytes of the Siebengebirge. Some of the trachytes about to be described contain moreover carbonates of magnesia and protoxyd of iron, and weather to some depth of a reddish-brown color from the peroxydation of the latter, like the trachyte from Chambly just noticed. Acids remove from many of these rocks, in addition to the carbonates, portions of alumina and alkalies. These are derived from a soluble silicate, which in the trachytes of Brome appears only as rare crystals of nepheline, and in Chambly as analcime and chabazite. In some of the compact and earthy varieties about Montreal, however, this soluble silicate exists to a large extent, and has the composition of natrolite. By this admixture of a zeolite the trachytes pass into phonolite.

The first of these trachytes which will be noticed forms a dyke near McGill College. The rock is divided by joints into irregular fragments, whose surfaces are often coated with thin-bladed crystals of an aluminous mineral, apparently zeolitic. Small brilliant crystals of cubic iron-pyrites, often highly modified, are disseminated through the mass. The rock has the hardness of feldspar, and a specific gravity of from 2.617 to 2.632. Its color is white, passing into bluish and grayish-white; it has a feebly shining lustre, and is slightly translucent on the edges, with a compact or finely granular texture, and an uneven sub-conchoidal fracture. Before the blow-pipe it fuses with intumescence into a white enamel. The rock in powder, is attacked even by acetic acid, which removes 0.8 per cent of carbonate of lime, besides 1.5 per cent of alumina and oxyd of iron; the latter apparently derived from a carbonate. Nitric acid dissolves a little more lime, oxydizes the pyrites, and takes up, besides alumina and alkalies, a considerable portion of manganese. This apparently exists in the form of sulphuret, since, while it is soluble in dilute nitric acid, the white portions of the rock afford no trace of manganese before the blow-pipe; although minute dark-colored grains, associated with the pyrites, were found to give an intense manganese reaction. From the residue after the action of the nitric acid, a solution of carbonate of soda removed a portion of silica; and the remainder, dried at 300° F., was free from iron and from manganese. Its analysis is given under IX; while that of the matters dissolved by nitric acid

and carbonate of soda from 100 parts of the rock, will be found under IX A.

A dyke of trachyte near to the last, and very similar to it in appearance, was submitted to the action of nitric acid, but the insoluble residue was not treated by carbonate of soda. Its analysis is given under X, while that of the soluble matters is to be found under X A. A white trachyte from a dyke at Lachine, resembled the preceding, but was somewhat earthy in its aspect, and effervesced with nitric acid, which removed a portion of lime equal to 7.40 per cent of carbonate. On boiling the pulverized rock with nitrate of ammonia, an amount of lime equal to 5.33 per cent of carbonate was dissolved. An accident prevented the complete determination of the alkalis in the feldspathic residue of this trachyte; and the soluble silica was not removed previous to the analysis, whose result is given under XI. The proportion of the potash to the soda was however found to be, by weight, nearly as two to three. The matters dissolved by nitric acid will be found under XI A.

Another dyke of trachyte from Lachine was concretionary, and stained by infiltration; the interior of the concretions was white and earthy. The substances removed from 100 parts of the rock by nitric acid and carbonate of soda, are given under B. A partial analysis of the insoluble residue showed it to be a feldspar allied to those of the preceding trachytes: the quantities of potash and soda were however nearly in the ratio of four to three.

A large dyke of trachyte in the limestone quarries at the Mile End, near Montreal, is remarkable for the amount of carbonates which it contains. It is grayish-white, with dark grey spots, granular, sub-vitreous in lustre, and holds a few crystals of hornblende. By ignition it loses 11.0 per cent. of its weight. In powder it effervesces freely with nitric acid, disengaging carbonic acid, and when heat is applied, red fumes from the peroxydation of the iron. 100 parts of the rock yielded in this way the soluble matters given under XII A. The composition of the residue, from which the soluble silica was not removed, is given under XII.

	IX.	X.	XI.	XII.
Silica,.....	63.25	62.90	58.50	61.62
Alumina,.....	22.12	23.10	24.90	21.00
Lime.....	.56	.45	.45	2.69
Potash,.....	5.92	2.43	....	4.66
Soda.....	6.29	8.69	....	5.35
Volatile.....	.93	1.40	2.10	2.37
	<hr/>	<hr/>	<hr/>	<hr/>
	99.07	98.97		97.69

A second determination of the alkalis in a portion of the trachyte IX, which had not previously been treated by acid, gave potash 5.40 and soda 6.49. A second analysis of X gave potash 2.28, and soda 7.95.

	IX A.	X A.	XI A.	B.	XII A.
Silica,	1.43	....	....	5.00	....
Alumina.....	2.43	....	1.27	1.32	4.84
Peroxyd of iron	2.40	2.84	1.47	2.51	2.63
Lime .....	.60	1.86	4.14	3.50	6.49
Magnesia.....	....	....	1.34	1.35	1.70
Potash, .....	.40	.25	undet.	undet.	undet
Soda.....	.98	.21	"	"	"
Red oxyd of manganese,....	1.31	.87	....	....	....

Of the matters soluble in nitric acid in the last-described trachyte, XII, the lime in the form of carbonate would equal not less than 11.60 per cent, the magnesia 3.58, and the iron 3.82 per cent of carbonates, in which condition by far the greater part of these bases are probably present.

PHONOLITE.

Associated with the numerous trachytic dykes at Lachine is one of the phonolite already referred to. It is brittle and somewhat schistose, breaking into angular fragments, and appears to consist of a reddish fawn-colored base, in which are disseminated greenish-white rounded masses, often grouped, and apparently concretionary in their structure. These greenish portions are sometimes half an inch or more in diameter, and cover from one third to one half of the surfaces. They are not very distinctly seen unless the rock is moistened. The hardness of the different portions does not greatly vary, and is nearly that of apatite. The specific gravity is very low, being only 2.414. The mass contains small cavities filled with carbonate of lime, which is rarely stained purple: it is also found in small films in the joints. The rock is granular in its fracture, without lustre, and is feebly translucent at the edges. When pulverized, and treated with nitric acid of specific gravity 1.25, a slight effervescence ensues, with abundant red fumes. The mass grows warm, and gelatinizes; and on washing out the acid solution, and treating the insoluble portion with a solution of caustic soda, a white granular residue remains. These reactions are obtained both with the fawn-colored and the greenish portions, but the amount of insoluble matter is greater from the

last. The rock is but slightly hygroscopic: a portion of it in powder lost only 0.2 per cent by a prolonged exposure to 212° F., but 7.10 per cent at a red heat.

For the quantitative analysis, the method already indicated was followed. It was found that while a dilute solution of caustic soda removed all of the gelatinous silica separated by the acid, it took up only a trace of alumina; leaving a feldspathic residue which was no longer attacked by nitric acid. The silica was separated from the alkaline liquid, and the acid solution was found to contain, besides alumina and soda, a little potash, some lime, magnesia, and iron, and traces of manganese. The greater part of the lime is evidently present as carbonate; for when a portion of the pulverized phonolite, which gave to nitric acid lime equal to 4.36 per cent of carbonate, was boiled with a solution of nitrate of ammonia, there were dissolved 3.87 per cent of carbonate of lime; besides which there was a separation of a considerable amount of oxyd from the decomposed carbonate of iron. From this reaction, and from the entire absence of sulphur, which was carefully sought for, it is probable that the whole of the iron, except the small portion of peroxyd which colors the rock, exists in the state of carbonate. In the following analyses, therefore, the lime and the iron, as well as a little magnesia, are calculated as carbonates. XIII is the result obtained with four grams of the reddish portion of the phonolite, as free as possible from the green; and XIV was obtained with two and a half grams of a mixture of the two colors.

	XIII.	XIV.
Soluble silicate, zeolite (A), by difference.	46.57	36.16
Insoluble silicate, feldspar (B).....	45.75	55.40
Carbonate of lime.....	3.63	4.36
" iron.....	3.52	3.72
" magnesia.....	.53	.36
	<hr/>	<hr/>
	100.00	100.00

In order to fix the composition of the soluble silicate, the amounts of the insoluble residue and of the separated silica, alumina, and alkalies, having been carefully determined, and the lime, magnesia, and oxyd of iron calculated as carbonates, the water was estimated by the loss. In this way were obtained the results given under XIII A, and XIV A; while the analyses of the insoluble silicate, which is a potash feldspar, are given under XIII B, and XIV B.

	XIII A.	XIV A.	Natrolite.	Analcime.
Silica.....	51.96	51.66	47.40	54.06
Alumina.....	24.42	24.88	26.09	23.20
Soda.....	12.93	13.05	16.02	14.10
Potash.....	1.15	1.28	....	....
Water.....	9.54	9.13	9.05	8.10
	100.00	100.00	100.00	100.00

The composition of this zeolitic mineral is intermediate between analcime and natrolite; but the readiness with which it gelatinizes with acids, leads to the conclusion that it belongs, in great part at least, to natrolite. The theoretical composition of these two zeolites is for the sake of comparison, placed alongside of the two analyses of the soluble portion of the phonolite.

	XIII B.	XIV B.
Silica.....	59.70	60.90
Alumina.....	23.25	24.45
Lime.....	.99	.45
Potash.....	9.16	undet.
Soda.....	2.97	"
Volatile.....	2.23	2.10
	98.30	....

The feldspars of the above trachytes and phonolite offer some considerable variations in their composition, especially in the proportions of the alkalis. In IX the proportions of potash and soda are nearly the same as in the trachytes of Brome, Shefford, and Chambly; and the same is true of XII. These are doubtless to be regarded as varieties of orthoclase with a large amount of soda, while in the feldspar from the phonolite the proportion of soda is very small. In X, on the contrary, the large predominance of soda indicates a composition approaching that of albite. It is further apparent, from a comparison of the feldspars of the other trachytes whose complete analyses are not given, that the proportions of the alkalis are liable to considerable variation, even in adjacent and apparently similar dykes. All of the above feldspars are probably to be referred to orthoclase, or to albite; but these, in the earthy trachytes, have undergone a commencement of decomposition; which consists in the loss of a portion of silica and alkali, and the combination of water, resulting in a formation of kaolin. An admixture of this substance will explain the increased amount of alumina, the deficiency of silica, and the presence of water in the feldspars of the more earthy of these trachytes.

These trachytic dykes are not confined to the vicinity of Montreal. To the southward, on the shores of Lake Champlain, there is found in and about Burlington, Vermont, a vast number of dykes of intrusive rock; some of which appear to intersect the strata of the Quebec group, and others those of the Trenton group. Some of these are described as being of greenstone; and others, as a white or yellowish-white feldspathic rock, often porphyritic from the presence of feldspar crystals. The base of a yellowish-gray porphyritic dyke from Shelburne, having a rough fracture, and a specific gravity of 2.60, gave to Prof. G. F. Barker, silica 67.30, alumina and peroxyd of iron 19.10, lime 0.79, magnesia, traces, potash 4.74, soda 6.04, volatile 1.70, = 99.67. It contained a little intermingled quartz; and the mass resulting from the fusion of the rock with an alkaline carbonate, afforded traces of a sulphuret. (Geology of Vermont, pages 579-707.)

Somewhat to the south of Burlington, on the west side of Lake Champlain, and near to Essex, there is a great mass of intrusive rock, found in the slates of the Hudson River formation. As described by Emmons, it is interstratified in an irregular manner among the layers of the unaltered sedimentary rocks, and has a fissile and schistose structure, which gives, at first sight, the aspect of stratification to what is undoubtedly an intrusive rock. When exposed to the action of the waves on the lake-shore, its structure appears to be columnar, and sometimes concretionary. This rock is described as composed of a reddish or pale leek-green compact feldspar, holding crystals of the same mineral. (Geology of New York, vol ii, page 84.) These intrusive feldspathic rocks on Lake Champlain resemble closely the trachytes of Montreal and Chambly,—with the latter of which, the trachyte of Shelburne, the only one of them which has been chemically examined, closely agrees in composition.

DOLERITES.

The anorthosites, which yet remain to be described, may be divided into two groups,—those composed of anorthic feldspars with augite, constituting the dolerites, and those in which similar feldspars are associated with hornblende. The general geognostical relations of these two groups of rocks in the districts under discussion have already been indicated.

GRENVILLE.—It has already been stated on page 163 that the oldest known intrusive masses which traverse the Laurentian

series are of dolerite, and that the dykes of this rocks are intersected by the syenite, which was succeeded by the orthophyre or quartziferous porphyry. Nothing corresponding to the syenite or the orthophyre is met with among the adjacent Lower Silurian strata, which are seen to repose upon the worn surfaces of these intrusive rocks. A fourth series of dykes of a porphyritic dolerite is however found to cut all of the preceding rocks, and is perhaps identical with some of the dolerites which intersect the Silurian rocks of the island of Montreal. In the other parts of the Laurentian series, so far as yet examined, intrusive rocks have been but seldom met with. Much of what has been called syenite and granite in various parts of the Laurentian region, seems, like the hypersthenite and other anorthosites of the Labrador series, to be indigenous.

The dykes of this most ancient dolerite or greenstone in Grenville, have a well-marked columnar structure at right angles to the plane of the dyke. They are fine grained, dark greenish-gray in color, and weather greyish-white. Under a lens, the rock is seen to consist of a greenish-white feldspar with a scaly fracture, mingled with grains of pyroxene, occasional plates of mica, and grains of pyrites. It contains no carbonates. Two analyses of portions of the dolerite, from dykes differing a little in texture, gave as follows under xv and xvi:

	xv.	xvi.	xvii.
Silica.....	50.35	50.25	52.20
Alumina.....	17.35	} 32.10	} 18.50
Peroxyd of iron.....	12.50		
Lime.....	10.19	9.63	7.34
Magnesia.....	4.92	5.04	4.17
Potash.....	.69	.58	2.14
Soda.....	2.28	2.12	2.41
Volatile.....	.75	1.00	2.50
	99.04	100.72	99.26

The iron in these analyses, although given above as peroxyd, exists in the form of protoxyd, and in the second specimen, in part as a sulphuret. These rocks, which appear to have the composition of mixtures of a basic feldspar with pyroxene, do not differ from ordinary dolerite.

The newer dolerite, which cuts the three other classes of eruptive rocks in the Laurentian region, has a grayish-black, very fine-grained

• With some titanac acid.

base, earthy and sub-conchoidal in fracture, and resembling somewhat the preceding. It contains small brilliant black grains of ilmenite, with others of sphene, and small scales of mica. Occasional masses of black cleavable augite, sometimes half an inch in diameter, give to the rock a porphyritic character. It contains besides, small cleavable masses of white carbonate of lime, with which the whole rock seems penetrated, When in powder, it effervesces freely in the cold with dilute nitric acid, and the solution evolves red fumes on heating. In this way there were dissolved, lime, equal to 8.70 per cent of carbonate, 0.50 of magnesia, and 6.50 of alumina and oxyd of iron = 15.70 per cent. The residue dried at 211° F., equalled 83.80 per cent. A portion of aluminous silicate had evidently been attacked by the acid. The dried residue gave on analysis the results which will be found above under XVII.

The dolerites of the Montreal district, besides forming numerous dykes, constitute the chief portions of the mountains of Montarville, Rougemont, and Mount Royal. In all of these however great diversities of composition are met with, which will be successively noticed.

MONTARVILLE.—The greater part of Montarville is composed of a coarse-grained granitoid dolerite, in which black cleavable augite predominates,—sometimes almost to the exclusion of any other mineral. Small portions of white feldspar, and scales of brown mica, are sparsely scattered through the rock, with grains of carbonate of lime. The removal of these by solution from the weathered surface often gives to it a pitted aspect. In other portions, the feldspathic element predominates, and the rock becomes porphyritic from the presence of large crystals of augite. The worn surfaces of the dolerite sometimes show alternations of this variety with another which is finer-grained and whiter. The two are arranged in bands, whose varying thickness and curving lines suggest the notion that they have been produced by the flow and the partial commingling of two semi-fluid masses.

Another remarkable variety of dolerite, found at Montarville, appears to be confined to a hill on the shore of the little lake about half a mile northward from the manor-house. The whole of this hill, with the exception of some adherent portions of indurated shale, seems to be composed of a granitoid dolerite, containing

a large proportion of olivine. This mineral occurs in rounded crystalline masses or imperfect crystals from one tenth to one half an inch in diameter, associated with a white or greenish-white crystalline feldspar, black augite, a little brown mica, and magnetite.

The proportion of olivine is very variable, but in some parts it is the predominant mineral. Its color is olive-green, passing into amber-yellow. The grains, which are translucent, are much fissured and very brittle. The pulverized olivine gelatinizes with chlorhydric acid in the cold, and is almost instantly decomposed when warmed with sulphuric acid diluted with its volume of water, the silica separating chiefly in a flocculent form, and enclosing small grains of the undecomposed mineral, which are left when the ignited silica is dissolved by a solution of soda. A little silica is however retained in solution, and is precipitated by ammonia with the oxyd of iron. Two analyses of different portions of the olivine made in this way gave, after deducting the undecomposed mineral, the following results:

Silica	37.13	37.17 =	Oxygen	19.82
Magnesia.....	39.36	39.68 =	"	15.87
Protoxyd of iron.....	22.57	22.54 =	"	5.10
	<hr/>	<hr/>		
	99.06	99.39		

The augite of this olivinitic dolerite appears in the form of small crystalline grains, and also in short thick and terminated prisms, which are readily detached from their matrix. They are often an inch in length by half an inch in diameter, and are sometimes partially coated by a film of brown mica. These crystals cleave readily, presenting brilliant surfaces, and are black in color, with an ash-gray streak. Their hardness is 6.0, and their specific gravity

3.34. Analysis gave as follows:

Silica.....	49.40
Alumina	6.70
Lime	21.88
Magnesia.....	13.06
Protoxyd of iron.....	7.83
Soda and traces of potash.....	.74
Volatile.....	.50
	<hr/>
	100.11

The augite which abounds in the non-olivinitic dolerite, that forms the greater part of Montarville, does not appear to differ from that just described.

An average specimen of this olivinitic dolerite, or peridotite, was reduced to powder: it did not effervesce with nitric acid, and when ignited lost only 0.5 per cent. When gently warmed with sulphuric acid, the olivine was readily decomposed, with the separation of flocculent silica; and by the subsequent use of a dilute solution of soda, followed by chlorhydric acid, and a second treatment with the alkaline ley, 55.0 per cent of the whole were dissolved. This portion consisted of silica 37.30, magnesia 33.50, protoxyd of iron 26.20, alumina 3.00 = 100.00: being equal to 18.4 of magnesia for the entire mass. In another experiment, 18.0 per cent were obtained. Taking the mean of the two analyses of olivine above referred to, which gives 39.5 per cent of magnesia, 18.0 parts of this base correspond to 45.5 parts of olivine. The remaining 9.5 parts of dissolved matter represent alumina and silica from the feldspar, and oxyd of iron from the magnetite; both of which were somewhat attacked by the acids. The undissolved portion of the rock equalled 44.7 per cent., and appeared to consist of a feldspar, with pyroxene, some mica, and a little magnetite. Its analysis afforded silica 49.35, alumina 18.92, protoxyd of iron 4.51, lime 18.36, magnesia 6.36, loss (alkalies?) 2.50; = 100.00.

In some portions of the dolerite of Montarville, the feldspar is more abundant, and appears in slender crystals with augite, and with a smaller proportion of olivine than the last. A specimen of this variety, being crushed and washed, gave 3.9 per cent. of magnetite, and 10.0 per cent of a mixture of ilmenite with olivine. The feldspar was obtained nearly pure, in yellowish vitreous grains, having a specific gravity of 2.73—2.74, and nearly the composition of labradorite. The results of its analysis are seen under XVIII.

	XVIII.	XIX.
Silica.....	53.10	53.60
Alumina.....	26.80	24.40
Peroxyd of iron.....	1.35	4.60
Lime.....	11.48	8.62
Magnesia.....	.72	.86
Potash.....	.71	undet.
Soda.....	4.24	"
Volatile.....	.60	.80
	<hr/>	<hr/>
	99.00	....

The dolerite of Montarville is traversed by veins belonging to several different periods. In one instance, the black and highly augitic mass is cut by a dyke of a fine-grained greyish-white dole-

rite. This is intersected by a dyke of a fine-grained greenish rock, which, in its turn, is cut off by another small dyke which is grayish-white like the first.

ROUGEMONT.—The rocks of Rougemont offer a general resemblance to those of Montarville. Some portions are a coarse-grained dolerite, in which augite greatly predominates, with grains of feldspar, and a little disseminated carbonate of lime. In some parts, the augite crystals are an inch or more in diameter, with brilliant cleavages; and grains of pyrites are abundant, with calcite in the interstices. This rock resembles the highly augitic dolerite of Montarville. Olivine is very abundant in two varieties of dolerite from Rougemont. One of these has a grayish-white finely granular feldspathic base, in which are disseminated black augite and amber-colored olivine, the latter sometimes in distinct crystals. The proportions of these elements sometimes vary in the same specimen; the feldspar forming more than half the mass in one part, while in another the augite and olivine predominate. By the action of the weather, the feldspar acquires an opaque white surface, upon which the black shining augite and the rusty-red decomposing olivine appear in strong contrast.

The dolerite of this mountain is traversed by numerous dykes, some of which are diorites like those of Monnoir and Belœil, about to be described. A dyke of compact dolerite, holding crystals of feldspar and grains of olivine, is found intersecting the strata of the Hudson River formation at St. Hyacinthe.

MOUNT ROYAL.—This hill which rises immediately in the rear of Montreal, consists for the most part of a mass of highly augitic dolerite. In some parts large crystals of augite, like those of Montarville, are disseminated through a fine-grained base, which is dark ash-gray in color, and often effervesces freely with acids, from the presence of a portion of intermingled carbonate of lime. At other times this is wanting, and the rock is a mass of black crystalline augite, constituting a veritable pyroxenite, from which feldspar is absent. Mixtures of augite with feldspar are also met with, constituting a granitoid dolerite, in parts of which the feldspar predominates, giving rise to a light grayish rock. Portions of this are sometimes found limited on either side by bands of nearly pure black pyroxenite, giving at first sight an aspect of stratification. The bands of these two varieties are found curiously contorted and interrupted, and as at Montarville, seem to have resulted from

movements in a heterogeneous pasty mass, which have effected a partial blending of an augitic magma with another more feldspathic in its nature.

The more augitic parts of Mount Royal contain, like the similar varieties from Rougemont and Montarville, considerable portions of magnetite, and some ilmenite. At the east end of the mountain a variety of dolerite, containing olivine, occurs. It consists of a base of grayish-white granular feldspar, which in the specimen examined constitutes about one half of the mass, and encloses crystals of brilliant black augite, and of semi-transparent amber-yellow olivine. This rock closely resembles the feldspathic peridotite of Rougemont, described above; but the imbedded crystals are somewhat larger, although less than those in the dolerite of Montarville. A portion of the feldspar, freed as much as possible from augite, furnished by analysis the result already given under XIX; which shows that it approaches labradorite in composition.

DIORITES.

YAMASKA.—It now remains to describe the diorites which have already been noticed as forming several important masses among the intrusive rocks of the Montreal group. In the first place may be considered that of Yamaska. The greater part of this mountain consists, as already described, of a micaceous granitoid trachyte; but the southeastern portion is entirely different, being a diorite made up of a pearly white crystalline translucent feldspar, with black brilliant hornblende, ilmenite, and magnetic iron. This rock is sometimes rather fine-grained, though the elements are always very distinct to the naked eye. In other parts are seen large cleavage-surfaces of feldspar half an inch in breadth, which exhibit in a very beautiful manner the striæ characteristic of the polysynthetic macles of the triclinic feldspars. The associated crystals of hornblende are always much smaller and less distinct, forming with grains of feldspar, a base, to which the larger feldspar crystals give a porphyritic aspect. Finer-grained bands, in which magnetite and ilmenite predominate, traverse the coarser portions, often reticulating; and the whole mass is also occasionally cut by dykes of a whitish or brownish-gray trachytic rock, which are often porphyritic, and may perhaps be branches from the trachytic part of the mountain.

A portion of the coarse-grained diorite selected for examination,

contained, besides the minerals already enumerated, small portions of blackish mica, with grains of pyrites, and a little disseminated carbonate of lime, which caused the mass to effervesce slightly with nitric acid. The macled feldspar crystals, sometimes half an inch in length, were so much penetrated by hornblende that they were not fit for analysis; but by crushing and washing the rock, a portion of the feldspar was obtained, which did not effervesce with nitric acid, and contained no visible impurity, except a few scales of mica; its specific gravity was 2.756—2.763. It was decomposed by hydrochloric acid, with separation of pulverulent silica; and its analysis, which is given under XX and XXI, shows it to be near to anorthite, and identical in composition with the feldspar of a diorite from Bogoslowsk, in the Ural Mountains. This is associated with a greenish-black hornblende containing some titanitic acid, with a little mica, and some quartz. (R. H. Scott, L. E. and D. Philos. Magazine [4], xv, 518.)

MONNOIR.—Monnoir or Mount Johnson is composed of a diorite, which, in its general aspect, greatly resembles that of Yamaska just described, except that it is rather more feldspathic. The finer-grained varieties are grayish in color, and exhibit a mixture of grains and small crystals of feldspar, with hornblende, brown mica, and magnetite. Frequently however the rock is much coarser-grained, consisting of feldspar grains, with slender prisms of black hornblende, often half an inch long and tenth of an inch broad, and numerous small crystals of amber-colored sphene. In this aggregate there are imbedded cleavable masses of the feldspar, sometimes an inch long by half an inch in breadth. At the southern foot of the mountain, large blocks of the coarse-grained diorite are found in a state of disintegration, affording detached crystals of feldspar with rounded angles, and weathered externally to an opaque white, from a partial decomposition. Near to the base of the mountain, a coarse-grained variety of the diorite encloses small but distinct crystals of brown mica; and a fine-grained micaceous variety, containing sphene, occurs near the summit.

The feldspar, in all the specimens examined from this mountain, appears to be uniform in character. Its color is white, rarely greenish or grayish; it has a vitreous lustre, inclining to pearly, and it is somewhat translucent. The cleavages of this feldspar resemble those of oligoclase, with which species it also agrees in specific gravity and chemical composition. The macled forms, so

common in the crystals of triclinic feldspars, have not however been detected in the specimens from this locality. A fragment of a crystal gave a density of 2.631, and another portion in powder, 2.659. The results of its analysis are given under XXII and XXIII.

	XX.	XXI.	XXII.	XXIII.	XXIV.
Silica.....	46.90	47.00	62.05	62.10	58.30
Alumina.....	31.10	} 32.65	22.60	....	} 24.72
Peroxyd of iron.....	1.35		.75	....
Lime.....	16.07	15.90	3.96	3.69	5.42
Magnesia.....	.65	....	....	....	.91
Potash.....	.58	....	1.80	....	2.74
Soda.....	1.77	....	7.95	....	6.73
Volatile.....	1.00	....	.80	....	.50
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	99.42	....	99.91	....	99.32

BELCÆIL.—The specimens which have been examined from this mountain consist of a kind of micaceous diorite. The feldspar, which so far predominates as to give a light gray color to the mass, is in white translucent vitreous cleavable grains; associated with small distinct prisms of black hornblende, scales of copper-colored mica, and grains of magnetite. The analysis of the feldspar, extracted by washing a portion of the crushed rock, and still containing a little mica, is given above under XXIV. This result approaches to those obtained from the micaceous feldspar rock of Yamaska, V and VI; which has been described as a kind of trachyte, and with the rock of Belcœil seems to constitute a passage between the trachytes and diorites.

RIGAUD.—A portion of Rigaud Mountain consists of a rather coarse-grained diorite, which is made up of a crystalline feldspar, white or greenish in color, with small prisms of brilliant black hornblende, and crystals of black mica. In some specimens the feldspar, and in others the hornblende predominates. This rock resembles the diorites of Belcœil and Monnoir.

The granitoid dolerites of the Montreal group, containing coarsely crystalline augite and olivine, break through the Lower Silurian strata; and portions of these two minerals, probably derived from these intrusive rocks, are found in the dolomitic conglomerates near Montreal, which in some cases include masses of Upper Silurian limestone, and are cut by dykes of a fine grained dolerite. These, which perhaps correspond to the newer dykes of the same rock at Grenville, show that there were at least three distinct

eruptions of dolerite,—one during the Silurian period, one before it, and another after it. The trachytes of Montreal and Chambly appear to be still more recent than these, and to traverse the newest dolerites.

The trachytes of Brome and Shefford seem to constitute a group apart; but the diorites of Yamaska and Mount Johnson, although similar in aspect, differ widely in chemical composition. Facts are still wanting to establish the geological age of these intrusive masses. The different dolerites, which are related in mineral composition, belong as we have seen to different geological periods; and it would not be safe to affirm that the different diorites or the different trachytes of this vicinity are contemporaneous. Nor, on the other hand, should even great discordances in chemical or mineralogical constitution be necessarily regarded as establishing a difference in the age of eruptive rocks. Evidence to the contrary of this is seen in the contiguous and intermingled masses of black pyroxenite and grey feldspathic dolerite in Mount Royal and Montarville; and it is not improbable that the olivinitic dolerite which is associated with these, may be contemporaneous. If, as has been maintained in the first part of this paper, the various intrusive rocks are only displaced sediments of deeply-buried and probably unconformable strata, it will readily be conceived that plastic masses of very unlike characters may be ejected simultaneously along a line of disruption.

The various intrusive masses of the Montreal group which have been here described, appear, from their compact and crystalline structure, to have been displaced and consolidated under the pressure of a considerable mass of superincumbent strata. The fact that even their summits, which are in some cases more than 1000 feet above the present level of the plain, appear equally solid and crystalline with their bases, implies the removal by denudation, since the eruption of these masses, of a thickness of sedimentary strata much exceeding their present height. This denudation must however have taken place before the eruption of the later trachytes and dolerites; since the dolomitic conglomerates, which enclose the fragments of the olivinitic dolerite and of Lower and Upper Silurian rocks, repose unconformably upon the Laurentian and the various Lower Silurian strata, in such a manner as to show that these offered nearly their present distribution at the epoch of the deposition of the conglomerates. If then, as is

probable, the exposure by denudation of the whole of the eight hills which have been described, took place at one epoch, these are all shown to have a greater antiquity than the trachytes and the dolerites, which traverse the conglomerates. The fine-grained and earthy trachytes of Montreal are consequently far more recent than the crystalline ones of Brome and Shefford; with which however, some of them agree in chemical composition.

The general absence of granite from among these intrusive masses is a fact worthy of notice. Quartz has not yet been detected in the feldspathic rocks of Brome and Shefford; although, as above mentioned, the base of the feldspathic porphyries of Chambly, and Shelburne, contains a slight excess of silica. The granitic rocks of Shipton, and of St. Joseph on the Chaudière, appear to be indigenous masses, belonging to the strata of the Quebec group; but the higher fossiliferous formations to the east of the Notre Dame Mountains, are traversed in various places by veins and great masses of intrusive granite, as in Stanstead, Barford, and many other places to the northeast, and along the frontier of Canada. It is worthy of note, that the intrusive masses on the two sides of the mountain range are, so far as yet observed, entirely distinct in character; and that eruptive rocks are generally wanting among the Notre Dame Mountains, which consist chiefly of stratified rocks. It is also to be remarked, that the intrusive granites at their eastern base, are not unlike, in mineralogical characters, to the indigenous granites of the mountains; thus suggesting the view that these are possibly the source of the intrusive granites which break through the Devonian strata. A similar relation has been pointed out by Durocher, in Scandinavia, where the palæozoic strata are broken by intrusive masses of granite, orthophyre, zircon-syenite, and diorite. These rocks, according to him, are specifically analogous to those of the underlying primitive gneiss, but petrographically distinct. (*Bull. Soc. Géol. de France*, [2], vi. 33.) These facts are in accordance with the theory of eruptive rocks developed at the commencement of this paper; and it would be easy to extend the comparison to the intrusive diorites and dolerites about Montreal, and to show their resemblance with the stratified feldspathic rocks of the Labrador series. (*Silliman's Journal* [2], xxix, 283, and xxxi, 414.)

IV. LOCAL METAMORPHISM.

In the second part of this paper I have asserted that the silicated minerals of crystalline rocks have a two-fold origin. In the first place they may result from the molecular change of silicated sediments. These are either derived from the mechanical disintegration and partial decomposition of pre-existing silicates, or have been generated by chemical processes in waters at the earth's surface. In this way steatite, serpentine, pyroxene, hornblende, chlorite, and in many cases garnet, epidote, and other silicates, are formed by a crystallization and molecular re-arrangement of chemically formed silicates, in a manner analogous to that in which mechanically derived clays are converted into crystalline species. I have however pointed out that in the second place many of these silicated minerals may be generated by chemical reactions which take place among the mechanically mixed elements of sediments under the influence of heat aided by alkaline solutions. Both of these methods are involved in rock-metamorphism; and in the case of the local alteration of rocks by igneous masses, it is easy by comparative examinations to trace the chemical changes involved in the production of silicated minerals by the second method. In this way Delesse has shown that in several cases where the chalk of Ireland has been altered by the proximity of intrusive traps, the sand and clay which the former contain have been converted into calcareous silicates. (*Ann. des Mines* [5], xii, pp. 189, 208, 212.)

An instructive example of this process is furnished at Montreal, where the bluish fossiliferous limestone of the Trenton group is traversed by dykes of dolerite, which are subordinate to the great intrusive mass of Mount Royal. The limestone for a distance of a foot or two, is hardened, but retains its bluish tint. Within a few inches, it is changed to a greenish-white color, which is seen to be due to a granular mineral disseminated in the white carbonate of lime. The unaltered limestones from the vicinity contain variable amounts of insoluble argillaceous matters. A specimen treated with dilute hydrochloric acid, left a residue of about twelve per cent of a fine clayey substance, colored by a small amount of carbonaceous matter, and mixed with a little pyrites, which was removed by dilute nitric acid. This residue, after ignition, gave to a solution of carbonate of soda, 95 per cent of its weight of soluble silica; and the insoluble portion, being sub-

mitted to analysis, gave the result I. A portion of the limestone which was near to the intrusive rock, and had become hardened and partially altered, was subjected to the action of dilute nitric acid, and gave an insoluble residue with the composition II. The more thoroughly altered greenish limestone was also treated with dilute nitric acid, which dissolved the carbonate of lime, and left a residue, the analyses of which, from two different portions of the rock, are given under III and IV.

	I.	II.	III.	IV.
Silica,.....	73.02	54.00	42.60	40.20
Alumina,.....	18.31	14.00	13.70	9.30
Lime,.....	.93	16.24	31.69	36.40
Magnesia,.....	.87	5.27	4.17	3.70
Protoxyd of iron,.....	traces	3.60	4.68	5.22
Potash,.....	5.55	3.14	undet.	undet.
Soda,.....	.89	1.22	"	"
Volatile,.....	....	.90	1.20	1.20
	<u>99.57</u>	<u>98.77</u>	<u>98.04</u>	<u>95.02</u>

The residue from the unaltered limestone, including the silica soluble in alkalis, contains nearly 75.5 hundredths of silica, and 16.5 of alumina. These, in the vicinity of the dolerite, have become saturated with protoxyd bases, including the small portions of magnesia and of oxyd of iron which the limestone contains. This process evidently involves a decomposition of the carbonate of lime, and the expulsion of the carbonic acid. It is worthy of remark that while the unaltered limestone contains a little carbonate of magnesia, the rock from which III was obtained yielded to dilute nitric acid not a trace of magnesia. II marks an intermediate stage in the process, and shows moreover that the alkalis are still retained in combination with the aluminous silicate. These granular silicates, which have been formed by local metamorphism, might, under favorable circumstances, have crystallized in the forms of feldspar, scapolite, garnet, pyroxene, or some other of the silicious minerals which so often occur in metamorphic limestones. The agent in producing these silicates of protoxyds at the expense of the carbonates of the limestone, was probably a portion of alkaline salt, either derived from the feldspathic matter of the limestone, or possibly infiltrated from the contiguous feldspathic rock; whose elevated temperature produced the reaction which has resulted in thus altering this limestone.

Similar examples of local alteration are met with in several other places near to the intrusive rocks of the Montreal group. The

schists of the Utica formation in contact with a dyke of intrusive rock at Point St. Charles, and also near a mass of trachyte on a small island opposite the city of Montreal, occasionally exhibit small crystals of pyroxene, and in some cases prisms of hornblende. Among similarly altered shales at Rougemont are beds which consist of a highly ferriferous crystalline dolomite intermingled with dark-green cleavable hornblende, which forms thin layers, or in other cases encloses small rounded masses of the dolomite. (See for a description and analyses of this rock the *Geology of Canada*, page 634.)

At Montarville the shales of the Hudson River formation are altered in the vicinity of the dolerite which forms the mass of the mountain. Some portions of the strata are very fine-grained, reddish-brown, and have an earthy sub-conchoidal fracture, with occasional cleavage joints. The hardness of this rock is not great, and it is apparently a kind of argillite; but between two beds of it is one of a harder coarse-grained rock, greenish-gray in color, and mottled with a lighter hue. This appears to be feldspathic in composition, and is penetrated in various directions by numerous slender prisms of black cleavable pyroxene, sometimes half an inch in length. The layers of sedimentation are distinctly marked in this bed, as well as in the finer-grained strata which enclose it, and the whole affords an interesting example of the different effects of the same agency upon beds of unlike composition; although it would be impossible without comparative chemical analyses to determine whether the silicate which has here crystallized in the form of pyroxene existed in the unaltered sediment, or whether, as in the case of the uncrystallized silicate from the altered limestone at Montreal, it has been generated under the influence of the intrusive rock. In by far the greater number of cases, the only apparent effect of the igneous rocks in the region under description upon the palæozoic limestones and shales, has been a very local induration. The appearance of crystals in these circumstances is a comparatively rare occurrence, and seems to depend upon conditions which are exceptional, showing, as I have elsewhere remarked, that heat and moisture are not the only condition of metamorphism. (*Silliman's Journal* [2], xxxvi, 219.)

With these few examples of local metamorphism I conclude the present paper; proposing however to give in a subsequent one the results of some investigations of certain indigenous crystalline rocks.

Montreal, March 15, 1864.