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THE

GEOLOGY OF ASCUTNEY MOUNTAIN, VERMONT

BY

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THE GEOLOGY OF ASCUTNEY MOUNTAIN, VERMONT.

By R. A. Daly.

INTRODUCTION.

Nature of the investigation.—The following pages embody the results of an investigation of the lithology and geology of a plexus of eruptive rocks and of the metamorphic aureole in schistose rocks surrounding the igneous bodies. The field work was begun in 1893, but numerous interruptions prevented the completion of the study until the present year. In the meantime an elaborate series of chemical analyses was made by Dr. Hillebrand (in 1896) and the results were published on pages 68–70 of Bulletin 148 of the United States Geological Survey. These analyses are here republished, with the oxides arranged in the order recommended by Dr. H. S. Washington.[a]

Acknowledgments.—The writer's best thanks are due to Dr. Hillebrand, for the completeness and accuracy of his analyses; to Prof. J. E. Wolff, of Harvard University, who not only suggested this piece of research, but also greatly assisted in the petrographical determinations; to Professor Rosenbusch, of Heidelberg, who likewise aided in the laboratory study of the collected material; to Dr. F. P. Gulliver, for the care he bestowed on the preparation of the topographical map; and especially to Dr. T. A. Jaggar, of Harvard University, who, after carrying on several weeks' field work in the area in collaboration, placed his notes and rock collection at the disposal of the writer. In addition, Dr. Jaggar has done much in the microscopic investigation of the specimens and in preparing the photographic illustrations for this report. He has also read the manuscript, which has been improved both in form and contents by his valuable suggestions.

[a] Am. Jour. Sci., 4th series, Vol. X, 1900, p. 59.

CHAPTER I.

PHYSICAL GEOGRAPHY.

GENERAL TOPOGRAPHY OF THE AREA.

Mount Ascutney is the most conspicuous elevation seen by the traveler in ascending the Connecticut River (see Pl. I, *A*). The mountain, as well as the rest of the area considered in this paper, is situated on the right bank of the river and near the town of Windsor, in southeastern Vermont. Though having an elevation of little more than 3,000 feet (915 meters) above sea level, Ascutney is very prominent as it rises from the floor of the deeply trenched master valley of New England. The railway bridge over the Connecticut at Windsor is but 301 feet (92 meters) above sea level; the summit of the mountain is, according to Dr. Gulliver's determination, 3,114 feet (950 meters) above the same datum[a] and lies only 3 miles from the river (see Pl. I, *B*). Thus the mountain is considerably more imposing than many other peaks in New England, which, although of the same or even greater height, yet rise from a more elevated base. Additional scenic importance attaches to Ascutney on account of its isolated position. Among the nearer noteworthy elevations are Ludlow and Shrewsbury mountains and Killington Peaks of the Green Mountain Range; accordingly, for a distance of 20 miles in every direction, the beautifully compact, broadly conical outline of Ascutney forms a principal feature of the landscape. Largely for this reason the mountain enjoys a special reputation for beauty among the inhabitants and tourists of New England.

The conditions for field work are good except in some parts of the main mountain, where thick second-growth timber effectually conceals the eruptive rocks. Two good paths to the summit, one from Brownsville, the other from the Windsor side, were open in 1898. The mountain can, however, be easily climbed from any direction.

The softened profiles of the mountain suggest, and a study of the geological structure of the region proves, that Ascutney is a residual of erosion (see Pl. VII). It has been carved out of this part of the once lofty Appalachian mountain system where the sedimentary rocks of the range have been intruded by several stocks and thick dikes of igneous rock. The relief features of the area discussed thus belong to the same category as the very common sugarloaf peaks of Vermont,

[a] C. H. Hitchcock estimated the height to be "about 3,168 feet:" Geology of New Hampshire, Vol. I, 1877, p. 180.

located on intrusive granites and syenites. The geological map (Pl. VII) indicates in an almost diagrammatic fashion the sympathy between relief and rock composition. Ascutney itself owes its existence primarily to a great stock of quartz-syenite. The picturesque ridge of Little Ascutney is held up by a strong rib of intrusive syenite-porphyry associated with other eruptives more resistant to the weather than either the gabbro-diorite stock on the north or the gneisses on the south. The shapely cone north of Little Ascutney, which, for purposes of convenience in this report, has been named "Pierson Peak" (after the hospitable owner of the farm at the base of the hill), is strictly controlled in form by a small elliptical stock of alkaline syenite cutting the softer diorites.

Apart from other more general considerations, the fact that these eruptive rocks are more resistant to weather than the surrounding schists is clear from the nature of the slopes and profiles at the contacts. As a rule there is an abrupt steepening of the ascent along the radiating spurs of the main mountain just above the contact between the sedimentary and eruptive rocks. At the same line of contact there is likewise a sudden change of gradient in the streams draining the mountain, as if corrasion were considerably easier on the schists than on the eruptive rocks. An example is seen at the beautiful "Crystal Cascade" on the southwest side of the main mountain. This general feature of the residuals of erosion in our area may be repeatedly and clearly seen in the granitic hills of New England and might serve to dispel any doubts which remain in the minds of those students of erosion who are skeptical as to the prevailing theory of New England reliefs, for it is doubtless true that the most illuminating treatment of New England topography finds best explanatian for its mountains and higher hills in the assumption of the superior strength of their component rocks—a strength, namely, superior to that of the rock masses immediately surrounding. In a score or two of instances in Vermont and New Hampshire striking differences of relief are faithfully associated with equally striking differences of lithologic composition. Plutonic eruptives compose the mountains and generally weak schists underlie the encircling lowlands. In these examples the greater height of the hills can scarcely be due to more pronounced initial uplift during the original mountain building. When, on the other hand, differential erosion is so clear for granitic mountains like Ascutney, it seems legitimate to extend the idea to many New England residuals of schistose composition, where, as yet, full corroborative evidence as to the validity of the same assumption is not obtainable.

The view that the rocks of the classic monadnock in New Hampshire are harder than the somewhat similar rocks about that mountain certainly wins most credibility from the general agreement of that assumption with the most fruitful explanation of the New England peneplain; but it would be a matter of considerable satisfaction to those who have to deal in theories of land sculpture if detailed petrographic and field studies of the schist monadnocks were made with intent to test the theory of differential hardness. Perhaps a microscopic study of similarly exposed monadnock rocks and lowland rocks would enable the investigator to ascertain the amount of post-Glacial weathering which has occurred. If quantitative estimates were likewise made as to the influence of jointage, rifting, cleavage, etc., the result should be to give a more scientific basis for the discussion of the residuals of erosion than now exists. In a rough way an analogous but incomplete study of the rocks of this area has sustained the monadnock theory of the origin of Ascutney and Little Ascutney. This theory, to be sure, here scarcely needs other substantiation than the facts of composition, structure, and present relief.

DRAINAGE.

The Connecticut River flows along a belt of soft rocks parallel to their strike, and is thus a typical longitudinal valley. In no part of its course is it more clearly "adjusted" to a relatively weak zone than on the "Calciferous mica-schist" eastward of the mountain. Similarly Mill Brook follows the strike of the rocks in that gorge-like part of its course between the elbow south-southeast of Windsor and its confluence with the Connecticut. Elsewhere Mill Brook, like the stream entering the main river near Ascutneyville, belongs to the class of "superposed" streams, having sunk its channel irregularly through drift and terrace sands into the underlying schists. Short but broad valleys, located partly on schists, partly on the comparatively soft diorite, separate Little Ascutney and Ascutney Mountain proper. These valleys are also adjusted to weak zones in the rocks, and belong to the now well-recognized class of "subsequent" valleys.

But it is not easy to place the radiating drainage of the main mountain in the accepted classification of stream courses. There is nothing to show that the eruptives of the area ever reached the surface to form volcanic flows or cones; they seem rather to have consolidated in the form of a complex stock-like boss. The structure of the region shows that the radiating drainage is not the result of inheritance from the surface of a dome in the overlying schists, in which a different pattern of drainage would have predominated, namely, a more or less rectangular network of stream courses. Such a dome would not likely be able to alter seriously the directions of the streams originating either in the folding of the schists or in the process by which newer valleys would be worn out on weak belts parallel to the strike. These radiating streams can not, thus, be regarded as "superposed" through the schist blanket once overlying the stocks.

There is here, in fact, a kind of drainage which is controlled in its development by constructional processes fundamentally different from those usually considered in a systematic discussion of streams. Folding, faulting, and glacial and volcanic accumulation are examples of processes leading to the formation of surfaces which are, in the initial stage, exposed to erosion. But there is a kind of subterranean construction to be found in the intrusion of large bodies of igneous rock, which may, in the course of time, affect the relief and drainage of a region much more conspicuously than the processes just mentioned. The uncovering, by erosion, of a boss of igneous material harder than the surrounding rock formations will necessitate either the true "superposition" of streams in the manner just suggested, but excluded, for good reasons, in the Ascutney instance, or the formation of new ones divergent, roughly speaking, from the center of the boss toward the lowlands of the less resistant formations. These latter streams are logically consequent on the intrusion and, to a greater or less extent, consequent in length and direction on the original contours and ground plan of the irruptive body. This may be true in a large way whatever the details of form in the upper surface of the igneous mass. Whether it be a regular boss with smooth profiles, or one irregularly terminated by apophyses into the overlying rock, the superior hardness of the intrusive will, in the end, tend to cause its projection, as a whole, above the soft-rock terrane; so that there will be brought about an approximation to the average original profile of the boss. There must in any case originate on its revealed surface a number of streams divergent from the central region of the boss and flowing toward the surrounding lower land.

Such streams are seen to be analogous to those which drain the retreating escarpments of tilted stratified beds—the class of "obsequent" streams as defined by Professor Davis. Obsequent streams drain the scarped front of a hard member of the stratified series and are the result of the excavation of lowlands by the lengthening and widening of valleys in an underlying softer formation. The radial drainage here considered is similarly caused by the removal of rock material less resistant to the weather than the intrusive igneous rock. At the same time, that removal means the origination of drainage "adjusted" to the soft encircling formation. The adjustment is here circumferential and centrifugal with reference to the middle point of the intrusive body, not longitudinal (parallel to the strike of a bedded formation), as in the case of those "subsequent" streams into which "obsequents" pour their waters.

The radial drainage of Ascutney is thus believed to owe its origin to the degradation of the encircling schists—a centrifugal control due to differential hardness. Located on a hard member, they are to be associated with obsequent drainage, and share with obsequent and subsequent drainage the characteristic of appearing only relatively late in the whole geographical cycle of degradation. They are also conditioned by the original form of the intrusive, and are thus consequent. To express their composite nature they may be called *subconsequent*, using a term which was first proposed by Professor Davis for what are generally coming to be called "subsequent" streams. His abandonment of the longer for the shorter term, which was independently invented by him and by Jukes, leaves "subconsequent" open to the special use to which we propose to attach it. The prefix "sub" is especially appropriate, as it serves to indicate the necessary lack of absolute and exact control possessed by the constructional form of the intruded body over the trend of this class of streams even where they run over the igneous rock. That control will, to some extent, be imperfect on account of a variety of circumstances connected with the removal of the cover and the apophyses penetrating the cover. While subconsequent drainage is always divergent, it may be radial or elliptical where the intrusive has a circular or elliptical ground plan; or bilateral, as in the case of many batholiths and great dike-like intrusions; or, finally, irregularly divergent.

GLACIATION OF MOUNT ASCUTNEY.

The similarity of form between Mount Ascutney and other residuals in the glaciated tract of New England, on the one hand, and the residuals of Georgia and the Carolinas on the other, particularly in respect to the systems of radiating drainage seen on all slopes of the northern mountains, is suggestive of the fact, which seems borne out by many others, that glacial erosion has very slightly affected the shape of these greater reliefs of New England. The accumulating evidence of intense glacial erosion in alpine valleys, whereby hundreds or even thousands of feet of fresh rock have been quarried away by master glaciers from their rock floors, recalls the question, raised oftentimes a generation ago, as to how much material was disturbed by the great Pleistocene glaciers of North America. The answer seems again to be unequivocal that such erosive work as that carried on during Pleistocene times in the Norwegian fiords, for example, was not paralleled in New England. If it had been, we should expect Mount Ascutney, once entirely overridden by ice, to possess a somewhat definite stoss-and-lee form and to have suffered a serious change in its drainage. The radiating ravines are so deep and contain such clear evidences of glaciation in their bottoms that they can not be ascribed to post-Glacial erosion. They have not the appearance of cirques, and hence can not be ascribed to the work of local glaciers, for which, indeed, on so small a mountain, the required gathering ground is lacking. These ravines and water courses must be pre-Glacial. This being the case, the conclusion lies near to hand that the Labrador ice sheet did not approach in erosive activity the local glaciers of Switzerland, Norway, Labrador, or Alaska. The northwest, north, and northeast slopes of Ascutney would have borne the brunt of the glacial attack and perhaps suffered a more vigorous onslaught than the lowlands on account of the projection of the mountain above the general glaciated floor, but these slopes on the stoss side are as well provided with the usual radiating stream courses as those on the south. It is highly improbable that such symmetry would persist if the Ascutney cone had been seriously affected in volume by the glacier. The same patent observation can be and has been made in many parts of northeastern America where the appropriate reliefs occur, but it is worthy of restatement in order to point out once again the mysterious contrast between the excavating power of present and past valley glaciers and of the incomparably greater Pleistocene ice caps.

The mantle of glacial drift in the area discussed is much interrupted and, in general, quite thin, so that outcrops of the bed rock are numerous. The fine terraces of the Connecticut and of Mill Brook cover some of the "Calciferous mica-schist" (Pl. I, *B*). The highest of these is 216 feet (66 meters) above low-water level of the river at Windsor. It was used by J. D. Dana as important evidence of the height to which the flooded Connecticut extended its banks in Champlain times.[a] The gneisses of the southwest portion of the area are blanketed over with the alluvium of the brook at Greenbush.

SUMMARY.

Mount Ascutney, like most of the mountains of New England, is a residual of erosion, a monadnock overlooking a dissected, rolling plateau. The relief as a whole and in its details is controlled by rock composition in a specially definite manner. Proofs of differential hardness are evident in the present topography, intrusive bodies contrasting in this respect with one another and with the adjacent schists. The drainage of the area is that of an ancient mountain system. There is clear adjustment of the streamways to soft structures, giving "longitudinal subsequent" streams and radially divergent "subconsequents." The latter occur on the main intrusive rock body, which dominates all the others through its superior strength against weathering influences and through its relatively greater volume. The discussion of this mountain, which is but one of a numerous family found in eastern North America, emphasizes once more the need of recognizing deep-seated intrusion as a constructive process no less important for certain regions than the faulting, folding, or some other initiating deformation of the earth's surface which begins a new cycle of erosion. The history of the Ascutney topography, including its drainage, begins logically and chronologically with the date of the intrusion of the Main syenite stock. The existing subconical form and the radiating stream courses of the mountain may be said to be "subconsequent" upon that constructional process of intrusion.

The general form of Ascutney was not essentially affected by the Pleistocene glaciation. A veneer of pre-Glacial weathered rock was removed and the rounding of minor points accomplished by the ice invasion, but the pre-Glacial Ascutney had practically the form of the present mountain.

[a] Am. Jour. Sci., 3d series, Vol. XXIII, 1882, p. 183.

CHAPTER II.

GENERAL DESCRIPTION OF THE SCHISTS IN THE AREA.

The fundamental rocks through which the eruptions took place naturally first demand attention. The following account of them will, however, be brief, as befits the main purpose of this paper. They consist of two conformable members, a phyllitic and a gneissic.

PHYLLITIC SERIES.

The numerous specimens collected from the phyllite indicate a tolerable uniformity in the lithological character of that rock throughout its whole extent in the neighborhood of Mount Ascutney. It is composed essentially of quartz, sericite (often partially replaced by biotite), argillaceous, chloritic, and carbonaceous material, accompanied by notable amounts of iron sulphides and titaniferous iron ore (Pl. II, *A*). Rare crystals of orthoclase and of a triclinic feldspar, equally rare grains of epidote, and perfect, minute crystals of rutile and of titanite are sporadically developed. The quartz forms interlocking grains between the sericite fibers and layers which produce the marked lamination of the rock. Straining in the quartz is at times notable and seems to be correlated with microscopic faulting in the rock as a whole. Along these incipient fault planes a further development of sericite has taken place, thus giving the rock the wavy appearance characteristic of strain-slip cleavage (Pl. II, *B*). Good examples of this phenomenon are to be found in the quarry beside Mill Pond near Windsor. Lenses and laminæ of milky quartz are very abundant and have sometimes shared in the crumbling of the phyllite, though generally they seem to have been formed posterior to its folding.

Very often through the series the argillaceous material is nearly or quite absent and we have a simple quartz-sericite-schist. An exceptionally fresh specimen of this phase, collected in the low cliffs just west of Ascutneyville (spec. 24), has been analyzed (Table I, p. 15.) It is practically a quartzite, which bears, in addition to the other essential constituent, sericite, very small amounts of orthoclase, an undetermined plagioclase, epidote, ilmenite, rutile, titanite, and a little pyrite, with probably pyrrhotite.

TABLE I.—*Analysis of quartz-sericite-schist (specimen 24) from cliffs west of Ascutneyville.*

	Per cent.
SiO_2	90.91
Al_2O_3	4.18
Fe_2O_3	0.22
FeO	1.27
MgO	0.37
CaO	0.22
Na_2O	0.77
K_2O	0.58
H_2O above 110° C.	0.74
H_2O below 110° C.	0.06
CO_2	0.18
TiO_2	0.28
ZrO_2	0.02
P_2O_5	0.05
Cl	Trace.
F	Trace.
FeS_2 and Fe_7S_8	[a] 0.11
MnO	Faint trace.
BaO	Trace.
Li_2O	Strong trace.
C	[b] 0.10
	100.06
Total S	0.056
Sp. gr	2.678

The phyllites outcrop on the edge of the upper terrace of the Connecticut River with a strike of N. 5° E. and an average dip of 50° E. (Pl. VII.)

The planes of foliation here and all across the series to the gneissic area are regarded as very closely coincident with the original bedding. Many beds of limestone from 3 inches to 2 feet (8 to 60 centimeters) in thickness are intercalated in the phyllites and are always, so far as observed, conformable with their foliation planes. C. H. Hitchcock used the foliation as expressive of true stratification and has remarked: "I believe the strata on both sides of Ascutney are monoclinal and dip easterly."[c] Farther to the west, in the monoclinal structures of the Green Mountains, patient and successful study of the actual bedding has showed a close correspondence of schistosity and true dip in the many folds overturned to the west.[d] On the other hand, there is no doubt that in other localites in this same phyllitic formation there is "striking unconformity between the planes of deposition and the fissility."[e]

[a] Note by Dr. Hillebrand, analyst: On boiling with dilute HCl, some H_2S is given off, followed by a strong and persistent odor of volatilizing sulphur, showing the decomposition of a sulphide with the formation of H_2S and the simultaneous deposition of sulphur. It is probable that both pyrite and pyrrhotite are present.

[b] Another sample gave 0.06 per cent carbon and 0.42 per cent CO_2.

[c] Geology of New Hampshire, Concord, 1877, Vol. II, p. 400.

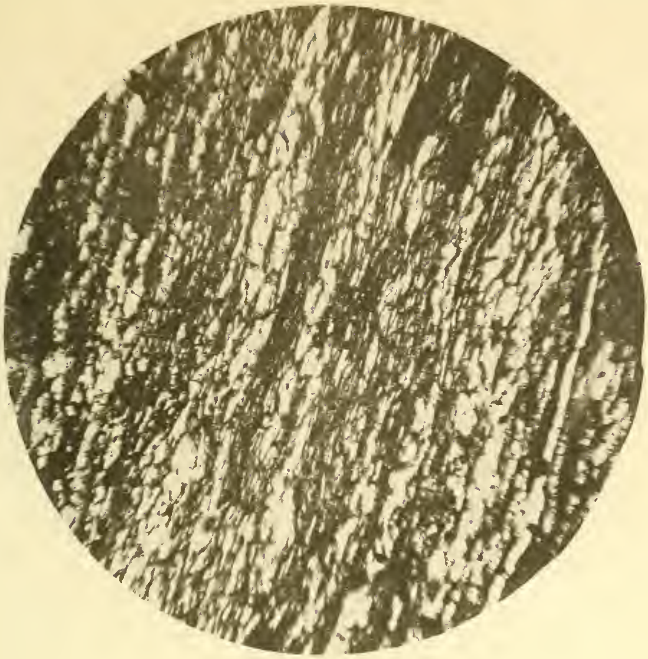
[d] See C. L. Whittle, The general structure of the main axis of the Green Mountains: Am. Jour. Sci., 3d series, Vol. XLVII, 1894, p. 347.

[e] C. H. Richardson: Proc. Am. Assoc. Adv. Sci., Boston meeting, 1898, p. 296.

PLATE II.

A, Unaltered phyllite, showing normal plane-parallel structure; ordinary light, $\times 20$. (See p. 14.)

B, Phyllite, showing bent laminæ and strain-slip cleavage; ordinary light, $\times 20$. (See p. 14.)



(A)

(B)

THE MERIDEN GRAVURE CO.

There is no better summary of the writer's views, obtained from but a limited study of the series in the vicinity of Ascutneyville, than that already given by Edward Hitchcock: "We have noticed no cases where the stratification and schistose structure did not essentially coincide, though often one or the other was obscure, very probably because there was a discordance of this kind, which careful study might have traced out."[a]

Westward across the strike on the north side of the mountain the dip of the phyllite is seen to steepen until the bedding shows an inclination of 75° or more to the east. These high dips occur about in the meridian passing through a point a half mile east of Brownsville, where, in places, the dip is even vertical. The strike ranges from N. 10° E. to N. 23° W., but is rarely far from its average trend, which is due north and south. The cross section on the south side of the mountain indicates a variation in the strike of from N. 15° E. to N. 20° W., with the average again practically north and south. The dip averages 60° to the east, though a rapid steepening below the granite quarries gives angles as high as 83°. The two sections of the phyllitic series thus correspond to a dynamically metamorphosed integral mass of sediments, deformed so as to present the appearance of a great thickness of conformable tilted rocks with a high dip to the east.

GNEISSIC SERIES.

West of the meridian which passes through the diorite-syenite contact appears a group of medium-grained to coarse-grained crystalline schists more varied in composition and more complex in structure than the phyllites. There is no distinct plane of junction between the two series. Both north and south of the mountain, going west, the phyllite simply assumes a more and more feldspathic character until it merges into a conformable and typical gneiss. No attempt has been made to unravel this complex, even so far as that is possible. A qualitative treatment only has been deemed sufficient for present purposes, and as a result only very slight differentiation of the gneisses is to be noted on the map.

The most abundant member of the gneissic series is a muscovite-biotite-epidote-gneiss of variable texture. It is often richly charged with scapolite. Likewise abundant are biotite-muscovite-gneiss, biotite-gneiss, muscovite-gneiss, epidote-gneiss, or mica-schists, all of which seem to be transitional into the main gneissic type. Very often the feldspars are large and the structure is that of a true augengneiss. All these types may be garnetiferous. With them are associated thin bands of beautifully crystallized hornblende-biotite-quartz-schists and epidotic hornblende-schists. The finest types of these hornblende-schists were found in a number of massive ledges on the west side of

[a] Geology of Vermont, Claremont, 1861, Vol. 1, p. 476.

the road running through Greenbush, and thus outside the limits of the area mapped, but excellent sill-like occurrences may be studied just below the Crystal Cascade. Thick pods of coarsely crystalline limestone and of marble, generally charged with nests of radiating tremolite (the "wood-rock" of the quarryman), are included in the gneissic area, but again outside the immediate region under consideration. The nearest of these lenses of limestone has been rather extensively quarried for the manufacture of quicklime at Amsden, about 2 miles southwest of Little Ascutney. Sheets of now greatly weathered diabase are not uncommon in the gneisses, and the apophyses from the diorites and syenites often assume the same form.

An intrusive sheet of composition and origin quite different from that of any other rock yet studied in the area was found exposed for a length of about 500 yards (458 meters) with a strike of N. 15° W. It is terminated at the northern end by the younger rock mass of the Main syenite stock at a point about one-half mile from Crystal Cascade. The southern end of the sheet is concealed by a drift. This sheet varies from 60 to 100 feet in thickness and dips, conformably with the quartz-epidote-schist, 55° to the east. The inclusion within its mass of horses of the schist and the appearance of apophyses from it within the latter clearly prove its intrusive nature (see Pl. VII).

A gneissic structure is generally visible on weathered surfaces, though it is sometimes quite absent. The sheet rock has evidently been squeezed with the schist, and both have been broken by faults of small throw. The light-gray hand specimen itself exhibits granulation, and the extensive alteration of the old eruptive is indicated by the presence of many irregular grayish to silvery-white blotches of muscovite (specimen 175). Dark-colored minerals are not visible macroscopically. Microscopic examination shows that the crushing has been profound. Abundant granulated quartz and orthoclase, greatly bent lamellæ of plagioclase and microcline (?), and the abundant muscovite present especially characteristic proofs. Besides epidote, which appears to be a metamorphic derivative from the plagioclase, rare zircon crystals and a few grains of an iron ore complete the list of constituents. A muscovite-gneiss at the present time, this rock was doubtless of the nature af an aplitic sill before the period of dynamic metamorphism. It is of interest in representing something like the condition to which the latter eruptives would have been reduced if, since intrusion and consolidation, they had been affected by mountain building on the scale indicated by the present attitude of the schists.

It has already been noted that on both sides of the mountain the phyllite assumes from east to west a more and more gneissic character in a fairly broad north-south zone. The strike and dip in this transition zone are similar to those of the phyllites proper, and they are retained in the gneisses on the south of the dioritic stock. On the north side, however, while conformable with the phyllite near the transition zone, the gneisses vary in strike from north and south to east and west. The average strike is about northwest to southeast. As the section is followed westward the gneisses are seen to be greatly contorted and to writhe about in the most irregular way, the angle of dip changing considerably with the strike. These structural changes are introduced so gradually in and west of the transition zone that they do not preclude the idea that the gneiss underlies the phyllites conformably. Such is believed to be the relation between the two series.

In this instance the chronological treatment of the rocks of the area has been deviated from. This has been done because the phyllites have greater stratigraphic simplicity, and dynamic metamorphism has affected them to a much smaller degree than the older crystalline schists. At the same time, the amount of light thrown on the origin of the gneisses by the brief and limited study of the phyllites is not that which would accrue from an accurate and detailed mapping of the schists far beyond the limits of the area mapped. The intimate association of the two series and the occurrence of the limestone pods in the gneiss render it highly probable that the gneiss is for the most part composed of material that was originally sedimentary. Beyond this general statement the facts obtained in the Ascutney area will not permit us to go, nor for the immediate purpose of this paper is it necessary to inquire further into the details of the history of the metamorphism.

GEOLOGIC AGE OF THE SCHISTS AND OF THE INTRUSIVE ROCKS.

Outside regions must be turned to for a solution of the difficult problem as to the age of the schists and, inferentially, as to the maximum age that may be assigned to the eruptives. The Vermont Survey Report of 1861 includes the phyllitic series in the "Calciferous mica schist," and states that this formation is overlain by clay slate which a "strong presumption" would place in the Devonian; and hence that the schist is at least Devonian, and may be older.[a] Speaking of the underlying gneiss, Edward Hitchcock wrote, "We have already made it probable that the Calciferous mica schist has been converted into gneiss from Ascutney southward. If so, whatever the age of the schist may be, that of the gneiss is the same."[b] Hitchcock left the question of age open, though he seems to have given weight to T. S. Hunt's conclusion, based on studies in the northern extension of these schists into Canada, that they are of Niagara or, at any rate, Upper Silurian age.[c] Emerson has proved that the Bernardston series of Vermont and Massachusetts is of Hamilton and Chemung age.[d] That series overlies the Calciferous mica schist, so that the latter is Lower Devonian or older.

[a] Vol. I, p. 485.
[b] Geology of Vermont, 1861, Vol. I, p. 470.
[c] Am. Jour. Sci., 2d series, Vol. XVIII, 1854, p. 198.
[d] Idem, Vol. XL, 1890, p. 263.

Recently the detailed field observations of C. H. Richardson have afforded more definite information. He divides the Calciferous mica schist into a calcareous member, the Washington limestone, and a noncalcareous member, the Bradford schist. The latter includes the phyllitic series of the Ascutney region. Richardson correlates the Bradford schist with the Goshen schist of Emerson in Massachusetts. The Bradford schist is "flanked on the east by a band of clay slate and on the west by the Washington limestone, which in turn is flanked on the west by a band of clay slate. The two bands of slate, the Bradford schist, and the Washington limestone lie unconformably both on the east and west on a synclinal trough of the hydromica-schist, which is Huronian." His discovery of fossils in the clay slate has enabled Richardson to prove it to belong to the Lower Silurian. "The Bradford schist and Washington limestone, which have oscillated from the 'Primitive' of Zadock Thompson to the Niagara of Professor Dana, are Lower Silurian, and, more definitely, Lower Trenton."[e]

The schists had been flexed into essentially their present attitude before any considerable eruption of igneous rock took place in this area. The sheets of amphibolite and sills of aplitic material noted above have been changed both in composition and structure by the dynamic action of the tilting process. They are, however, of minor importance, and do not weaken the conclusion that the mountain-building forces had practically ceased acting before the eruptive masses of Ascutney had appeared in the main conduit. Occasionally the feldspars and biotite crystals of the rock in the oldest (gabbro-diorite) stock show considerable straining and bending, but such effects are far inferior in degree to those which would result if the diorite had undergone the enormous pressure necessitated in the folding of the sediments. The still younger intrusives show even less evidence of squeezing or dislocation since they were consolidated.

The principal intrusions are, accordingly, post-Trenton in age, and probably, if we may judge from the analogy of other granitic intrusions in the Appalachian system, post-Carboniferous and pre-Cretaceous. Nearer than that they can not as yet be more definitely dated.

SUMMARY.

The irruptives of Mount Ascutney cut a series of tilted schists assigned to horizons equivalent with that of the Bradford schist or older; i. e., they are regarded as Trenton or pre-Trenton in age. The overlying phyllites—the "Calciferous mica-schist" of the geological survey of Vermont—belong to the Bradford schist proper. While highly metamorphic and greatly deformed, the phyllites, with the interbedded quartzitic and thin limestone bands, show an apparent

[e] Proc. Am. Assoc. Adv. Sci., Vol. XLVII, 1898, p. 296.

parallelism between schistosity planes and stratification planes. Beneath this series is a conformable group of schistose rocks consisting of common mica-gneisses, epidote-gneisses, amphibolites, and crystalline limestone.

The intrusions are of later date than the last great period of rock folding which has affected the Ascutney region, and the balance of probability makes them post-Carboniferous and pre-Cretaceous in age.

CHAPTER III.

CONTACT METAMORPHISM.

THE METAMORPHIC AUREOLE.

The metamorphic aureole developed about the stocks is worthy of detailed consideration. As one approaches the contact from any side of the mountain he speedily notes plentiful evidences of the squeezing, crumpling, and fracturing of the schists, which thus have a more complex structure than they have at some distance away from the massive rocks. Especially good examples of this may be seen on the cleared spurs on the southeast side of Ascutney Mountain proper. There, as elsewhere, further proof of the energetic nature of the intrusions is to be found in the numerous apophyses sent into the bedded series and in the disruption of blocks, great and small, from the latter, often forming a "permeation area" in the eruptive masses; but the purpose of the present chapter relates not so much to the dynamics of the metamorphic action as to the mineralogical changes which have taken place in the schists.

The heat and the mineralizers accompanying the intrusions have produced alterations which are most important in the phyllites and associated limestones. On account of the well-known mineralogical stability of the gneisses and of the quartzitic bands the metamorphic effects upon these rocks have been mechanical rather than chemical or mineralogical.

The breadth of the aureole is not great in any part. Indisputable contact metamorphism has not anywhere been recognized at much over 600 feet (183 meters) from the contact, and may often be distinctly seen no more than 300 feet (91 meters) away from the same line. In the phyllitic series the metamorphic belt averages about 500 feet (154 meters) in width, and that irrespective of the attitude of the schists and irrespective of the stock nearest to which the measurement is made. The Main syenite stock has controlled the metamorphic action, although the Basic stock seems to have slightly intensified the action at the triple contacts of syenite, phyllite, and diorite. It is essentially correct to speak of the metamorphism of the phyllites as resident in one aureole produced by the intrusion of the Main stock.

CHANGES IN THE LIMESTONES.

The interbedded calcareous layers of the phyllitic series are specially sensitive to this contact transformation. Two different rock types result from the alteration of the fine-grained bluish-gray siliceous limestone, which is composed simply of calcite, quartz, and carbonaceous matter (spec. 114).

The first of these phases of recrystallization has resulted from an abundant replacement of the calcite by epidote, the other constituents remaining unchanged. This variety was found at several points in the aureole. Of the occurrences known, that farthest removed from the syenite lies about 600 feet (183 meters) from the contact at the base of the prominent 2,350-foot spur bearing east by north of the summit. A very similar phase was discovered only 3 feet (0.9 meter) from the contact at the Crystal Cascade. Here scapolite is also developed and rare grains of titanite and brownish-green hornblende are accessory (spec. 100).

The second phase is illustrated in a specimen from a field just west of the old road leading up to the quarries in the granite. The ledge from which it was taken is 450 feet (137 meters) from the contact with that intrusive. Attention was first called to it by the very noticeable roughness of the weathered surface, which betrayed the presence of some mineral in roundish masses more resistant to the weather than the other constituents (spec. 5). The fresh specimen is light gray, mottled with these subcircular, rather darker-colored, oily-looking areas about 6 millimeters in diameter and at an average distance of 1 to 2 centimeters apart. Under the microscope the areas resolve themselves into irregular aggregations of the colorless to yellowish lime-garnet (grossularite), inclosing large amounts of calcite. The occurrence is thus similar to that described by Harker and Marr in the metamorphosed limestone of the Shap Fell region in England[a] and to many others of different localities.

The garnet never shows crystal form, nor, except in rare cases, any distinct cleavage. The usual optical anomalies and zonal extinction are present. The anisotropic property is very unevenly distributed throughout the areas. It may be completely absent in one grain and give a polarization tint like that of zoisite in a contiguous individual. The double refraction shows that in some instances the areas are occupied by single poikilitic crystals of the grossularite as shown by the uniform extinction on revolving the section between crossed nicols. The same test would seem to indicate the composite character of other masses which are aggregates of small individuals. The only other change from the normal limestone is the complete disappearance of carbonaceous matter. Quartz remains in relatively high proportion and occurs with calcite as inclusions in the garnet.

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[a] Quart. Jour. Geol. Soc., Vol. XLVII, 1891, p. 311.

METAMORPHISM OF THE PHYLLITES.

The average normal phyllite is, as we have seen, considerably more argillaceous than the quartzitic schist analyzed (see Table I, p. 15). The minerals characterizing the rocks resulting from the alteration are, as a rule, those which might be expected from mere recrystallization of the original constituents, viz, quartz, sericite, chlorite, clayey matter, iron ores, and sulphides.

There is no definite succession of zones of metamorphic action, either of color, structure, or mineral aggregation, as in the classic region of Barr Andlau. The macroscopic changes are simple and uniform in all parts of the aureole. Quartz veins and eyes become more numerous as the contact is approached; the lamination of the schist becomes, at the same time, more and more lost, and the rock takes on an increasingly compact and indurated look. Yet even at the contact itself the presence of quartzose laminæ in the original phyllite often entails a partial preservation of the schistose structure. Occasionally obscure spotted and knotted areas are found, but they are not conspicuous nor are they arranged in any fixed order.

The general mineralogical changes may be summarized as comprising a progressive disappearance of sericite, quartz, and argillaceous substance and a corresponding development of biotite, red garnet, cordierite, pleonaste, corundum, and sillimanite. These new minerals naturally occur most abundantly and in larger crystals near the contact than farther out in the aureole. In tracing these changes, the attempt was made to collect specimens along the strike, thus inviting, though, on account of the variability and disturbed character of the schist and because of the lack of sufficient outcrops, not entirely securing, the maximum of certainty as to just how great has been the influence of this local metamorphism on lithological units. Three fairly representative sections of the contact zone were made in this way; perhaps no better means of describing the phenomena of the zone can be adopted than to consider each of the sections somewhat in detail.

SERIES A OF SPECIMENS FROM THE METAMORPHIC AUREOLE.

The first of these sections in the aureole is noted on the geological map as occurring at the syenite contact on the north side of the mountain; the set of specimens collected there may be called "Series A." For ease of reference each of the following paragraphs relating to the description of the specimens is preceded by a number indicating the distance from the contact of the specimen to which that paragraph refers.

500 feet (*154 meters*).—Five hundred feet from the contact the phyllite shows some crumpling and other evidences of disturbances; so far as known, however, no new mineral has been developed at that distance.

400 feet (*122 meters*).—One hundred feet nearer, the sericite is largely replaced by an indeterminable chloritic substance, but it is probable that this phase also is original.

300 feet (*91 meters*).—Somewhere within the next 100 feet measured toward the contact there is a comparatively abrupt appearance of true contact minerals, coupled with a decided loss of the original fissility of the rock (spec. 129). At 300 feet from the syenite, there is a partial replacement of the argillaceous and chloritic material and of quartz by cordierite, while the whole rock is filled with a swarm of extremely minute, light-green, isotropic grains with high, single refraction. An occasional grain of epidote lies with the iron sulphides (pyrite and probably pyrrhotite) in the planes of schistosity, which are still to be seen, both macroscopically and in the thin section.

250 feet (*77 meters*).—Fifty feet nearer, the metamorphism has affected the whole rock. Its original dark-gray color has now a bluish cast (spec. 128). A high degree of induration with a corresponding loss of lamination and an increase in the specific gravity are characteristic. A peculiar feature of this hand specimen is the presence of numerous roundish and isolated areas of what can be discerned, even macroscopically, to be granitic aggregates of quartz, feldspar, and other minerals embedded in the general rock matrix. They bear a relation to the transformed schist analogous to that of a miarole to its igneous host, and, for lack of a better term, they may be called "pseudo-miaroles." Microscopic examination shows that the basis of the rock is now cordierite occurring in interlocking individuals 2 to 3 millimeters in diameter. It is always poikilitic either from the mutual intergrowth of several crystals of its own substance or from the swarms of mineral inclusions of different sorts (the "sieve-structure" of Salomon). Those inclusions are the same as the other constituents of the hornfels, viz, numerous small shreds of intensely pleochroic brown biotite, abundant, irregular grains of deep-green spinel, pyrite, pyrrhotite, ilmenite, tourmaline of brown and yellow tones, quartz, and minute black, probably carbonaceous particles.

These various inclusions cloud the whole thin section except in the more quartzose laminæ, which are doubtless residual from the original rock, and in the pseudo-miaroles. They are also lacking in the numerous stringers of quartz which traverse the schist. Probably the recrystallization of the schist was complete before the quartz was laid down in the veinules and the pseudo-miaroles were filled with their granitic contents. The latter consists of the minerals characteristic of the adjacent syenite—microperthite, cryptoperthite, quartz, brown alkaline hornblende, and rare zircons. With them is often associated a pale-reddish garnet averaging about 1 millimeter in diameter. The quartz is so abundant as to give the hypidiomorphic-granular aggregate the composition of a true granite. These pseudo-miaroles when round in outline measure from 3 to 5 millimeters in diameter; when, less often, they are elongated in the section they measure from 5 to 10 millimeters in length. They are not connected with one another or with distinct apophysal veins from the syenite, but are completely surrounded by the cordieritic matrix. It looks as if there had been a shrinkage of volume in the schist during its recrystallization and the resulting cavities were subsequently filled with the granitic substance by a pneumatolytic process. We have, whatever be the explanation, a striking case of feldspathization of schist by an intrusive granitic rock wherein the channels of approach of the feldspathic material were of submicroscopic dimensions. The deep-green spinel is pleonaste, which is now of increasing importance as we go toward the eruptive rock. It was this mineral that was seen at the 300-foot distance, where the very small grains were indeterminable. Similar fine material is present here, but it grades up into larger individuals which are undoubtedly pleonaste. Here, too, the pleonaste has an interesting localized distribution, being grouped in roundish clusters composed of many crystals. In one case the whole of one well-marked cluster about 0.3 of a millimeter in diameter is included in a single crystal of cordierite. The spinel is usually without crystal form and occurs as drop-like bodies. It is worthy of note that not only in this case, but in all parts of the aureole, pleonaste and the metamorphic biotite are in reciprocal relation to each other; where one is abundant the other, relatively, is rare. This fact correlates with the observation of Lacroix that spinel is a common product of the alteration of mica in inclusions caught up in lavas,[a] and with our own observation that, close to the contact, where we should expect the more stable products of metamorphism, the biotite is often completely replaced by pleonaste.

150 feet (46 meters).—One hundred feet nearer the contact the schist is macroscopically similar to the rock found at 250 feet in its compactness, lack of pronounced schistosity, and bluish-gray color, but lacks the pseudo-miaroles and is more strongly charged with the red garnet (spec. 127). Mineralogically the most important difference is found in the entrance of corundum as a new metamorphic constituent. This occurs as irregular colorless grains, often grouped in clusters about ilmenite in the form of a mantle. This new mineral is in small amount and its description may be deferred for better occurrences at other localities. Cordierite again composes most of the schist. It has here, too, the pleochroic halos found about inclusions, as well as other usual features. Pleonaste, with a clustering habit, is comparatively abundant, and biotite is rare. The garnets appear in large individuals, showing characteristic cleavage and inclusions, and also in the form of well-crystallized minute dodecahedrons without inclusions or cleavage.

[a] Les enclaves des roches volcaniques, Macon, 1893, p. 599.

Many of the larger crystals form the centers of eyes and are then wrapped about by mica plates. Generally, however, the garnet is surrounded by a clear zone of quartz and cordierite, unaccompanied by iron compounds, which have either been used to build up the garnet or are included in zones within that mineral. Though the pseudo-miaroles are absent, there is evidence of some feldspathization of the schist. Occasional crystals of microperthite may be discerned in the thin section. They are products of late crystallization, as they are intersertally related to the cordierite; like the feldspars of the pseudo-miaroles, they are free from inclusions of pleonaste, etc.

100 feet (31 meters.)—A specimen (No. 126) taken from a ledge 100 feet from the contact, seems in several respects to show a local exception to the general effect of metamorphism on the phyllites. Biotite is once more developed in profusion, while pleonaste is quite subordinate. Corundum is absent. Cordierite is again the principal constituent and acts as host to the pleonaste clusters. The iron sulphides are conspicuous in the hand specimen. Dr. Hillebrand remarks:

On boiling the powdered rock with dilute hydrochloric acid considerable H_2S is evolved and sulphur is set free, as can be plainly perceived by the strong smell of volatilizing sulphur accompanying that of H_2S. The decomposition begins at a moderate heat. After a time the evolution of the H_2S ceases and the smell of sulphur is no longer noticeable, and there is then found only one-third of the total sulphur left in the residue, presumably wholly as pyrite. The rest of the sulphide is magnetic and, dissolving readily in HCl with the evolution of H_2S, may be considered as quite certainly pyrrhotite.

The feldspar is much increased in amount, is notably microperthitic, and occurs in the same relations as in the last specimen described. For the first time, the feldspar shows the Carlsbad twins characteristic of the microperthite of the syenites. A chemical analysis has been made of this phase (Table II, col. 1). As a whole it corresponds to the analysis of a phyllite rich in argillaceous material. The soda is to be ascribed mainly to the feldspar, and is thus believed to have been introduced by hydrothermal action. On the supposition that all the sulphide exists as pyrite, the proportions of the iron compounds would be—

	Per cent.
Fe_3O_3	0.03
FeO	6.41
FeS_2	0.58

If two-thirds of the sulphide is pyrrhotite, these compounds should be recalculated to the following proportions:

	Per cent.
Fe_2O_3	0.30
FeO	6.00
FeS_2	0.19
Fe_7S_8	0.53

The latter proportions are, for the reason already noted, believed to be more nearly correct and are accordingly entered in the total analysis. The carbon percentage is extremely variable, corresponding to the irregular distribution of the coaly matter in the schist. One independent determination gave 0.03 per cent carbon instead of 0.40 per cent, as found for the rock fragment analyzed completely. Two analyses of typical cordierite-mica-hornfels from southern Carinthia (Table II, cols. 3 and 4), show a rather strong similarity to that of the Ascutney rock.

50 feet (*15.5 meters*).—Fifty feet from the contact a specimen (No. 125) was collected that showed a reversion to the normal sequence of the mineral occurrences as the contact is approached. The pleonaste once more largely supplants the biotite and is, in fact, more abundant than ever. It clouds the whole of the thin section, though there is a tendency toward a grouping along planes apparently representing the original schistosity. Corundum and tourmaline, like the biotite, occur but sparingly. The schist is strongly impregnated with small quartz veins and with lenses 1 to 2 millimeters in thickness, composed of quartz, microperthite, and brown biotite. The evidence is not so clear as in the case of the pseudo-miaroles that these granite lenses are not actually connected with one another and with the stock rock, but it is highly probable that both types of the granitic aggregates are to be referred to the same pneumatolytic origin.

25 feet (*8 meters*).—Halfway to the contact the rock is still the massive dark bluish-gray heavy hornfels, hardly to be distinguished in the hand specimen from the altered schist collected from the 200 or more feet of section over which we have just passed (spec. 124). A notable difference from the hornfels at 50 feet consists in the abundance of corundum, which is even more plentiful than the pleonaste. Cordierite is here again the chief constituent. While it presents the usual poikilitic interlocking habit, it sometimes has definite crystal form, with the common hexagonal sections from the base and rectangular sections from the prism. Biotite is an accessory, but tourmaline has disappeared and does not reappear between this point and the syenite. Microperthite occurs in intersertal contact with the cordierite, but is only a rather rare accessory. Besides ilmenite or titaniferous magnetite, the iron compounds include both pyrite and pyrrhotite. The test for the occurrence of the latter mineral and the method of its determination in amount are the same as has been outlined above. The strong basicity of the hornfels is noteworthy, as well as the high content of alumina. The latter easily explains the richness of the rock in corundum[a] (see Table II, col. 2).

[a] Cf. J. Morozewicz, Experimentelle Untersuchungen über die Bildung der Minerale im Magma: Tscher. Min. und Petrog. Mitth., Vol. XVIII, 1898, p. 57.

TABLE II.—*Analyses of cordierite-hornfels.*

	1.	2.	3.	4.
SiO_2	58.35	45.30	55.68	56.88
TiO_2	0.87	1.48		
Al_2O_3	21.30	30.51	21.91	20.86
Fe_2O_3	0.30	0.24	2.63	2.66
FeO	6.00	8.80	6.90	4.54
MgO	2.10	3.11	3.57	3.15
CaO	0.85	0.90	0.89	1.29
Na_2O	1.60	1.65	1.01	0.91
K_2O	5.63	4.84	6.34	7.49
H_2O above 110° C.	[a] 0.86	[a] 1.05	[a] 1.41	[a] 2.36
H_2O below 110° C.	0.31	0.26		
CO_2	None.	Trace?		
P_2O_5	0.18	0.12		
SO^3	None.	0.04		
Cl	0.03	0.04		
F	Undet.	0.04		
FeS_2	0.19	0.36		
Fe_7S_8	0.53	0.96		
NiO, CoO	0.03	0.02		
MnO	0.13	0.20		
BaO	0.05	0.03		
SrO	Trace.	Trace.		
Li_2O	Strong tr.	Strong tr.		
CuO	Trace.	?		
C	[b] 0.40	[c] 0.17		
	99.71	100.12	100.34	100.14
O=F,Cl		0.02		
		100.10		
Total S	0.31	0.19		
Sp. gr	2.673	2.835		

[a] Loss on ignition.
[b] Another sample gave 0.03 per cent carbon and no CO_2.
[c] Another sample gave 0.03 per cent carbon and 0.04 per cent CO_2.

1. Cordierite-biotite-microperthite-hornfels, a phase of the exomorphic zone 100 feet (31 meters) from the contact, north side, Ascutney Mountain; analysis by Hillebrand.

2. Cordierite-corundum-pleonaste-hornfels, taken from the same cross section of the exomorphic zone as No. 1, 25 feet (8 meters) from the contact; analysis by Hillebrand.

3. Cordierite-biotite-orthoclase-hornfels, Schaida, S. Carinthia; analysis by Graber, Jahrb. der K.-k. geol. Reichsanst., 1897, Vol. XLVII, p. 290.

4. Cordierite-biotite-plagioclase-hornfels, M. Doja, S. Carinthia; analysis by Von Zeynek. See Graber, ibid., p. 290.

6 feet and 1 foot (1.8 meters and 0.3 meter).—A specimen taken at a point 6 feet from the contact (spec. 123), and another taken from a point only 1 foot from it (spec. 122), are very similar to each other and to the phase just described. There is, however, a decrease in corundum and an increase in pleonaste, which now possesses perfect crystal form. The octahedra are excellently developed, and are furthermore interesting, as they show the octahedral cleavage, which is seldom seen in rock-forming occurrences. The clustering habit of the pleonaste is strongly marked in both specimens. Corundum often appears as a core, about which the concentration of pleonaste took place. In other cases, the grouping is wholly in quartz crystals in a manner similar to that already noted for the clusters in cordierite.

This study of the cross section of the aureole may be summarized in tabular form as follows:

Summary of cross section of series A of metamorphic aureole.

Distance from the contact.		Compound name of aureole phase, showing its essential constitution.	Accessory and subordinate mineral constituents.
Feet.	*Meters.*		
600	183	Unaltered argillaceous phyllite	Pyrite, pyrrhotite (?), ilmenite, carbonaceous matter.
500	154	The same, crumpled	Do.
400	122	Crumpled chloritic phyllite	Do.
300	91	Cordierite-quartz-hornfels	Biotite, pleonaste, epidote, pyrrhotite, pyrite, ilmenite, carbon.
250	77	Pseudo - miarolitic cordierite-biotite-quartz-microperthite-hornfels.	Pyrite, pyrrhotite, ilmenite, carbon, tourmaline, garnet, hornblende, zircon.
150	46	Cordierite - garnet - pleonaste-quartz-hornfels.	Pyrite, pyrrhotite, corundum, ilmenite, carbon.
100	31	Cordierite - biotite - microperthite-hornfels.	Pyrite, pyrrhotite, pleonaste, carbon (graphite ?), ilmenite.
50	15.5	Cordierite - pleonaste - microperthite-hornfels.	Pyrrhotite, pyrite, biotite, ilmenite, carbon (graphite ?), tourmaline.
25	8	Cordierite-corundum-pleonaste-hornfels.	Biotite, microperthite, pyrrhotite, pyrite, ilmenite, carbon.
6 and 1	1.8 and 0.3	Cordierite-pleonaste-corundum-hornfels.	Do.

SERIES B OF SPECIMENS FROM THE METAMORPHIC AUREOLE.

A second suite of specimens was collected from a section across the metamorphosed belt just south of Brownsville. The aureole is here at least 600 feet wide, the relatively greater breadth being probably due to the proximity of the diorite as well as the syenite. The effects produced by the intrusives are practically the same as in Series A.

600 feet (*183 meters*).—Six hundred feet from the contact along the strike and 500 feet across it (spec. 136), garnets, tourmaline, corundum, and a little cordierite are already found in the phyllite, which, in its unaltered phase, is more quartzose than in Series A. The quartz preserves much of its original importance; it is charged to a remarkable degree with liquid inclusions, often containing gas bubbles. Biotite is present, and is also doubtless inherited from the original schist. Rare epidote is accessory. No feldspar is recognizable. Certain colorless grains with high single and low double refraction have the appearance of andalusite, but its presence could not be proved on account of the small size of the individuals.

300 feet (*91 meters*).—Three hundred feet from the contact pleonaste appears as small disseminated grains for the first time (spec. 135).

100 feet (*31 meters*).—One hundred feet from the contact the schistose structure is no longer visible macroscopically, though it appears in the thin section (spec. 134). The biotite assumes a concretionary rather than a plane-parallel arrangement. The increased importance of cordierite and the entrance of a few needles of sillimanite are the other chief points of difference from the last locality.

45 feet (*14 meters*).—At 45 feet pleonaste and corundum are quite prominent, both in abundance and in size of the individuals (spec. 133). Sillimanite increases in quantity. Andalusite is, as before, doubtfully present.

15 feet (*5 meters*).—At 15 feet, tourmaline is added to the list of essentials (spec. 132). The pleonaste has two types of aggregation. Besides appearing on the familiar clusters, it accumulates in long strings, which reach 2 millimeters or more in length and have a uniform breadth of about 0.1 millimeter, reminding one of the linear development of chlorite in the classic desmosite (Pl. III, *A*). This second kind of aggregation does not seem to have any fixed relation to single individuals of other constituents, and the masses of pleonaste pierce the rock in all directions. Again, this mineral is inclosed by the cordierite in a way not observed elsewhere in the aureole. Numerous rectangular grains of spinel may be arranged with their longer axes parallel to the chief axis of the cordierite host. Idiomorphic cordierite also incloses prisms of tourmaline with a similar orientation. Corundum is first seen here to assume a crystal form. Sillimanite is a common accessory.

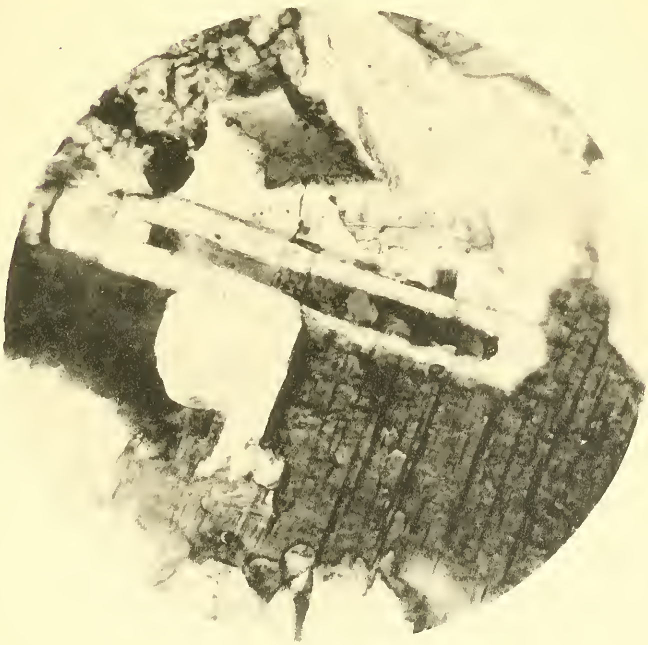
5 feet (*1.5 meters*).—A specimen (No. 131) taken only 5 feet from the contact shows a rarity of metamorphic minerals which can only be

PLATE III.

A, Hornfels containing abundant pleonaste (black, of high relief) and corundum (white, of high relief) in a matrix composed chiefly of cordierite (a characteristic linear aggregate of pleonaste is conspicuous); ordinary light, × 12. (See p. 39.) Compare with Pl. II, *A* and *B*, illustrating the same phyllite from which this hornfels has been produced by contact metamorphism.

B, Thin section of quartz-bearing hornblende-biotite diorite, showing an apatite crystal inclosing a core of brown glass; ordinary light, × 50.

(A)



(B)

THE MERIDEN GRAVURE CO.

explained as characterizing a phase of the schist which was originally less richly charged with the argillaceous material that has elsewhere yielded, under the metamorphic process, the minerals above mentioned. The schistose structure is reverted to; garnet, pleonaste, corundum, and tourmaline are present, but are very subordinate and confined to the structure planes. Intersertal microperthite forms an accessory· it shows occasionally the Carlsbad twinning.

At the contact there is the same relative poverty in metamorphic products and probably for a similar reason to that adduced for the last phase (spec. 130). The rock is a compact mass of quartz, chloritized biotite, and pleonaste, with ilmenite, tourmaline, cordierite, and corundum as accessories.

SERIES C OF SPECIMENS FROM THE METAMORPHIC AUREOLE.

A third suite of specimens illustrating the contact zone was collected on the south side of the mountain. The phenomena are essentially similar to those in Series A. It would be unprofitable to give a detailed description of them, as it would be in the nature of repetition. The perfection of the crystallization of corundum is, however, worthy of special note. Within the belt 10 feet (3 meters) or more, measured out from the contact, it is an abundant essential constituent of the rock. Both basal and prismatic sections of the idiomorphic and granular crystals exhibit cores of vivid blue in the otherwise colorless mineral. Each of these cores is oriented with the longer axis parallel to the chief axis of the corundum individual. Rotated over the polarizer alone, the basal section shows no change of color; in other sections a striking pleochroism, from deep blue to colorless, is characteristic.

COMPARISON OF THE METAMORPHIC EFFECTS.

The constant nature of the metamorphism is indicated not only by the correspondence of these three series of specimens, but also by many specimens collected from points isolated in the contact zone and not connected in the serial arrangement of a cross section. Wherever the comparison could be fairly instituted, the alteration of the phyllitic rocks was seen to be of the same character, whether produced by syenite, granite, or gabbro-diorite. It is another illustration of a now familiar fact—that so widely divergent intrusive types as granite, syenite, diorite, diabases, and peridotite may form similar types of hornfels.[a]

The general order of the metamorphic effects to be observed as one approaches the contact may be stated as follows:

At 500 feet or less from the contact there begins to be apparent a distinct loss of schistosity in the phyllite. The rock gains in massiveness and in specific gravity. The extent of these changes, as of all

[a] Cf. Lacroix, Comptes Rendus, 18 févr., 1895.

the others, is manifestly controlled by the nature of the particular phyllitic band studied. The dominant mineralogical essential of the aureole is cordierite, which appears suddenly and abundantly in the outer part of the aureole. Second in importance to that mineral is pleonaste, assuming greater quantitative importance and greater size and perfection of crystal form in its individuals as the contact is neared. Metamorphic biotite is likewise abundant. Its increase means, as a rule, a decrease of pleonaste in that particular phase. Corundum behaves like the spinel in its progressive development toward the contact, but appears later in the section. Sillimanite is confined to the inner part of the zone, but is never abundant. Garnet, tourmaline, and andalusite (?) are sporadic, appearing and disappearing irregularly in the cross section, though more likely to appear at its inner extremity.

Feldspathization characterizes the aureole as far, at least, as 300 feet (91 meters) from the intrusive. It is highly probable, however, from the evidence of the hornfels analyses and of the microscopic examination, that the transfer of material from the stock magmas to their country rock is but subordinate in quantity. The mere heat of the intrusion would doubtless have been sufficient to produce some of the more important new minerals. Cordierite and spinel in abundance have been formed in coal-bearing mica-slates (schists) through the melting up of the slates during the combustion of the coal.[a] These minerals have also been observed to be the result of the alteration of the micaceous inclusions caught up by volcanic flows. The question as to just how much material has been added to the schists, either as alkaline silicate or in other form, can, however, not be satisfactorily and finally discussed until the same phyllitic band has been followed across the aureole and analyses been made from that band where it is unaltered as well as where it has been strongly metamorphosed. So far it has proved apparently impossible to follow any one band across the whole zone. The only analysis yet made of the unaltered schist relates to a quartzitic phase outcropping at a distance from the mountain (see Table I). If all the soda and potash in even that phase were to enter into the proper combinations with the alumina and silica as much as ten per cent or thereabouts of alkaline feldspar would result. The belief that feldspathization has really occurred would thus be more strongly upheld by the peculiar nature of the actual microperthitic intergrowth, so similar in every respect with the feldspar of the adjacent syenite, and by the nonoccurrence of that intergrowth in the phyllite outside the aureole, rather than by the evidence derived from the analysis of an unaltered phyllite more argillaceous than the quartzitic phase.

A list of the metamorphic constituents of the aureole, arranged in the relative order of abundance as nearly as may be by mere inspection of thin sections, may complete this brief summary.

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[a] Lacroix, Les enclaves des roches volcaniques, Macon, 1893, p. 577.

List of metamorphic constituents of the aureole.

IN THE LIMESTONES.

Epidote.
Grossularite.
Scapolite.
Hornblende.
Titanite.

IN THE PHYLLITES.

Cordierite.
Biotite.
Pleonaste.
Corundum.
Lime-iron garnet.
Sillimanite.
Pyrrhotite.
Pyrite.
Tourmaline.
Andalusite (?).
Graphite (?).

Microperthite Quartz Brown hornblende Biotite	Introduced substance of the "pseudo-miaroles" and intersertal areas.

There are strong resemblances between this list and those made out by G. H. Williams at the Cruger's section (diorites of the Cortlandt series metamorphosing biotite-muscovite schists),[a] and by Teller and Von John in the Tyrol (norites and diorites cutting phyllites and gneisses).[b]

SUMMARY.

The schists display unequal effects of contact metamorphism where they lie in contact with the intrusive bodies. As was to be expected, the gneisses are much the more stable and exhibit little mineralogical change even close to the eruptive contacts, but the abundant argillacous material of the phyllites has been extensively recrystallized into a well-defined zone of hornfels. Cordierite, pleonaste, biotite, garnet, corundum, and epidote form the chief secondary minerals thus developed. The limestone bands have richly yielded grossularite and epidote in the same contact zone. Repeated occurrences of interstitial microperthitic feldspar lead to the conclusion that, during the intrusion of the syenites and granite, feldspathization of the phyllitic country rock has taken place.

[a] Am. Jour. Sci., 3d series, Vol. XXXVI, 1888, p. 254.
[b] Jahrbuch K.-k. geol. Reichsanstalt, Vol. XXXII, 1882, pp. 655 and ff.

CHAPTER IV.

THE ERUPTIVE ROCKS.

GENERAL TABLE AND CORRELATION.

It was thus into a series of tilted metamorphosed sediments that the irruptions with which we are here particularly concerned began (see Pl. VII). The variety, as well as the relative ages of the resulting rock bodies, is indicated in the accompanying table, which gives a summary statement of the succession, from the oldest to the youngest intrusive:

TABLE III.—*Rock bodies resulting from the irruptions.*

(From oldest to youngest.)

A. Basic stock of five chief phases, viz:
- a. Augite-gabbro.
- b. Hornblende-biotite-augite-gabbro.
- c. Biotite-hornblende-diorite.
- d. Biotite-augite-hornblende-diorite.
- e. Orthoclase-microperthite-bearing hornblende-biotite-diorite (containing basic segregations) = acid essexite.

This stock is cut by—
1. Reticulate intrusions (forming intrusion-breccias) of augite-biotite-diorite with and without essential hornblende.
2. Dikes of "windsorite," the alkaline equivalent of granodiorite.
3. Nordmarkite porphyry stock-like dike of Little Ascutney (bearing basic segregations and cut by Nos. 6 and 7).
4. Main stock (B) of Ascutney Mountain and its apophyses.
5. Pulaskite (quartzless biotite-nordmarkite) stock of Pierson Peak.
6. Hornblende-paisanite dike (cut by camptonites).
7. Camptonite dikes.
8. Diabase dikes (?).

B. Main stock of Ascutney Mountain, of four chief phases, viz:
- f. Hornblende-biotite-nordmarkite of granitic structure (bearing basic segregations).
- g. Hornblende-biotite-augite-nordmarkite of porphyritic structure (bearing basic segregations).
- h. Alkaline granites without essential bisilicates.
- i. Monzonite.

This stock is cut by—

9. Hornblende paisanite dikes.
10. Camptonite dikes.
11. Diabase dikes.
12. Common muscovite aplite.
13. Stock C.

C. Stock of alkaline biotite-granite (bearing basic segregations).

A general correlation of these intrusives in terms of eruptive periods and composition may be made in the form of a second table:

First eruptive period	A (a, b, c, d, e)	Gabbro-dioritic magma.[a]
Second eruptive period	1 and 2	
Third eruptive period	B (f, g, h, i), 3 and 5	Syenitic magma.
Fourth eruptive period	6 and 9	
Fifth eruptive period	C and 12	Granitic magma and aplite.
Sixth eruptive period	7 and 10, 8 and 11	Lamprophyres.

The reference of the individual intrusives to the different magmas or their derivatives is indisputable except in the case of No. 2, which is intermediate both in composition and in geological age between the Basic stock and the Main syenite stock. The reference to the different eruptive periods as stated in the table is to some extent arbitrary. The stocks A, B, and C certainly followed one another in the order named. As the map shows, the conduit through which the substantial contributions to the whole mass were made migrated from west to east. The intimate field relations of A, 1 and 2, seem to show that all three antedate the syenites. Nos. 1 and 2 cut A and are probably older than B or its equivalent. Nos. 3 and 5 are correlated with B on the ground of close mineralogical and structural similarity; they are clearly older than Nos. 6 and 9, which were probably not strictly contemporaneous. Though stock C also cuts B, it is probably not contemporaneous with No. 6 or No. 9. It is probable, though not proved, that stock B is older than the lamprophyres, which are certainly younger than all the syenitic intrusions.

In all the stocks and in many dikes of the area, nodular masses of segregational basic materials occur. They are most common in the syenites, less so in the alkaline granite stock, and comparatively rare in the diorities. These nodules were early noted and described by Edward Hitchcock and others, and remarked for their extreme abundance. They will be treated of in some detail in the following pages in connection with the petrographical description of their parent rocks.

It will be seen that among the petrographical methods employed, those for the determination of the feldspars have been in the most constant requisition. In order to avoid repetition and a certain degree of monotony in the description, the actual readings on which the determinations of the various species have been based are, as a rule, not given in the text. In general, several independent methods have been used for each determination. Examples of these are noted in the discussion of the rocks composing the largest stocks examined. In the compound names of some of the rock types, as well as in the tables of mineralogical composition, the mineral constituents are entered in the order of decreasing importance in their respective rocks.

[a] A magma intermediate in average composition between gabbro and diorite. The adjective is not derived from the term "gabbro-diorite," as used by G. H. Williams or by Törnebohm.

GABBROS, DIORITES, AND RELATED ROCKS.

BASIC STOCK; GABBRO AND DIORITE PHASES.

The oldest of the intrusives illustrates the common characteristic of basic stocks in exhibiting considerable variation of composition, structure, color, and texture in its rock types. A large number of thin sections were made from specimens collected in all parts of the stock. They show that its material occurs in the form of five different phases, repeatedly occurring in more or less typical form, and connected with one another by transitions. All five seem to have been differentiated from the product of a single intrusion. That we have here to do with an eruptive of a truly exotic nature is abundantly proved at almost any point of the schist contact. Both to the north and to the south of Little Ascutney excellent examples of intrusive dikes and sills, plainly apophysal from the massive rock, are to be found cutting the gneisses. The horses of schistose rock are so abundant at many contacts as to make up veritable flow breccias, and fragments are occasionally found several hundred yards from the contact.

Phase d is the one rock type from the Basic stock which has been chemically analyzed. It is somewhat more acid than the average type, but it was selected on account of its relative freshness. The specimen analyzed (Table IV, col. 1) was taken from some blasted ledges about 100 yards north of Mr. Pierson's house, on the notch road between the two Ascutneys. It is a fairly coarse-grained dark bluish-gray quartz-diorite of typical hypidiomorphic granular structure, in which the essential dark-colored silicates are biotite and a diopsidic augite with subordinate brown hornblende (spec. 35).

The feldspar of the rock is almost always multiple-twinned, following the albite law, more rarely the pericline law. The very common association of albite and Carlsbad twinning in the slide makes it possible to determine the feldspar with a high degree of accuracy. In addition, Becke's method of differential single refraction, the reading of extinctions on cleavage pieces and on sections cut parallel to the bissectrices, and the principle of equal illumination in the zoned individuals agreed well in establishing the average mixture of the soda and lime molecules as one slightly more acid than the basic oligoclase, $Ab_2 An_1$. Yet single individuals may vary from the acid oligoclase $Ab_4 An_1$ to bytownite $Ab_1 An_4$. Zoned crystals are common. The cores range from $Ab_1 An_4$ to $Ab_2 An_1$, with an average close to the andesine $Ab_4 An_3$, while the outer zones seem to be invariably more acid, with an upper limit at the acid oligoclase $Ab_4 An_1$.

The tolerably high percentage of potash in the analysis leads one to suspect a potash feldspar, but diligent search has so far failed to establish the presence of either orthoclase or microcline. The refraction of the rare untwinned individuals was carefully compared in a number of slides with the refraction of quartz and undoubted plagioclase, and showed, often with the corroboration of convergent light, that these untwinned individuals are likewise soda-lime feldspars averaging basic oligoclase. The determination of orthoclase in the rock powder is impossible because the basic oligoclases and acid andesines occur in such profusion. The potash of the analysis must, then, be referred primarily to the biotite, and, in a notable degree, to isomorphic mixture with the soda-lime feldspar. That there must be some potash outside of the biotite is not to be doubted, for, granting the high proportion of 10 per cent of potash in the biotite, and crediting that mineral with all the oxide, there must be at least 23.4 per cent biotite in the rock. Inspection shows that even that minimum proportion of the mica is not represented, although it is next the feldspar in abundance. It has the usual properties of biotite from normal granitic rocks—powerful pleochroism and absorption in brown and yellow tones, extremely small optical angle, and parallel extinction.

The augite is crystallized both alone and in the form of intergrowths with hornblende. In both cases the habit of the mineral is that of common diopsidic, colorless to pale greenish, allotriomorphic individuals from 1 to 5 millimeters in diameter. A third cleavage parallel to (100) occurs in a few sections. Twinning parallel to (001) is not rare. Pleochroism is absent. The alteration is largely confined to chloritization, but paramorphic changes to a uralitic amphibole are common.

The brown hornblende almost invariably forms intergrowths, either irregular or oriented in parallel fashion with augite. In all cases the mineral is doubtless primary. The pleochroism is as follows:

a. Pale grayish yellow.

b. Greenish brown with a tinge of olive (medium absorption).

c. Brown (medium to strong absorption).

$\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The prismatic angle is 55° 32′ (average of measurements on eight cleavage pieces). The extinction on (110) is about 12° 30′, and on (010) about 15°. It is seen that the mineral belongs to a common variety of amphibole.

Quartz forms allotriomorphic, cementing grains which represent the last stage in the crystallization of the rock. It is never present in large amount. Gas and liquid inclusions, often simulating negative crystals in form, are common, particularly in the coarser-grained specimens of the rock.

Apatite needles and larger crystals are abundant. A characteristic feature of this accessory is the common inclusion, in the form of elongated cores, of isotropic, probably glass, bodies of a deep-brown color (Pl. III, *B*.)

Ilmenite or titaniferous magnetite and primary titanite with weak pleochroism are important accessories. Large zircon crystals and occasional grains of pyrite complete the list of accessories.

The structure is hydiomorphic-granular. The feldspar is often idiomorphic against both augite and quartz. The biotite is always idiomorphic against quartz, rarely against feldspar, and may inclose all the other constituents in poikilitic fashion. The augite is usually intersertal with reference to the feldspar and incloses all the accessories. The sequence of crystallization appears to have been (in order from the oldest to the youngest mineral) as follows:

Apatite.
Titanite, zircon and ilmenite.
Feldspar.
Augite (and hornblende). } Nearly contemporaneous.
Biotite.
Quartz.

The composition of the biotite, augite, and hornblende not being known, it is not possible to calculate the analysis. The analysis agrees with the microscopic examination in placing this rock decidedly in the class of true diorites, as a *biotite-augite-hornblende-diorite*. For ease of reference, columns 2 and 3 are entered in Table IV in order to show the similarity between our rock and a fair average diorite and also the limits of chemical variation which can be found in a list of typical analyses from that rock group. From its field associations one might expect the Basic stock to have given a higher proportion of alkalies in its average phase. For this reason column 4 has been added to point the dissimilarity between the Ascutney rock and essexite, the alkaline type nearest to it in general habit. The absence of monoclinic feldspar and of olivine among the constituents, and the relatively low proportion of soda and of ferric iron compared to the essexite, serve to dispel the a priori notion that the alkaline stocks on the east should be accompanied, in their common conduit, by an intrusive of essexitic or allied alkaline habit if that intrusive were to be a plagioclase rock of basic character.

Phase c.—A second phase intimately allied to the first, both in field relations and lithological characters, is represented in a long series of outcrops lying southeast of Mr. Pierson's house on the Notch road. Two specimens of the brownish-gray, medium-grained rock were selected at a point 500 yards distant from the house, and proved to be a normal *biotite-hornblende-diorite*, with structure and accessories similar to those in phase *d* (spec. 32). The feldspars generally show two zones of growth; the cores average a labradorite between $Ab_1 An_1$ and $Ab_2 An_3$, the narrower mantling zone averaging the oligoclase $Ab_3 An_1$. The average soda-lime feldspar is probably close to that of the analyzed phase. The chief difference from the latter rock lies in the replacement of the augite by an idiomorphic brown hornblende of much deeper absorption than that characterizing the intergrown hornblende of phase *d*. Here the scheme of absorption is: **a**. Yellow. **b**. Deep brown, with a suggestion of olive-green. **c**. Deep chestnut-brown. $c > b > a$ or $c = b > a$.

One or two large subidiomorphic individuals of nearly colorless augite have been found in the slides. In each case a broad mantle of the deep-brown hornblende surrounds the augite in parallel intergrowth. The biotite is of the same nature as in phase *d*, but much less abundant and seldom poikilitic.

TABLE IV.—*Analyses of diorites and essexite.*

	1.	2.	3.	4.
SiO_2	52.12	56.52	52.00–62.80	47.94
Al_2O_3	16.35	16.31	12.41–18.00	17.44
Fe_2O_3	3.68	4.28	0.77– 7.42	6.84
FeO	6.02	5.92	2.41–12.84	6.51
MgO	4.14	4.32	2.02– 8.03	2.02
CaO	7.25	6.94	4.99– 8.98	7.47
Na_2O	3.65	3.43	2.31– 4.65	5.63
K_2O	2.34	1.44	0.44– 2.37	2.79
H_2O above 110° C	0.88	1.03	0.16– 2.24	2.04
H_2O below 110° C	0.25			
CO_2	0.07	----------	----------	----------
TiO_2	2.10	0.25	0.03– 1.10	0.20
ZrO_2	0.02	----------	----------	----------
P_2O_5	0.89	0.40	0.17– 1.06	1.04
Cl	0.09	----------	----------	----------
F	0.03	----------	----------	----------
FeS_2	0.24	----------	----------	----------
NiO, CoO	Trace.	----------	----------	----------
MnO	0.17	0.14	----------	----------
BaO	0.04	----------	----------	----------
SrO	Trace?	----------	----------	----------
Li_2O	Trace.	----------	----------	----------
	100.33	100.98	----------	99.92
O=F, Cl	0.03			
	100.30			
Total S	0.13			
Sp. gr	2.936			

1. Biotite-augite-hornblende-diorite, Basic stock, Ascutney Mountain. Analysis by Hillebrand.

2. Average of a series of 16 typical diorites, compiled by Brögger, Die Eruptivgesteine des Christianiagebietes, Vol. II, 1895, p. 37.

3. Limits of variation in the above-mentioned 16 analyses.

4. Classic essexite, Salem Neck, Salem, Mass. Analysis by Dittrich.

Phase b.—At various points in the stock, especially west and south of Pierson Peak and near the crest of Little Ascutney ridge (spec. 61), the rock becomes coarser than in either of the two phases just described and shows a distinct difference of composition from either. At the same time, repeated examination of ledes in the field could discover no difference of age among the three. This third phase is dark colored and remarkable for its richness in bisilicates, which have a strong poikilitic habit. Augite and biotite of the general character of those minerals in phase *d*, and large independent crystals with augite intergrowths of brown hornblende similar to that in phase *c*, are the essential dark-colored constituents. The biotite has, however, an optical angle considerably greater than elsewhere observed in the stock; it was measured and found to be a few minutes more than 9°.

A long series of feldspar determinations accorded with one's first impression of the rock in studying the hand specimen, that it belongs to a phase much more basic than *c* and *d*. The prevalence and large size of the Carlsbad albite twins and the uniform behavior of the feldspar enables us to state conclusively that the average feldspar in this phase is close to basic labradorite, Ab_2An_3, with a narrow range above and below the acidity of that mixture. Primary quartz is entirely absent. Nearly colorless titanite is especially abundant, both alone and surrounding the large ilmenites after the manner of leucoxene.

The basicity of this phase unquestionably places it among the gabbros, and it may be called a *hornblende-biotite-augite-gabbro*, notwithstanding the absence of true diallage among the constituents.[a] It probably rivals phase *d* in the amount of surface covered in the stock.

Phase a.—In the fields west-southwest of Pierson Peak a fourth variant of the rock outcrops in the form of an unusually coarse-grained type (spec. 112). It is more feldspathic than phase *b* and hence of a lighter color. Biotite and hornblende have almost completely disappeared, the former being a rare accessory, the latter forming occasionally a mantle about augite. The light reddish-brown feldspar is again very uniform and averages the basic labradorite, Ab_2An_3. The usual accessories are present excepting quartz. The structure is the hypidiomorphic granular, but on account of the intersertal relation of the augite to the feldspar, it assumes the special habit of diabase. The poikilitic nature of the augite is very striking. The phase has the composition and other characters of a typical diabase excepting in its geological occurrence. It may be called an *augite-gabbro*, though diallage is here, too, wanting.

Phase e.—Finally, a fifth phase remains to be noted, which is not important on account of the amount of area covered by it in the stock as a whole, but which merits particular attention on account of its

[a] We can not but agree with Judd (Quart. Jour. Geol. Soc., Vol XLII, 1886) and Lacroix (Bull. serv. carte geol France, No. 67, Vol. X, 1899, p. 27) in regarding it as indifferent, for purposes of nomenclature, whether the pyroxene of a gabbro possess the diallagic structure or not.

forming a transitional rock type between the true gabbros and diorites on the one hand and the alkaline rocks of the region on the other. This phase was discovered just north of the contact between the stock and the great syenite-porphyry dike of Little Ascutney, and opposite the middle of that dike. The rock is fairly fresh and tolerably coarse grained, and is rich in feldspar, brown hornblende, and biotite (spec. 59). Augite forms in a few rare instances small cores of hornblende intergrowths. The accessories common to all the phases are present, and, in addition, some free interstitial quartz. But the feldspars are in great contrast to those so far noted as occurring in the stock. Plagioclase, averaging near the andesine Ab_5An_3 is dominant; oligoclase ranging between Ab_3An_1 and Ab_2An_1 is common. The plagioclase is sometimes surrounded by a mantle of oriented microperthite. What is still more noteworthy is the existence of much free orthoclase and microperthite alongside the triclinic feldspar. The order of crystallization is as follows:

Apatite.
Titanite, zircon, and ilmenite.
Augite, hornblende, and biotite.
Oligoclase-andesine.
Orthoclase and microperthite.
Quartz.

The structure of the rock is the usual hypidiomorphic granular. Its true relation to the diorites is indicated if we call it an *orthoclase-microperthite-bearing hornblende-biotite-diorite*. Yet the rock is clearly allied to a somewhat acid form of essexite.

BASIC SEGREGATIONS.

In phase *e*, at the locality indicated, basic segregations were sparingly found (spec. 59a). These are of distinctly darker color than the parent rock, and both macroscopically and microscopically are seen to be finer grained. They are roundish in form and average about 1 inch (2.6 mm.) in diameter. The boundary between nodule and parent rock is not definite; they merge into each other in a gradual way. The nodules are essentially composed of plagioclase, hornblende, and biotite grouped with a panallotriomorphic structure. The feldspar is zoned; the most acid zone is the oligoclase, Ab_4An_1, and the average feldspar is near labradorite, Ab_1An_1. No certain orthoclase or microperthitic feldspar could be identified in the slide. The dark constituents have the usual properties of those minerals in this stock. The augite is more abundant here than in the parent rock, though again generally it occurs in the form of intergrowths with the hornblende. Zircon is very rare, but apatite unusually abundant. A little interstitial quartz is accessory.

TABLE V.—*Analysis (by Hillebrand) of hornblende-biotite-diorite nodule.*

	Per cent.
SiO_2	55.28
Al_2O_3	17.23
Fe_2O_3	1.54
FeO	6.23
MgO	2.69
CaO	5.60
Na_2O	5.42
K_2O	2.12
H_2O above 110° C	0.71
H_2O below 110° C	0.20
CO_2	0.04
TiO_2	1.64
ZrO_2	Trace.
P_2O_5	0.73
Cl	0.07
F	0.28
FeS_2	0.07
MnO	0.24
BaO	0.06
SrO	Faint trace.
Li_2O	Trace.
	100.15
O=F, Cl	0.13
	100.02
Total S	0.038
Sp. gr	2.822

The analysis of one of these nodules agrees with the microscopic diagnosis (except in the matter of structure) in placing it in classification among the hornblende-biotite-diorites (Table V). The high soda relates the nodule to essexite. It is more basic than its host, though more acid than the diorite analyzed (phase *d*.) The high fluorine is again noteworthy.

DIORITIC DIKES CUTTING THE BASIC STOCK.

Following the consolidation of the Basic stock the same magma which it represents seems to have been erupted a second time, and as a result we have networks of interlacing dikes in various parts of the stock. These are oftentimes so numerous as to give the bare ledges the appearance of mosaics on a large scale. Occasionally the younger intrusive has so extensively displaced the older as to form miniature stock-like bodies sending out apophyses into the coarser rock and inclosing horses of the latter. The mosaics are thus intrusion-breccias or flow-breccias. The younger intrusives cut with apparent indifference both the gabbroitic and the dioritic phases of the stock.

In color, mineralogical and chemical composition, and even in structure, the dikes are closely allied to the diorite analyzed. In the fields southeast of Pierson Peak both the younger and older rocks are augite-biotite-hornblende-diorites (spec. 147). Within a hundred yards a second network of dikes is characterized by the complete absence of hornblende and by a remarkably perfect zonal structure in its feldspar (spec. 145*a*). The great range in acidity of these feldspars was not found equaled in any other rock of the whole region. By the method of equal illumination, checked by the behavior of each zone in convergent light, it could be proved that the core of such a feldspar may be a true anorthite. Outside the core basic labradorite near Ab_1An_2 is succeeded by a third zone of oligoclase near Ab_2An_1, and outside of all there comes a narrow zone of the albite $Ab_{12}An_1$. The average of several determinations on Carlsbad albite twins gave basic oligoclase, Ab_2An_1, as the average feldspar of the rock. The usual accessories are present. This rock is a typical *augite-biotite-diorite.*

A very similar type occurs in the form of a series of parallel dikes on the northern slope of Little Ascutney and at its eastern end (spec. 184). Here a significant amount of orthoclase was discovered among the accessories. In immediate association with the first group of reticulate dikes mentioned, another group of a lighter color but of similar structure showed in the microscopic examination a still greater proportion of orthoclase, which is accompanied by microperthite. The bulk of the feldspar is still, however, near the basic oligoclase Ab_2An_1. Biotite is the only other essential. Augite fails and brown hornblende is a rare accessory. The type may be called a *biotite-diorite* bearing accessory orthoclase and microperthite.

"WINDSORITE" DIKES CUTTING THE BASIC STOCK.

Potash-feldspar finally becomes of nearly equal importance among the essential minerals of these rocks in a set of light-colored, pinkish-gray dikes 1 to 3 feet (0.3 m. to 0.9 m.) in width; traversing the stock in the notch just northeast of the eastern end of Little Ascutney (spec. 77), and again on the notch road near Mr. Pierson's house. The dikes at the former locality seem to have been cut off by the porphyry occurring on Little Ascutney. The plagioclase varies from andesine, Ab_5An_3, to oligoclase, Ab_3An_1, the average mixture being probably basic oligoclase, Ab_2An_1. The triclinic feldspar is often surrounded by mantles of orthoclase or microperthite. Orthoclase, microperthite, and, probably, soda orthoclase, especially the first two named, are the alkaline feldspars, the abundance of which is reflected in the chemical analysis of this rock type (Table VI, column 1).[a] Shreds, irregular plates, and, rarely, idiomorphic crystals of biotite represent the only other essential. Rare grains of augite and still rarer bleached indi-

[a] Through a mistake, a fragment of diorite from the younger dikes was included in the sample of this rock sent to Washington for analysis. This unfortunate fact explains the difference between column K (the vitiated analysis) and column L on page 69 of Bulletin 148 and on page 25 of Bulletin 168 of this Survey.

viduals of hornblende with ilmenite, apatite, zircon, and (doubtfully) titanite, compose the list of accessories. Pyrite developed secondarily on the joint planes explains the sulphide of the analysis. The mica must be rich in magnesia and is probably a meroxene. Quartz occurs interstitially in comparatively large amount. The bisilicate and biotite exhibit a great amount of magmatic resorption, and it is therefore difficult to be certain of the order of crystallization. It is probably as follows:

Apatite.
Zircon.
Ilmenite and titanite.
Biotite, augite, and hornblende.
Andesine and oligoclase.
Microperthite, orthoclase, and soda orthoclase.
Quartz.

No analysis of the mica has been made. On account of its small amount in the rock, no serious error in the calculation of the other and more important essentials will be made if we assume that in the biotite there is 20 per cent MgO, 40 per cent SiO_2, and 8 per cent K_2O. On this supposition, the quantitative mineralogical composition of the rock was calculated as follows:

Mineralogical composition of windsorite.

	Per cent.
Albite molecule	38.5
Orthoclase molecule	28.5
Anorthite molecule	11.5
Quartz	13.0
Biotite	5.0
Magnetite and ilmenite	2.5
Diopside, apatite, and zircon	1.0

If the average plagioclase = Ab_2An_1, the rock contains 34.5 per cent soda-lime feldspar and 44 per cent alkali feldspar.

TABLE VI.—*Analyses of windsorite and other rocks.*

	1.	2.	3.	4.	5.
SiO_2	64.62	67.14	65.00	59.00–68.50	65.65
Al_2O_3	16.46	15.37	16.00	14.00–17.00	16.84
Fe_2O_3	1.82	2.24	1.50	1.50– 2.25	4.01
FeO	2.14	1.93	3.00	1.50– 4.50	
MgO	1.10	1.36	2.00	1.00– 2.50	0.13
CaO	2.39	3.60	5.00	3.00– 6,50	2.47
Na_2O	4.57	3.29	3.50	2.50– 4.50	5.04
K_2O	5.21	4.06	2.25	1.00– 3.50	5.27
H_2O above 110° C	0.39	0.59			0.30
H_2O below 110° C	0.13	0.07			
CO_2	0.11				
TiO_2	0.81				
ZrO_2	0.03				
P_2O_5	0.21				
Cl	0.05				
FeS_2	0.19				
MnO	0.12				
BaO	0.03				
SrO	Trace.				
Li_2O	Trace.				
CuO	Trace.				
Remainder		0.35	1.75		
	100.38	100.00	100.00		99.71
O=F, Cl	0.01				
	100.37				
Total S	0.10				
Sp. gr	2.666				

1. Dike of windsorite, Little Ascutney Mountain; analysis by Hillebrand.
2. Average of two typical quartz-monzonites, from the Sierra Nevada. Turner, Jour. Geol., Vol. VII, 1899, p. 152.
3. Average composition of granodiorite, according to Lindgren. Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1896, p. 35.
4. Limits of variation in granodiorite, according to Lindgren. Ibid., p. 35.
5. Alkaline augite-hornblende-syenite (nordmarkite), Diana, New York; analyzed by C. H. Smyth, Bull. Geol. Soc. Am., Vol. VI, 1895, p. 274.

Table VI represents type analyses of related rocks. Of these and of the Ascutney dike the essential mineralogical composition is as follows:

1. Basic oligoclase, microperthite, orthoclase, quartz, biotite.
2. Oligoclase, quartz, orthoclase, biotite, amphibole.

3. Oligoclase-andesine (usually andesine), quartz, orthoclase, biotite, green hornblende.
5. Microperthite, albite, augite, hornblende.

This rock belongs to another type intermediate between the orthoclase rocks and the plagioclase rocks. It is almost identical in chemical composition with certain nordmarkites (cf. col. 5), but the lime is practically all in the highly important essential, basic oligoclase. This character definitively removes the rock from the nordmarkites. We can not, on account of the high alkalies and relatively low lime, place it in the group of the granodiorites (cf. cols. 3 and 4), nor, for the same reason, in the group of the quartz-monzonites (cf. col. 2), though in general the affinities are stronger with the last-named group than with any other already well-defined type. The soda and the combined alkalies are too high to characterize a normal lime-alkali quartz-syenite. The rock is, in reality, a leukocratic analogue of the quartz-monzonites in which augite is replaced by biotite. It may also be considered as the alkaline equivalent of granodiorite. Standing in a class by itself, both with respect to the other Ascutney intrusives and with respect to the types now recognized in our rock classifications, the name *windsorite* is proposed for the rock in order to fix this type and to facilitate reference to it. The name is taken from that of the neighboring town northeast of the main mountain. Windsorite may be defined as a leukocratic, hypidiomorphic-granular rock, composed essentially of alkaline feldspar (microperthite and orthoclase), basic oligoclase, quartz, and biotite, and characterized by high alkalies (potash slightly in excess of the soda), relatively low lime (contained essentially in the plagioclase), low iron, and low magnesia.

SYENITES.

The Basic stock is cut by several large independent bodies of syenitic habit. Their rocks are so similar in compositon that, as in the case of the dioritic rocks, a detailed petrographical description of a chief phase in one of the bodies will suffice to illustrate the larger part of what may be said in description of the other phases and related intrusives. In this way some repetition may be avoided.

MAIN SYENITE STOCK; ITS PHASES.

As we have already seen, Mount Ascutney owes its strong relief to the largest intrusive mass in the area discussed—the Main syenite stock covering about 4 square miles (10.5 square kilometers). The intrusive character of the rock is plainly indicated at almost any part of the contacts with the diorites, gneisses, or phyllites (see Pl. VI). The walls of the conduit appear to be usually nearly vertical, inasmuch as the line of contact in all but two or three cases runs straight across the radiating gulches and does not turn up or down the corresponding brook beds. The latter rule is departed from at three of the largest ravines in the mountain. At Crystal Cascade the schists stand vertical or dip at high angles to the east-northeast. They form a blunt projection into the igneous body, and, on account of their relative softness, the strong gulch below the cascade has been worn out. The actual surface of contact between schist and syenite is exposed for a vertical distance of 100 feet. That sample contact is nearly vertical. A second deep ravine, 1 mile east of the cascade, may be explained as located on a similar broad tongue of schist less resistant to the weather than the syenite to right and left of the ravine. At only one point does the surface of contact seem to depart from verticality, namely, at the picturesque ravine south of Brownsville. There the schists dip under the syenite as if the latter had, during intrusion, followed the planes of schistosity after the manner of a sill or laccolith. But this observation stands alone, and such a structural relation must be regarded as exceptional and very local.

The syenite showed a general independence of the structure of the invaded rocks as it found its way up from its deep-lying source. Both to north and to south of the mountain the schists strike steadily toward the stock. They are not essentially displaced from their original tilted position, except as a result of some relatively slight crumpling in the contact zone, but are cut squarely off by the syenite. This is true at the eastern contact as well. At several points the contact plane was observed to cut across the structural plane of the phyllites. If, however, the intrusion had been controlled by the latter, we should expect the surface of contact to dip eastward and the zone of metamorphic change in the schists to be broader there, at the eastern end, than elsewhere. The facts do not agree with either conclusion.

The syenite thus constitutes a pipe-like stock of roundish outline, the cylindrical form being modified by a few large projections of schist in place and by the irregular stock of the younger Ascutneyville granite.

A notable characteristic of the Main stock, as of the older one, is the variability of the rocks composing it. Though they are everywhere related to the group of the alkaline syenites, they exhibit important mineralogical, chemical, and structural differences. Four chief types of the variations in color, grain, structure, proportion of dark-colored to light-colored constituents, and the distribution of inclosed basic segregations, are to be distinguished. In the field the transition of these types into one another is so complete that they must be regarded as the differentiated product of one body of magma. As yet there is no certain observation forthcoming to show that there was more than one eruptive period for all four, even in the sense of the intimately associated diorite and reticulate dikes of the Basic stock, or in the sense of Brögger's hypothesis of the cutting of still unconsolidated augite-syenites by elæolite-syenite. It will be remembered that Brögger introduced that hypothesis in order to explain the field association of the Christiania rocks.[a]

Like the still younger granite, the syenite has, in general, a finer texture than the gabbro-diorites. This contrast is to be related to the greater basicity of the latter rather than to any essential difference of physical conditions under which the intrusion of the basic and acid stocks occurred.

Phase f, nordmarkite of granitic habit.—The only quarry that has recently been worked in the Ascutney area is situated within a few hundred feet of the contact with the schists in the first of the four phases of the Main syenite. Various attempts have been made to use the stone for monuments and for ornamental purposes generally, but, for a reason which will be noted further on, a market could not be permanently secured by the owners. The quarry seems to have been practically abandoned. The finest blocks yet taken out are doubtless those which are to be seen in the large columns of the library building at Columbia University, New York City.

The rock, as represented in the quarry, is a handsome, dark-green syenite, in this place characterized by medium to coarse grain and a typical eugranitic structure (spec. 42); elsewhere this phase grades into one possessing a trachytic structure. It is a syenite with variable amounts of free quartz and a low percentage of colored constituents. Primary veins or flow streaks are common; they are usually finer-grained than the average rock, and are even more poorly provided with bisilicates. In addition to the feldspars and accessory quartz, the list of minerals includes, in the order of their abundance, a hornblende, biotite, a pyroxene, allanite, titaniferous magnetite, apatite, pyrite, zircon, monazite, and a lime-iron garnet. The order of their crystallization seems to have been as follows:

Apatite.
Zircon.
Magnetite, pyrite, garnet.
Monazite and allanite.
Augite, hornblende, and biotite.
Oligoclase.
Alkaline feldspars.
Quartz.

The feldspars.—The constituents which determine the structure, texture, and color of the syenite are the feldspars (Pl. IV, *A*.) Of these, microperthite is by far the most abundant, and with it are associated orthoclase, soda-orthoclase, microcline, and a plagioclase. There is no observable difference in the macroscopic habit of these feldspars, and it was only by the careful study of slides and rock powder that all the species could be determined. All of them are undoubtedly the product of primary crystallization.

[a] Zeit. für Kryst., Vol. XVI, 1890, p. 281.

The microperthite is especially interesting on account of its typical development. The usual intergrowth is that of orthoclase with a plagioclase varying from albite to an acid oligoclase near Ab_5An_1, but on many cleavage pieces it was easily proved that the triclinic feldspar was intergrown with a monoclinic, itself strongly charged with the soda molecule. Such individuals gave extinctions of 12° and 19° on (010) for the two kinds of lamellæ, thus indicating the association of nearly pure albite with an orthoclase that stands at the extreme soda end of the series, generally designated by the name "soda-orthoclase." In all cases the intergrowth follows the law whereby the triclinic lamellæ lie in the monoclinic feldspar parallel to a steep orthodome; the angle of 72° between the albite lamellæ and the basal cleavage on (010) indicates that this dome may be $(\bar{8}01)$, the one noted in this relation to intergrowth by Brögger. From the normal microperthite there are all transitions to what would appear to be true cryptoperthite. Both ends of the series sometimes show the murchisonite parting, which is unusually clean and definite.

The tabular crystals of well-lamellated microperthite from a highly feldspathic phase on the Brownsville slope of the mountain represent a very high proportion of soda in the mixture, as shown by the polarization phenomena and the specific gravity of from 2.610 to 2.611 at 17° C. Generally, however, the proportion of potash to soda is about 1:1, corresponding to a specific gravity of from 2.584 to 2.595 at the same temperature. The same average ratio is believed to characterize the feldspars of the rock as a whole. It is true that there is a not unimportant amount of orthoclase and soda-orthoclase in most of the slides, yet this lowering of the otherwise high percentage of soda is occasionally counterbalanced by a little free oligoclase and always by a microperthite which is richer in the triclinic component than the average stated.

The pure potash feldspar is relatively rare. It occurs as orthoclase and as microcline, both contemporaneous with the microperthite in their period of crystallization.

The plagioclase is no more than accessory. The usual optical methods of determination agreed in showing that it belongs to a series from practically pure albite to the oligoclase Ab_5An_1. Anorthoclase could not be demonstrated in any of the Ascutney rocks, nor should it, on account of the lowness of lime, be expected. Barium oxide doubtless occurs in isomorphic relation with the soda and potash of the feldspars. No hyalophane has been discovered in the rock.

Rapid tarnishing on exposure to air.—One of the most remarkable properties of this rock consists of the unstable character of its color. When broken out of the quarry a fresh specimen is uniformly, on the surface of fracture, a light bluish gray. In the course of twenty-four hours, under atmospheric conditions, this tint changes to one with a greenish tinge, and after an exposure to the air of about thirty days it has become a deep brownish green—the color we have noted for the numerous blocks of the quarry. This green color is in its turn lost when the rock has suffered more pronounced weathering after many years of exposure. The final change gives the familiar yellows and browns of a decomposed ferruginous rock. In this stock the rapid change from gray to green was observed only in phase *f*, as exposed on the north and northwest slopes of the mountain.

Examination quickly showed that the color change of the rock is conditioned by the feldspar and that it is altogether a superficial phenomenon, taking place only where the air has access to the mineral. The question has naturally arisen as to the cause of this peculiar instability of color, and a number of experiments were carried out which have thrown light on the problem. To show that one or more of the principal atmospheric gases were essential to the reaction, a gray piece of the fresh rock was immersed in a stream of carbon dioxide gas for twenty minutes and then kept in an atmosphere of that gas for twenty-four hours. No appreciable change was noted in the original gray tint, showing that in all probability the carbonatization of some unknown element in the feldspar could not explain the alteration of tint. The inference was ready to hand that it was rather due to oxidation. A gray fragment of the rock was accordingly placed in an atmosphere of purified oxygen over night. A perceptible change to the green color resulted. The same piece was then changed to an intense green by an exposure of thirty minutes to a stream of oxygen, while the fragment was kept at a temperature of about 150° C.

The further question remained: What oxidizable substance present in the feldspar would, on uniting with the oxygen of the air, furnish the required color? That it is not organic was shown by the fact that before the blowpipe the green tint was not only not destroyed, but, on the contrary, was deepened in the oxidizing flame—another testimony to the fact of oxidation as the true cause. Partial decolorization resulted from the application of the reducing flame. The probable explanation of the color change is found in the oxidation of the ferrous oxide of the feldspars to the ferric, thus giving a yellow which, in combination with the fundamental blue-gray of the under layers of the crystal substance, affords the green of the altered surface. In acids the mineral is decolorized to the original bluish gray, which is permanent, and the filtrate gives a strong reaction for iron. A high power of the microscope shows that the perfectly fresh feldspars are all crowded with myriads of extremely minute blackish granules. It is possible that this dust is composed of ferrous oxide, dating as to its period of formation from the time of the original crystallization of the rock. If this be true, we can derive the instability of color from one of the most familiar reactions in the history of metasomatic processes.

Were the coloring substance uniformly distributed throughout the body of the rock, this syenite would make a favorite material for decorative purposes, for it is capable of a fine polish; but the distribution is, unfortunately, very uneven, and the consequence is that the polished monument or shaft is often blemished with streaks of lighter and darker hue than the average. Furthermore, as already implied, the tint of any specimen can never be said to be permanent. As the oxidation progresses, the bluish tone of the feldspar substance beneath the surface will have less and less influence on the color mixture and a more brownish tone will result. This is what has actually happened in the case of several tombstones which have stood for some years in the cemeteries of Brownsville and Windsor.

A similarly rapid change of color—from a grayish green to a more pronounced green—on exposure to the air, has been described by Cushing as characterizing the squeezed augite-syenites near Loon Lake, New York.[a] He suggests staining from the oxidation of the ferrous iron derived from decomposed hypersthene as a possible cause of the rusty brown color, but leaves open the question of the causes of the early stages of the color change. He points out that the uncrushed crystals are always less green than the feldspar granulated by pressure. This would be expected as one result of the increased ease with which oxidizing fluids would circulate in the rock after crushing. The gray color of the Ascutney rock corresponds with its other properties in showing that it has not been subjected to such squeezing as that once suffered by the New York syenite, which in other respects is strikingly similar to our rock. Types very close to both of these in nature and origin occur at Killington Peak in western Vermont and at Shefford Mountain, Quebec, and possess the same peculiar green color. At the latter locality the change from the fresh gray to green has also been observed. It may be noted in passing that green is a favorite hue for several species of alkaline rocks. Tinguaites are commonly green, like the groundmass of pantellerites, and grorudite from the classic locality is green, the color in the last mentioned rock being due, however, to the essential ægirine.

Hornblende.—The next most important constituent of the syenite is a hornblende belonging to the alkali-iron group of amphiboles. Often idiomorphic against the feldspars, it yet commonly possesses the feature characteristic of hornblendes that have grown in an alkaline magma—namely the irregular outline due to resorption.[b] Within the cavities thus formed by this magmatic solution, feldspar and quartz have crystallized, and in section have the appearance of inclusions in the hornblende. The color of the mineral varies through shades of brown according to the following scheme:

a, light greenish brown to grayish yellow.
b, deep greenish brown to olive-brown.
c, grayish olive-green.

[a] Bull. Geol. Soc. Am., Vol. X, 1899, p. 178.
[b] Cf. Brögger, Zeitschr. für Kryst., Vol. XVI, p. 131.

The absorption parallel to **b** and **c** is very strong; **b**>**c**>**a**.

By the use of cleavage pieces mounted on the Fedoroff table, the extinction was determined on (010) at 16°. The extinction on the cleavage plate itself was found to average 14° 39′. By turning the plate about an axis at once coincident with the vertical axis of the crystal and parallel with the principal section of the polarizer, it was possible to test the curve of extinction in the vertical zone. Readings were taken at positions of the cleavage plate where the plane of symmetry made angles of 42° 30′, 47° 30′, and 77° 30′ with the plane passing through the crystal at right angles to the axis of the microscope. The corresponding angles of extinction were found to be 16° 50′, 17° 25′, and 12° 0′. These results mean an angle of extinction on (010) of 16°, and an optical angle of about 70° for the amphibole.[a] Etch figures on a cleavage plate immediately oriented the crystal and therewith the ellipsoid of optical elasticity.[b] The optical axis **c** lies in the obtuse angle β in Tschermak's orientation. These conclusions were checked by the close study of rock slides, and chance sections of the hornblende favorable to the rough measurement of the optical angle and to the determination of c : **c** confirmed the results derived from the use of cleavage pieces.

The usual twinning parallel to (100) was observed.

The angle of the cleavage prism was measured on about twenty individuals and found to vary from 55° 13′ to 56° 0′, with an average of 55° 32′. This great variation from the mean is not to be explained by poor reflexes or by the personal equation of the observer, but must be conditioned by some as yet unknown cause or causes.[c] The specific gravity was taken with the Klein solution; it averaged 3.272 at 17°C., varying in a suite of ten specimens from 3.266 to 3.278. A thin splinter of the mineral melts quietly in the Bunsen burner with a strong soda flame. In view of such properties we can place this hornblende near barkevikite, in the alkali-iron series developed by Brögger.[d] Poikilitic intergrowths with biotite and allanite and parallel intergrowth with augite make it impossible to separate the hornblende and thus permit a chemical analysis of it being made, but it is plainly rich in ferric oxide and soda.

Augite.—Compared with the amphibole, the pyroxene is present in very subordinate amount. It almost invariably occurs in the cores of parallel intergrowths with the hornblende, which there is every reason to believe is primary and has thus not been derived from the pyroxene either by magmatic or by metasomatic changes. The augite has the usual diopsidic habit of most augite-syenites; the optical angle

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[a] Proc. Am. Acad. Arts and Sciences, Vol. XXXIV, 1899, p. 311.

[b] Ibid., p. 373.

[c] There is need for a thorough investigation of the whole amphibole group for the purpose of fixing the series of prismatic angles, as they undoubtedly vary with the chemical composition, and the student of the amphiboles would probably be repaid if he set about the task of finding the possible causes for the noteworthy variation in the angle for the same species from one locality.

[d] Gesteine der Grorudit-Tinguait Serie, p. 33.

is, however, remarkably small, 45° 15′ being measured in oil. The extinction angle was not found on account of the lack of favorable material.

Biotite.—In about equal proportion with the pyroxene is a deep-brown primary mica characterized by normal properties. The optical plane and the plane of symmetry are coincident. From the low percentage of magnesia in the total analysis it appears that the mica is a true lepidomelane and not a meroxene. The formation of skeleton crystals by magmatic resorption is here also very striking.

Allanite.—The rock of the Windsor quarry contains an important accessory not recognized in any other part of the syenite stock. It occurs in the form of elongated anhedral grains, either independent or associated as irregular intergrowths with the hornblende. In the hand specimen the mineral can be readily made out by its black color, waxy to lustrous appearance, and by the presence of only one good cleavage. In many cases the individuals are as much as half a centimeter long. The most striking microscopic property is the extremely strong pleochroism and absorption. The colors vary from cinnamon-brown to deep walnut-brown in some individuals; in others chestnut-brown and purplish brown appeared, while in the thicker slides the more powerful absorption gave almost absolute blackness. The single refraction seemed to be higher than that of hornblende, but the double refraction was weaker. In addition to the good cleavage visible macroscopically, there was also present a less perfect cleavage transverse to the former at a high angle. Before the blowpipe the cleavage pieces fused with intumescence to a black magnetic glass. Such an association of properties seemed to indicate allanite, and an examination of some material from Suhl (orthite) confirmed the close similarity with that mineral. The conviction became a practical certainty when some fragments were dissolved in hydrofluoric acid, and from the solution an excellent test for cerium was obtained by precipitating with ammonium oxalate.

The allanite is (on account of the strong magmatic resorption) never idiomorphic. Yet it must be one of the oldest constituents of the rock, as it is inclosed by the hornblende, in which it often forms lively pleochroic halos. The two minerals are sometimes intergrown, but the allanite never incloses the other. Apatite, zircon, and magnetite antedate both in the order of crystallization.

We have here, then, one more example showing the importance of allanite in eruptive rocks. As early as 1885 Iddings and Cross noted the occurrence of the mineral at 28 localities and in 9 rock-types, including granite, gneiss, granite-porphyry, quartz-porphyry, diorite, dacite, and rhyolite.[a] Since then it has been discovered at many other localities, including some where the rock is alkaline and related in character to the Ascutney syenite, e. g., the hornblende granite of

[a] Am. Jour. Sci., 3d series, Vol. XXX, 1885, p. 108.

Essex County, Mass.,[a] and the quartz-syenite of Loon Lake, New York.[b]

Monazite.—A second accessory which was attended with considerable difficulty in its determination occurs in some amount in the quarry rock. It has never been observed macroscopically, but only in the slide, where it is found in the form of roundish grains reaching 1 millimeter in diameter. These are nearly colorless, with a grayish-yellow tint, and are characterized by high single refraction and by high double refraction, giving polarization colors of the third order. Crystal form is always lacking, but optical tests showed the mineral to be biaxial and monoclinic or triclinic. The cleavages, about at right angles to each other, were seen in the section of one small individual. The mineral was found to be difficultly soluble in nitric acid and more easily in hydrochloric acid. From the solution a precipitate with molybdate of ammonia was obtained, one too abundant to be explained by the associated apatite, and thus showed the grains to belong, without doubt, to a phosphate. The quantity of the solution was so small as to render impossible the sure determination of the rare earths which should be expected if the mineral be really monazite. Yet it may best be ascribed to that species as the phosphate nearest in optical properties to the one with which we are dealing.

The grains inclose numerous apatite needles of great minuteness and a few square sections of magnetite. All three minerals seem to have crystallized before the essential constituents. The monazite further shows an interesting paragenesis with the allanite, the latter sometimes appearing as a mantle about the former. Such an intimate association of a phosphate with a member of the epidote family is rather surprising, but from the study of the material in hand both minerals seem to be primary.

The magnetite is titaniferous. It is inclosed as a primary mineral by all the other constituents except apatite. Its habit is the usual one of granitic eruptives.

Titanite is rather less common than in the diorites, but possesses the same features as in the older rock. It incloses apatite; its relation to zircon is indeterminable as to the period of crystallization.

Apatite is, as usual, most abundant in the vicinity of the bisilicates, and is accordingly here, as in the feldspathic phases of the stock as a whole, very rare.

Zircon is more common than in the phases of the Basic stock. Its habit is, however, the same, excepting that it here shows a pronounced color and pleochroism.

E, pigment irregularly distributed—pale violet and colorless.

O, solid color—paler violet.

The zircon is younger than the apatite and seems to have accompanied the titaniferous magetite in its crystallization. Irregular

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[a] Jour. Geol., Vol. VI, 1898, p. 792.

[b] H. P. Cushing, Bull. Geol. Soc. Am., Vol. X, 1899, p. 180.

roundish inclusions with wide margins of total reflection are ascribed to imprisoned gas.

Quartz is uniformly allotriomorphic and interstitial. Fluid cavities and negative crystals are very numerous. The filling material of the latter could be well studied here on account of the remarkable perfection of the forms. In many cases double bubbles, that unite on heating the preparation, indicate carbonic acid gas in a saturated solution of water. The usual orientation of the negative crystals with their chief axes parallel to that of their host is easily demonstrable, especially in the isotropic sections of the quartz; in them the fluids lie in six-sided cavities, whose sharp outlines are of exceptionally clear definition.

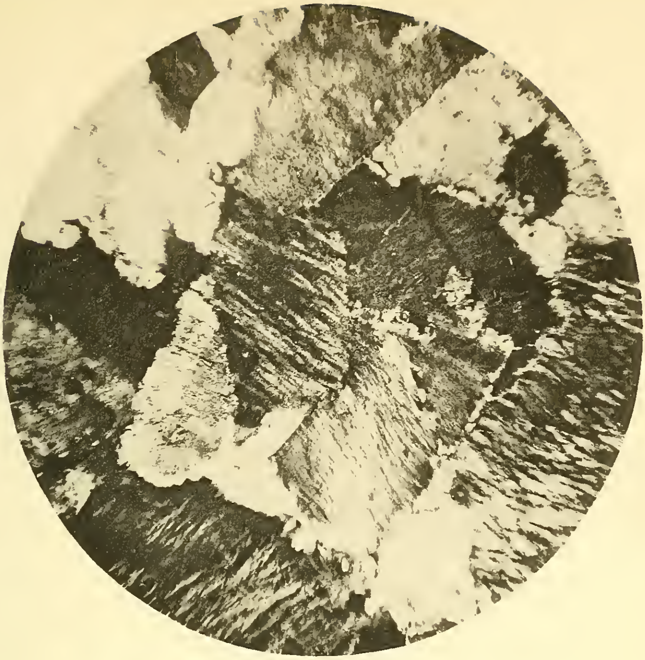
The extremely few grains of reddish common garnet were found in this phase only in those thin sections made from specimens collected near the schist contact and are doubtless to be referred to slight endomorphic influence exercised by the country rock on the eruptive.

Basic nodules, from 1 to 2 inches (2.6 to 5.2 centimeters) in diameter are occasionally seen in the quarry rock. They are differentiated mineralogically from their parent rock simply by a greater richness in hornblende, which is here, too, strikingly corroded. One can not be sure that the poikilitic habit of the mineral is anything more than apparent; primary inclusion of quartz and feldspar might give the same appearance in thin section as that due to extensive embaying of the hornblende by the caustic feldspathic magma.

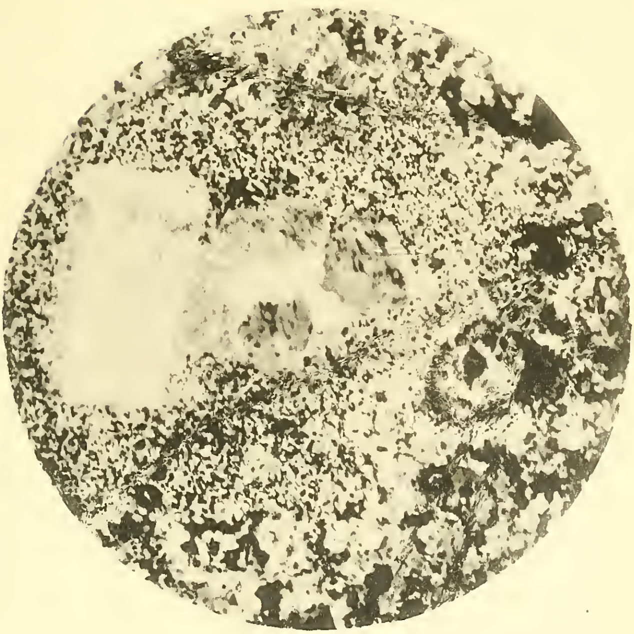
PLATE IV.

A. Typical thin section of the nordmarkite of the Main stock, granitic phase, composed almost entirely of microperthite and quartz; crossed nicols, $\times$ 20. (See p. 50.)

B. Pyroclastic feldspar (soda-orthoclase) surrounded by a reaction rim rich in alkaline hornblende, from the large paisanite dike on northwest slope of Ascutney Mountain; crossed nicols, $\times$ 7. (See p. 71.)



(A)



(B)

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TABLE VII.—*Analyses of nordmarkite and other rocks.*

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	65.43	64.88	64.04	60.45	60.03	60.5–67.0	61.49	65.43
Al_2O_3	16.11	16.24	17.92	20.14	20.76	20.0–17.5	16.14	16.96
Fe_2O_3	1.15	1.37	0.96	} 3.80	4.01	} 4.0– 3.0	5.81	1.55
FeO	2.85	2.70	2.08		0.75			1.53
MgO	0.40	0.89	0.59	1.27	0.80	1.0– 0.5	0.99	0.22
CaO	1.49	1.92	1.00	1.68	2.62	2.0– 1.5	1.67	1.36
Na_2O	5.00	5.00	6.67	7.23	5.96	7.0– 6.5	6.19	5.95
K_2O	5.97	5.61	6.08	5.12	5.48	5.0– 6.0	5.70	5.36
H_2O above 110° C	0.39	0.46	} 1.18	0.71	[a] 0.59	----	[a] 1.17	0.82
H_2O below 110° C	0.19	0.19						
CO_2	Trace?	None.	----	----	----	----	----	None.
TiO_2	0.50	0.69	} 0.62	----	----	----	----	0.16
ZrO_2	0.11	0.13						
P_2O_5	0.13	0.13	----	----	0.07	----	0.53	0.02
SO_3	None.	None.	----	----	----	----	----	0.06
Cl	0.05	0.04	----	----	----	----	----	0.04
F	0.08	0.08	----	----	----	----	----	----
FeS_2	0.07	----	----	----	----	----	----	----
BaO	0.03	0.06	----	----	----	----	----	None.
MnO	0.23	0.14	0.23	----	Trace.	----	0.28	0.40
SrO	Trace.	Faint trace.	----	----	----	----	----	----
Li_2O	Strong trace.	Trace.	----	----	----	----	----	----
	100.18	100.53	101.37	100.40	100.07	----	99.97	99.86
O=F, Cl	0.04	0.04	----	----	----	----	----	----
	100.14	100.49	----	----	----	----	----	----
Total S	0.036	----	----	----	----	----	----	----
Sp. gr	2.659	2.683	----	----	----	----	----	----

[a] Loss on ignition.

1. Hornblende-biotite-nordmarkite of granitic structure, Ascutney Mountain (phase *f*); analysis by Hillebrand.
2. Hornblende-biotite-augite-nordmarkite of porphyritic structure, Ascutney Mountain (phase *g*); analysis by Hillebrand.
3. Classic nordmarkite, Tonsenås, Norway; Brögger, Zeitschr. für Kryst., Vol. XVI, 1890, p. 54.
4. Classic nordmarkite, Aueröd, Norway: Brögger, ibid., p. 54.
5. Classic pulaskite, Fourche Mountain; Williams. Arkansas Geol. Surv., Ann. Rept. for 1890, Vol. II, p. 70.
6. Limits of variation in nordmarkites and related quartz-syenites, according to Brögger, op. cit., p. 81.
7. Average analysis of three syenite-porphyry dikes from the northern Adirondacks; Cushing, Bull. Geol. Soc. Am., Vol. IX, 1898, p. 248.
8. Nordmarkite of Shefford Mountain; Dresser, Am. Geol., Vol. XXVIII, 1901, p. 209.

From the analysis of the fresh quarry rock (Table VII, col. 1) the table of molecular proportions was calculated as follows:

	Analysis.	Molecular proportions.
SiO_2	65.43	1.0905
Al_2O_3	16.11	0.1579
Fe_2O_3	1.15	0.0079
FeO	2.85	0.0396
MnO	0.23	0.0032
MgO	0.40	0.0100
CaO	1.49	0.0266
Na_2O	5.00	0.0806
K_2O	5.97	0.0635
TiO_2	0.50	0.0061
ZrO_2	0.11	0.0011
P_2O_5	0.13	0.0009
Cl	0.05	0.0014

A partial determination shows that zircon forms 0.2 per cent of the rock; apatite, 0.4 per cent; magnetite (crediting it with all the Fe_2O_3), 1.8 per cent. A careful mechanical separation of the hornblende permitted a rough estimation of its total amount; slightly impure from included and intermixed allanite, biotite, and magnetite, it composed 5.2 per cent by weight of the total powder. Allowing for its impurity, we shall not be far from the truth in regarding 5 per cent as the proportion of hornblende. Arbitrarily estimating the lime content of the hornblende as 10 per cent (near barkevikite), the proportion of the anorthite molecule, after allowing also for the lime in the apatite, was calculated at 4 per cent. On the supposition that all the soda occurs in the albite molecule and all the potash in the orthoclase molecule, they would respectively compose 42 and 35.3 per cent of the rock. Both these figures must be slightly too high. The result of the whole calculation shows the following approximate composition:

	Per cent.
Albite molecule	41.0
Orthoclase molecule	35.0
Quartz	11.0
Hornblende	5.0
Anorthite molecule	4.0
Magnetite	1.8
Apatite	0.4
Zircon	0.2
Biotite, titanite, diopside, and allanite	1.6
	100.0

Three determinations of the specific gravity of the rock gave an average of 2.659 at 17° C.

The geological relations, structure, and constitution of this phase clearly place the rock among the alkaline quartz-syenites, closely allied to the nordmarkites of Tonsenås and other localities in the Christiania region (compare cols. 1, 3, and 6). Brögger's table gives the limiting values in the percentage composition of nordmarkite. Two other American examples are noted in columns 7 and 8.

Phase g.—The porphyritic phase of the stock is widespread, especially on the east and southeast sides of the mountain. The rock is structurally, but neither chemically nor mineralogically, except as regards some of the accessories, to be distinguished from the normal equigranular type. This second phase is exhibited on a large scale on the prominent bald knob east of the main summit.

The color of the rock is always a light gray or pinkish gray, which is stable and does not change to green on exposure (spec. 115). The phenocrysts are almost always roundish feldspars which may reach the diameter of one centimeter or more; much more rarely a hornblende or augite individual will approach the same dimension. The phenocrystic feldspars are microperthite, orthoclase, albite, and oligoclase, often arranged in groups of two or more large individuals. The first named is probably the most abundant, but is much less predominant than in the granitic phase on account of the greater amount of free albite and oligoclase. The orthoclase, to judge from its typical specific gravity (2.594 at 16° C.), must contain considerable soda in intimate mixture. The acid oligoclase and albite are often surrounded by a thin mantle of orthoclase, which is thus later in origin. Microcline is probably present among the phenocrysts, but is quite rare.

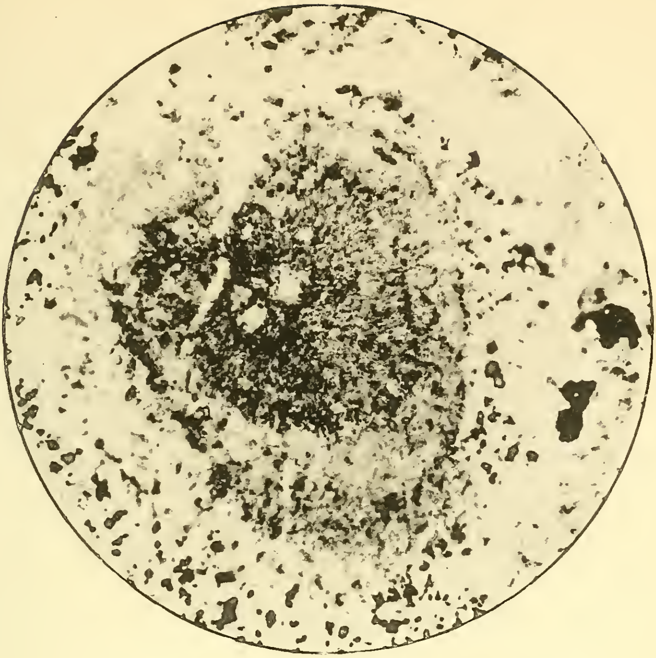
The groundmass is a hypidiomorphic pepper-and-salt mixture of the same essential minerals as in phase *f*. The diopsidic augite, brown hornblende, and the biotite are more abundant than in that phase, causing the specific gravity of the rock to be higher (here 2.685 at 17° C.). The augite, as in the phenocrysts, seems always to occur as cores in intergrowths with the primary hornblende. Corrosion of the dark-colored silicates is much less pronounced than in the granitic phase; they exhibit, correspondingly more often, idiomorphic outlines. Free quartz in the form of small interstitial grains occurs, but is not so prominent an accessory as in phase *f*. Titanite is here more abundant, and explains the somewhat higher percentage of TiO_2 in the analysis. The higher MgO is ascribed to the more abundant biotite.

The rock shows no indications of crushing; we can not, therefore, attribute the porphyritic structure to cataclastic processes. The groundmass has unquestionably crystallized in its present form from an igneous magma. The order of crystallization of its component minerals is the same as in the green rock. Several facts favor the view that the feldspar phenocrysts belong to an earlier stage in the crystallization than that which produced the groundmass.

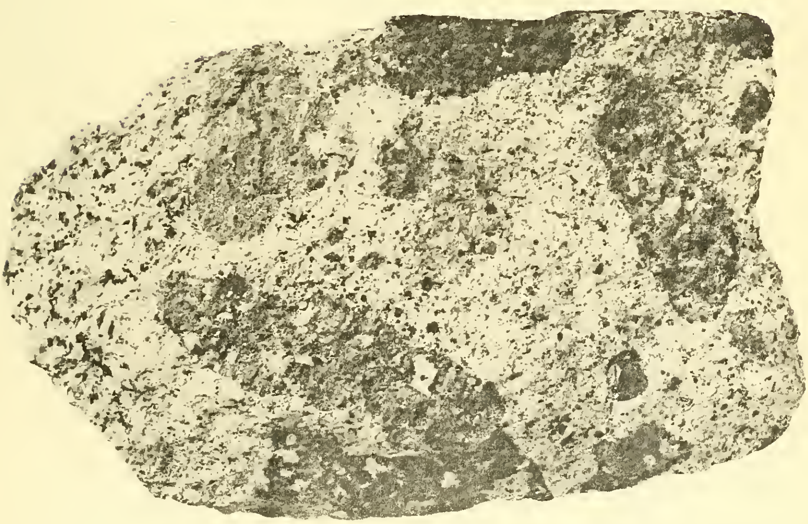
PLATE V.

A, Segregation of mica and hornblende concentrically arranged, in paisanite (the same section of the segregation also appears in the lower right-hand quadrant of the micrograph represented in Pl. IV, *B*); ordinary light, $\times$ 24. (See p. 72.)

B, Basic segregations in nordmarkite at Crystal Cascade; one-half natural size. (See p. 64.)



(A)



(B)

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Feldspars of similar nature and size are abundant in the basic segregations with which this phase is richly charged, and with them are granitic groupings of several individuals separated by interstitial quartz. The segregations are mostly composed of those minerals of the groundmass which crystallize out in an early stage of consolidation. The large feldspars and the groups would thus antedate that groundmass. The feldspar phenocrysts which are mantled with orthoclase very often present the appearance of having been extensively corroded by the magma before the mantles grew about them. It is probable, also, that there were two generations of the bisilicates. The granitic groupings of large individuals suggest that the porphyritic structure may be largely due to protoclastic action breaking up a coarse-grained granitic rock already more or less completely solidified in the conduit when the somewhat later magma of the "groundmass" was erupted. On the other hand, we can not exclude the possibility that this phase is the result of chilling, developing a porphyritic structure equivalent to that which may be seen in the endomorphic zone and in the apophyses of the granitic phase; for it is often impossible to distinguish hand specimens of the latter rocks from typical specimens of phase *g*. The problem thus merits further inquiry.

One of the most peculiar features of the syenites which may be seen in all the phases, but is best exemplified in this particular phase, is the presence in the rock of numerous dark, roundish spots or kernels. These vary from 1 millimeter to 1 centimeter in diameter. They occur in all parts of the rock, but are specially abundant in the basic segregations, which will be more fully described hereafter. The kernels belong to two classes, which show the common characteristic of a core and mantle structure. Within a relatively thin black outer covering of felted, often radially arranged, biotite (and less conspicuously hornblende) there is a core of variable composition. The latter may be composed entirely of chlorite and magnetite; of chlorite, magnetite, biotite, and a uralitic amphibole; or entirely of a light-green pleochroic actinolitic hornblende. The last mentioned is the commonest type of core.

The mantle is to be regarded as a reaction rim. The chloritic cores are the product of the alteration of augite, probably in consequence of metasomatic action. The actinolitic kernels are likewise plainly derived, but in no one of some twenty-five slides could there be found a remnant of the original mineral at the heart of the kernel. The similarity in size and general relations between these and the chloritic kernels suggest that augite was here, too, the original material from which the hornblende felt was constructed. The freshness of the biotite rim, the absence of secondary ore and chlorite, and the complete freshness of the hornblende core lead to the conclusion that the alteration took place before or during the consolidation of the rock.

This class of kernels would thus fall into the class of magmatic pseudomorphs after pyroxene. One is reminded of the analogous ocellar alteration of olivine into hornblende.

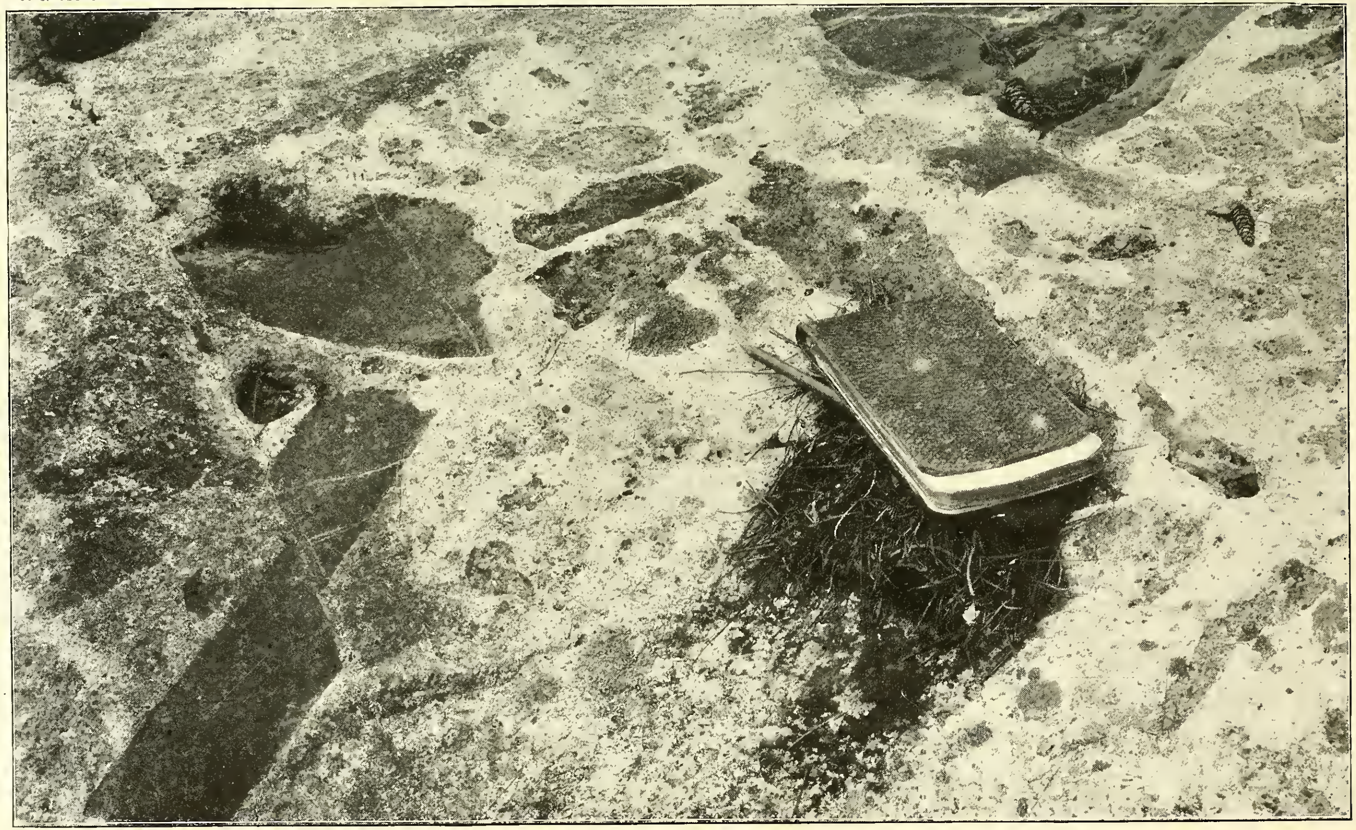
Chemically this phase is practically identical with the green granular rock (cf. columns 1 and 2 in Table VII). Mineralogically the similarity is almost as close. The only important difference is in the structure. Phase *g* may then be classified as a *nordmarkite with a porphyritic habit.*

BASIC SEGREGATIONS.

Every observant visitor to Ascutney is struck by the extreme richness of the Main syenite stock in basic inclosures of generally a nodular form, and he might also note that they are more abundant in the porphyritic phase than elsewhere (Pl. V, *B* and Pl. VI). They are distributed with great irregularity. Sometimes they occupy as much as one-half of the volume of the rock, if one may judge from the appearance of even broad ledges. At other times the nodules are separated by many feet or yards of the normal rock. Partly on account of their abundance in erratics won from the mountains a well-defined glacial bowlder train has been shown by C. H. Hitchcock to exist in the lee of Mount Ascutney.[a] The nodules are dark gray to dark greenish gray in color, spheroidal or ellipsoidal in shape as a rule, and of all sizes up to those occupying several cubic feet. The section of one of them, outcropping near the contact with the granite at the southeast end of the mountain, was found to measure 2 by 10 feet. While the much darker color causes the nodules to be in striking contrast with the normal rock in hand specimen or in ledge, microscopic study proves an intimate dovetailing and interlocking of the minerals between the two. The nodule has not been enriched in the bisilicates by the special impoverishment of the matrix immediately surrounding, for in no case could there be found a zone about the nodule distinctly lighter in color than the normal rock. This is the more difficult to understand because of the very evident lack of flow structure in the rock as a whole. The nodules seem to have formed quietly in the magma after it had suffered its "mise en place" and not to have been disturbed in position since. Even those which are decidedly elongated do not show the degree of common orientation which we should expect if they had floated in a streaming fluid matrix.

The nodular masses are themselves porphyritic. Large, irregularly bounded crystals of microperthite, cryptoperthite, microcline, orthoclase and plagioclase (averaging acid labradorite Ab_1An_1), green hornblende, and the usual diopsidic augite, with or without a hornblende mantle, form the phenocrysts (see Pl. V, *B*). The dark matrix is a fine-grained granular, panallotriomorphic mass of hornblende, oligo-

[a] Bull. Geol. Soc. Am., Vol. I, 1890, p. 30.



BASIC SEGREGATIONS AND INCLUSIONS OF SCHIST IN NORDMARKITE AT CRYSTAL CASCADE.

clase, biotite, and quartz, with abundant grains or idiomorphic crystals of titanite, ilmenite, apatite, and zircon. The microperthite and labradorite of the phenocrysts and the hornblende, biotite, and oligoclase of the groundmass are really the essential constituents. The pleochroism of the hornblende seems to indicate that it is less alkaine than the amphibole of the matrix.

a, pale yellowish green.
b, grayish green (absorption medium to strong).
c, grass-green to leek-green (absorption medium to strong).
b = **c** > **a**.

As already noted above, these segregations characteristically contain light-colored, coarsely crystalline areas from 1 to 2 centimeters in diameter, similar in composition to the normal syenite of phase *f*, i. e. equigranular aggregates of alkali-feldspar and bisilicates. These have the appearance of having functioned as centers of crystallization during the growth of the nodule, although there is a complete absence of both radial and concentric structure in the nodules.[a] In no case was there observed an approach to the "Kugelstruktur" of the rock at Virvik or at the well-known Corsican locality.

The specific gravity of the average segregation is near 2.850, and is thus considerably higher than that of the matrix, and still higher than that of the molten magma which represented the yet uncrystallized matrix. Unless that matrix possessed a high degree of viscosity during the formation of the nodules, they must have sunk down in the magma, and we might expect to find them concentrated in the lower part of the conduit; yet they appear to be distributed in about equal average proportion in all parts of the stock where the porphyritic phase was found, whether at the summit or 2,000 feet vertically below. This fact agrees with the absence of flow structure in the rock in forcing us to take the view that the segregations do not belong to the preeruptive period, as advocated by Lacroix, Michael Lévy, Graber, and others for other occurrences. The nodules had best be referred to an early stage in the actual consolidation of the syenite already occupying its conduit.

The accompanying Table VIII (col. 1) shows the analysis of the average segregation from phase *g* (spec. 66). Columns 3, 4, and 5 give, for purposes of comparison, the analyses of classic essexite, classic monzonite, and an average diorite.

The essential mineralogical composition of these rocks is as follows:

1. Oligoclase, microperthite, cryptoperthite, acid labradorite, microcline, orthoclase, hornblende, biotite, augite.
2. Microperthite, hornblende, orthoclase.
3. Labradorite, orthoclase (nepheline), augite, biotite, barkevikitic hornblende (olivine).
4. Orthoclase, oligoclase, andesine, labradorite, augite, green hornblende, biotite.

[a] Cf. Chrustschoff, Mém. Acad. imp. sci. St. Pétersbourg, Ser. VII, Vol. XLII, No. 3, 1891, p 86.

TABLE VIII.—*Analyses of basic segregations, etc.*

	1.	2.	3.	4.	5.
SiO_2	56.51	56.53	47.94	55.88	56.52
Al_2O_3	16.59	16.47	17.44	18.77	16.31
Fe_2O_3	1.35	1.58	6.84	[a] 8.20	4.28
FeO	6.59	5.40	6.51		5.92
MgO	2.52	2.67	2.02	2.01	4.32
CaO	4.96	4.90	7.47	7.00	6.94
Na_2O	5.15	5.59	5.63	3.17	3.43
K_2O	3.05	3.80	2.79	3.67	1.44
H_2O above 110° C	0.71	0.60	2.04	1.25	1.03
H_2O below 110° C	0.21	0.23			
CO_2	0.33	0.05	-------	-------	-------
TiO_2	1.20	1.40	0.20	-------	0.25
ZrO_2	0.04	0.03	-------	-------	-------
P_2O_5	0.41	0.27	1.04	-------	0.40
Cl	0.07	0.07	-------	-------	-------
F	0.24	0.19	-------	-------	-------
FeS_2	0.06	Trace	-------	-------	-------
NiO, CoO	Trace?	Trace	-------	-------	-------
MnO	0.24	0.20	-------	-------	-------
BaO	0.03	Trace	-------	-------	-------
SrO	Trace	Trace	-------	-------	-------
Li_2O	Trace	Trace	-------	-------	-------
	100.26	99.98	99.92	99.95	100.98
O=F, Cl	0.11	0.09	-------	-------	-------
	100.15	99.89	-------	-------	-------
Total S	0.03	Trace	-------	-------	-------
Sp. gr	2.849	2.756	-------	-------	-------

[a] With MnO.

1. Basic segregation in phase *g* of Main nordmarkite stock; analysis by Hillebrand.

2. Basic segregation in dike of hornblende-paisanite, Ascutney Mountain; analysis by Hillebrand.

3. Classic essexite, Salem Neck, Salem, Mass.; analysis by Dittrich.

4. Average analysis of monzonite, according to Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. II, 1895, p. 39.

5. Average analysis of sixteen typical diorites, according to Brögger, ibid., p. 37.

There is a relationship of the segregation with each of these types, though that with monzonite is the closest. The writer has seen in the laboratory of M. Fouqué, in Paris, thin sections of monzonite from

Predazzo, made from a contact phase of that rock. The structure and the small proportion of monoclinic feldspar showed close similarity of this phase of the monzonite with the Ascutney segregations.

Two other phases of the Main stock may be noted, not only on account of their importance in the field but also because they represent interesting extremes in the differentiation of the syenitic magma.

Phase h outcrops extensively in a belt about 400 yards (366 meters) wide and adjacent to the contacts with diorite and gneiss on the northwest side of the mountain. It is probably a special part of the endomorphic zone of the stock, as the phase has not been found anywhere else than in the belt specified (spec. 34). This member of the rock body is composed essentially of microperthite, usually in Carlsbad twins, and an amount of quartz sufficient to place the rock among the granites. Biotite, diopside, zircon, and magnetite are the accessories, but make up probably no more than 1 per cent of the rock. One grain of garnet, another of what is doubtless corundum, two individuals of a brown hornblende, and a few needles of apatite were discovered in the two sections that have been prepared from this phase.

The original color of the rock is due to the feldspar and is a striking dark oil green, which is permanent in the hand specimen, and doubtless represents a late stage in the series of color changes already described for the quarry rock. The structure is often fluidal or trachytic as governed by the tabular feldspars.

To form an idea of the relative proportions of the soda and potash molecules in the rock the specific gravity of some thirty cleavage pieces of the feldspar was determined. Specific gravity could be safely relied upon on account of the freshness of the rock and on account of the lack of inclusions in the feldspar. The average for the thirty pieces was 2.594 at 22° C.; the range of specific gravity was from 2.582 to 2.612. The extinction angles showed that the albite of the intergrowth is nearly pure and has only a very small intermixture with the lime molecule. Accepting Brögger's values for the specific gravities of pure albite and pure orthoclase the average for this rock corresponds to a microperthite in which the two silicates occur in about equal proportion, with the albite the more abundant. The specific gravity of the rock is 2.616 at the same temperature. If we assume that the ratio Ab:Or=41:35 as in the granitic phase, that the lime is 1 per cent of the rock and the accessories 1 per cent, there would be about 20 per cent quartz in the rock. This rough estimate agrees with that made by inspection of the thin sections. This phase is thus a true *alkaline granite* at the extreme end of the series which leads to a rock with the composition of an aplite while preserving the hypidiomorphic-granular structure. A very similar rock occurs near Stratford, N. H., Albany, N. H., and Stark, N. H. These are illustrated in the collection of Professor Rosenbusch at Heidelberg. They all possess a higher proportion of bisilicates than phase *h*.

Another variety of true granite, into which the syenite is transitional, outcrops at the main summit of the mountain. It has the ordinary pinkish color of the average syenite of the stock. The composition is essentially the same as that just described for phase *h*.

Phase i.—Near the most westerly triple contact of granite stock, syenite stock, and phyllites, a fourth phase of the syenite was speedily noted in the field as unlike all the others in bearing an unusual amount of dark-colored minerals (spec. 111). The light-gray feldspars still give the dominant tone of color to this phase, which is also alkaline. The structure is that of phase *f*, equigranular; the grain is somewhat coarser. Basic segregations fail altogether or are very rare. The chief mineralogical difference between this phase and the others is found in the character of the feldspars. Triclinic feldspar is now one of the chief essentials. It varies in composition from the labradorite Ab_3An_4 to the andesine Ab_4An_3. Microperthite and orthoclase, hornblende, diopside, and biotite, with the properties of these minerals in phase *f*, are the other essentials; the same accessories are found here excepting allanite, monazite, and garnet. In addition there is a second hornblende among the essentials, with the following scheme of pleochroism and absorption:

a, Yellowish brown.
b, Deep brown to black, with specially strong absorption.
c, Deep brown, with a trace of olive-green.

$\mathbf{b} > \mathbf{c} > \mathbf{a}$.

The augite occurs only as cores in intergrowth with hornblende. Quartz is very subordinate among the accessories.

The basic character of this phase, its richness in bisilicate, the presence of much essential andesine-labradorite, coupled with the alkaline habit of the rock, are properties which relate the rock closely to *monzonite*. The resemblance of the Ascutney hand specimens and those from the classic locality of Mount Mulatto is very striking.

ENDOMORPHIC ZONE OF THE SYENITE STOCK.

All four phases of the stock are habitually more acid near the contact than elsewhere. Free quartz is even macroscopically so dominant that the contact rock stamps itself as a true granite. The usual chilling phenomena occur within a narrow zone not more than 20 feet across. Three feet from the contact the feldspar and quartz become idiomorphic and are embedded in a microcrystalline, often granophyric, groundmass, and a granite-porphyry is thus developed. Apophyses fail to show as much bisilicate as the parent rock body, have more free quartz, and tend toward the structure of a typical aplite. Excellent examples may be studied among some thick sheets on the north slope of the mountain, below the quarry. This endomorphic increase of silica is paralleled in the Christiania region, where augite granite occurs as the contact phase of augite syenite rich in nepheline.[a]

GREAT SYENITE-PORPHYRY DIKE OF LITTLE ASCUTNEY MOUNTAIN.

The stock-like dike to which Little Ascutney chiefly owes its existence is remarkable for following in its general east-west course the zone of contact between the diorite and gneiss (Pl. VII and fig. 1). Throughout its whole extent the south wall of the dike is schist and the north wall is either diorite or the green dike mapped as "paisanite." This replacement of the zone of contact rocks by a later intrusive is undoubtedly due to the weakness of that zone, which is elsewhere evident in the extensive brecciation and crumpling of the schistose rock. Small apophyses from the dike into both schist and diorite clearly prove the syenite-porphyry to be the younger rock.

The dike is quite uniform in composition from end to end, though there is a coarsening of grain from the walls toward the center. The rock is almost the exact equivalent of the average porphyritic phase of the Main syenite stock, and a detailed description is therefore unnecessary (spec. 76). Hornblende and biotite are the essential dark-colored minerals. They and the feldspars again display a great amount of magmatic corrosion; this caustic action is here, as so often elsewhere in alkaline rocks, responsible for the rarity of idiomorphic boundaries among the phenocrysts, as, indeed, it may be responsible for the general rarity of porphyritic dike representatives of the alkaline magmas as a whole. Plagioclase seems to be entirely absent from this rock except in the form of a few rare phenocrysts of an acid oligoclase. Microperthite is not so abundant, either in the groundmass or among the phenocrysts, as it is in the porphyritic phase of the Main syenite stock.

The dike is to be classified as a *nordmarkite-porphyry*.

Dark patches of basic material are very common in this dike. They are roundish in form and vary from a fraction of an inch to 3 or 4 inches in diameter. In color and general macroscopic appearance they are similar to the nodules from phase *g* in the Main stock. The correspondence is more fully shown in the thin section. The same constituents are present as in the typical segregation of the Main stock and in the same relative amounts. That exception is significant. Both in the phenocrystic constituents and in the groundmass of the nodule microperthite is not so abundant as in the nodules from phase *g*. This fact indicates another proof of close sympathy between nodule and host and of the indigenous origin of the latter. The nodules themselves add another evidence to the community of origin between this dike and the Main stock. There can be little doubt that the two intrusions were products of essentially contemporaneous eruptions from a common magma.

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[a] Zeit. für Kryst., Vol. XVI, 1890, p. 327.

SYENITE STOCK OF PIERSON PEAK.

The same may be said of the small stock of Pierson Peak. The plan of this rock body is elliptical. The longer axis measures 400 yards (366 meters), running about N 70° E; the minor axis measures 175 yards (160 meters). Coarse-grained apophyses prove the intrusive origin of the rock. It is uniformly a coarse-grained, light gray to light pinkish-gray alkaline syenite, with a proportion of dark colored constituents which is low even in comparison with the phases of the Main stock (spec. 62). The structure is the typical hypidiomorphic-granular, the order of crystallization that of phase *f* of the Main stock. Microperthite, orthoclase, and biotite are the essentials. Quartz, hornblende, augite, apatite, and zircon are all notably rare accessories; more important are titaniferous magnetite and titanite, the latter being unusually abundant. Basic segregations fail altogether or are extremely rare. The endomorphic zone is characterized by an almost complete lack of colored constituents and of quartz.

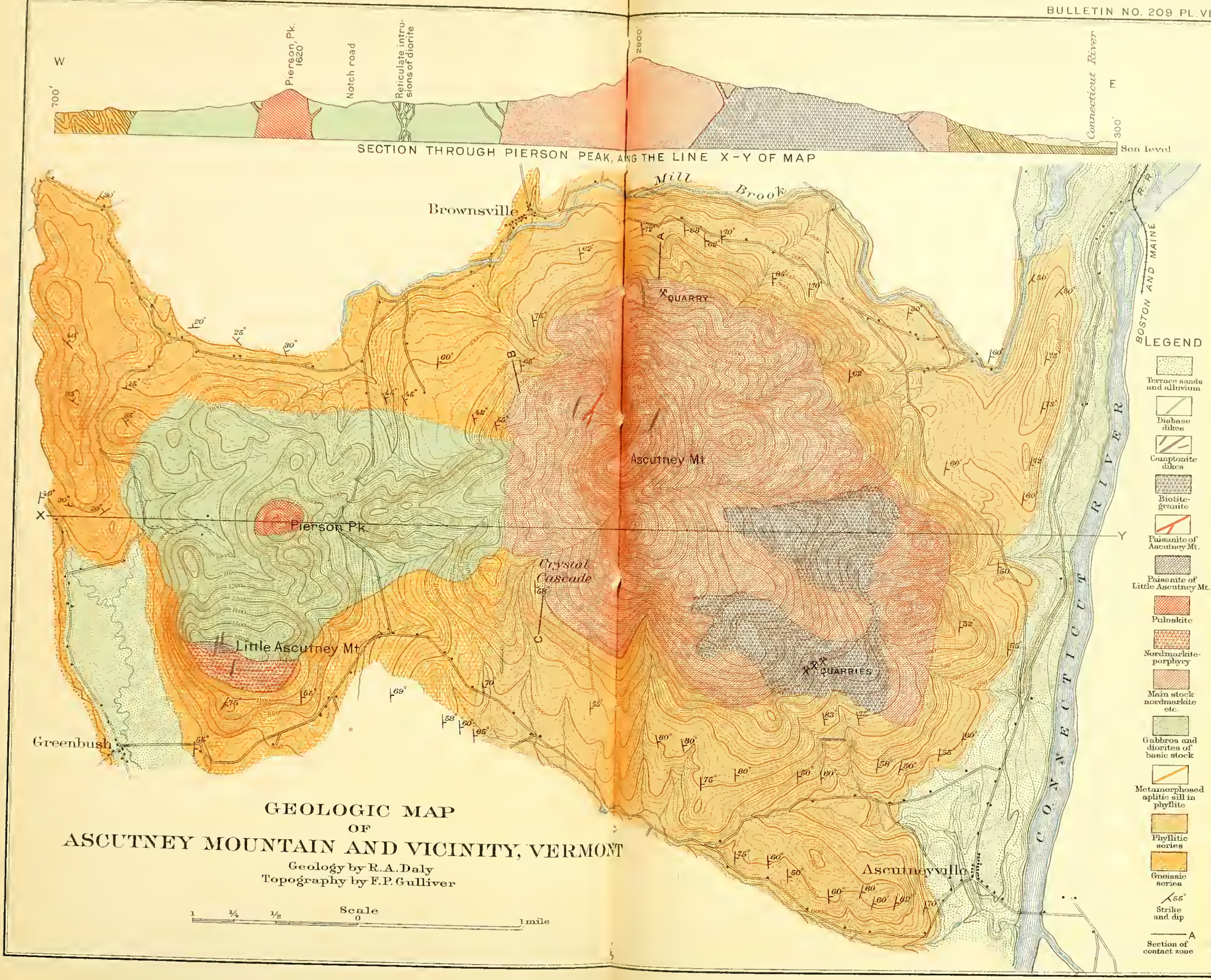
All the minerals have the same characters as in the granular phases of the Main stock. The rock is a nearly quartzless biotite-nordmarkite, or *pulaskite*. The writer proposes that the existing difficulty of differentiating these two rock types (compare cols. 4 and 5, Table VII, p. 59) be obviated by confining the name "pulaskite" to a rock which is in all other respects the equivalent of the nordmarkites except in the absence or subordination of accessory free quartz among the constituents. Excepting for a higher proportion of bisilicates in the Arkansas syenite, it would be hard to distinguish macroscopically this Ascutney rock from the classic pulaskite of Fourche Mountain; there is similar close parallelism with a geographically remote occurrence of the same type—that of Portella des Eiras at Monchique, Portugal.

APLITIC DIKES CUTTING THE SYENITES.

Three kinds of acid dikes have been found cutting the various syenites of the area. Two of these are intimately related to the stock phases; the third has variant features. It may be noted that there is an unusual lack of pegmatite veins both in the syenites and elsewhere about Ascutney.

PAISANITE DIKE CUTTING THE MAIN STOCK.

On the logging road running up from a sawmill on the northwest slope of Ascutney Mountain proper, toward the main summit, a dike was discovered in the dark-green granular phase *f* of the Main stock at about the 1,600-foot contour (see Pl. VII). The general trend of the dike is northeast-southwest, but at the road it bifurcates into two branches—one, 40 feet (12 meters) wide, striking N. 40° E.; the other, 50 feet (15 meters) wide, striking N. 25° E. The dike, as a whole, is visible only for about 100 yards (91 meters); at each end its continuation is lost in the underbrush and talus of the steep mountain side.



GEOLOGIC MAP
OF
ASCUTNEY MOUNTAIN AND VICINITY, VERMONT

Geology by R. A. Daly
Topography by F. P. Gulliver

Scale
1 ¼ ½ 0 1 mile

A. HOEN & CO. BALTIMORE

The rock is a light-tinted, pinkish-gray, pepper-and-salt, fine-grained, somewhat porphyritic aggregate of microperthite, soda-orthoclase, quartz, and alkaline hornblende, abundantly charged with basic segregations, with kernels of biotite and hornblende, and with pyroclastic feldspars won from the coarse syenite through which the dike passed during intrusion (spec. 139). The general habit is suggestively like that of the porphyritic phase *g* of the Main stock, and we must believe that the two are products of the same magma. Yet, as we have seen, the implication that phase *f* and phase *g* are of different ages (the former being cut by the latter) does not agree with the fact of observation in the field. It is probable that there was not a great interval of time between the intrusion of the Main stock and that of this dike.

The dike is characterized by a conspicuous platy structure due to jointing, and, near its walls, exhibits, for the space of a foot or two from the contacts, a strong fluidal character which is the more pronounced as the basic segregations have shared in the movement and are pulled out in long, dark-colored streaks in the dike.

The phenocrysts are either microperthite or, more rarely, orthoclase; they are specially abundant and are difficult to distinguish from the pyroclastic feldspars. The texture of the rock is really controlled by the groundmass, the structure of which is aplitic or panallotriomorphic. It is composed of microperthite, quartz, and brown hornblende, with properties identical with those of phase *f* in the Main stock. The hornblende always occurs in the form of small, poikilitic, and greatly resorbed grains. No biotite, diopside, or plagioclase were discoverable. Titanite, ilmenite, zircon, and apatite are, as usual, the accessories.

The pyroclastic feldspars are of special interest. They occur as single individuals or as groups (with interstitial quartz) of the same structure and grain as the country rock of the dike itself. Close study in the field showed conclusively that they are of pyroclastic origin. Their presence in the still unconsolidated dike affected its crystallization, so that many of these foreign feldspars are surrounded by typical reaction rims of material considerably more basic than the average groundmass of the dike. The usual appearance of the feldspar inclosure with its basic aureole is illustrated in Pl. IV, *B* (p. 58). The feldspar in this case is soda-orthoclase, and in the reaction of the extensively corroded feldspar with the matrix, the bisilicate of the reaction rim is even more strongly charged with soda than the brown hornblende of the average groundmass. The rim is an interlocking aggregate of microperthite and amphibole, with abundant magnetite and some zircon and apatite. The amphibole has bluish tones, as indicated by the scheme of pleochroism and absorption.

$\mathfrak{a}$, brownish yellow.

$\mathfrak{b}$, deep blue-green.

$\mathfrak{c}$, deep chestnut-brown, with a tinge of blue on the edges.

$\mathfrak{b}>\mathfrak{c}>\mathfrak{a}$, or perhaps $\mathfrak{b}=\mathfrak{c}>\mathfrak{a}$.

The extinction c: **c** is about 19°.

This same hornblende forms minute basic segregations varying in size up to 1 or 2 millimeters in diameter. These lie in the general groundmass of the dike, and are not directly connected with the pyroclastic feldspars. Other segregations or replacements which recall the "kernels" of the Main syenite, and yet show somewhat different composition and structure, also occur in the groundmass. One of these is illustrated in Pl. V, *A* (p. 62). It is composed entirely of a faintly pleochroic, yellow to light-brown, biotitic mica arranged in alternating concentric zones with a blue hornblende. The pleochroism of the latter is:

a, pale straw-yellow.
b, deepish green-blue.
c, blue, with a trace of green.
c about=**b**>**a**.

The origin of these concentrically arranged mica-hornblende aggregations has not yet been determined. Their resemblance to the kernels of the Main syenite, which have been interpreted as magmatic pseudomorphs, is only partial. Especially difficult of understanding is the recurrence of the zones of mica and hornblende.

BASIC SEGREGATIONS.

The usual basic segregation of the dike is very similar to that in the porphyritic phase of the Main syenite (spec. 141). It is a dark-gray, mottled aggregate of phenocrysts and pyroclastic feldspars surrounded by a dense, granular groundmass of panallotriomorphic brown hornblende, microperthite, and orthoclase. Here there can be no doubt that the segregation grew under the directing influence of the large feldspars now seen within their mass, for the segregation of basic material is decidedly more pronounced in the immediate vicinity of the feldspars than elsewhere in the nodules. The nodules vary in size up to 2 or 3 inches (5.2 to 7.8 cm.) in diameter. In one slide a large crystal of pale-green augite with a mantle of green hornblende was found, suggesting that, after all, the kernels of this rock may have been derived from that mineral through magmatic influences. The hornblende of these larger segregations has a bluish cast, and seems to belong to a variety of amphibole intermediate between the hornblende of the reaction rim described above and the normal hornblende of the Main syenite. The specific gravity of a typical segregation was found to be 2.756; that of the parent rock, 2.633.

The chemical analysis of the average matrix in which the basic segregations lie is given in the Table IX, col. 1, p. 75; that of an average segregation from the dike is entered in Table VIII, col. 2, p. 66. The structure and composition, both mineralogical and chemical, relate the dike most intimately with *paisanite*, as described by Osann (see Table IX, column 5). If we assume that there is 5 per cent of soda in the hornblende, and that that mineral makes up 3 per cent of the rock (a fair estimate after inspection of the slide), the mineral composition of the rock can be thus roughly determined as the following:

	Per cent.
Albite molecule	36.4
Orthoclase molecule	29.6
Quartz	29.5
Hornblende	3.0
Titanite	.5
Other accessories	1.0
	100

The analysis of the segregation does not lend itself to calculation on account of the abundance of the hornblende, the constitution of which is unknown. The essential equivalence of this analysis and that of the basic segregation from phase *g* of the Main syenite is striking. Again, among normal rocks, we must go to the monzonites for the nearest allies, chemically speaking, to these nodular masses. Mineralogically, the greatest difference between segregation and its matrix is found in the absence of triclinic feldspar in the former.

COMMON MUSCOVITE-APLITE OF THE MAIN STOCK.

Due south of the Windsor quarry, at the 2,350-foot contour, a dike about 1 foot (0.3 meter) in diameter traverses the syenite at a point where the latter is porphyritic and full of segregations. No other dike of the same composition has been discovered in the area, but it is highly probable that others exist. This dike is a typical aplite, a panallotriomorphic sugary mixture of quartz, orthoclase, and albite, with a little microperthitic feldspar and a few shreds of muscovite (spec. 191). The last mentioned mineral occupies certain areas in the thin section as if it is secondary after feldspar; in other cases, patches of matted quartz and muscovite represent the filling of small miaroles which are common in the rock. Numerous miarolitic cavities bearing terminated quartz crystals and muscovite plates are visible in the hand specimen.

PAISANITE DIKE ON LITTLE ASCUTNEY MOUNTAIN.

On referring to the plan of Little Ascutney intrusives (fig. 1) it will be seen that there is intercalated between the great syenite-porphyry dike of that ridge and the diorites on the north a second interrupted dike, which thus entered the same zone of weakness at the schist-contact as that earlier followed by the porphyry. This second dike is much smaller than the first, but measures, nevertheless, about 50 yards (46 meters) in width at the broadest part. It is probably this rock that was referred to by Hawes as the "granitell of Little Ascutney."[a] It sends apophysal tongues into the diorite and is similarly believed to be younger than the porphyry, although only on account of the chilling phenomena observed in hand specimen and slide from the smaller dike where it is in contact with the other.

Hints as to the relationship of this dike are to be found in the ledge and hand specimen. When quite fresh the rock is a fine pale gray with a blue tone; in a few days it changes color to the same handsome olive-gray green which has been described as characteristic of the Windsor quarry rock. The resemblance between the two rocks is also manifest in the way in which they fracture, and in the peculiarly vibrant musical note given out when a large fragment is struck with the hammer. Certain of the finer-grained streaks in the quarry can hardly be distinguished from the green dike in the hand specimen.

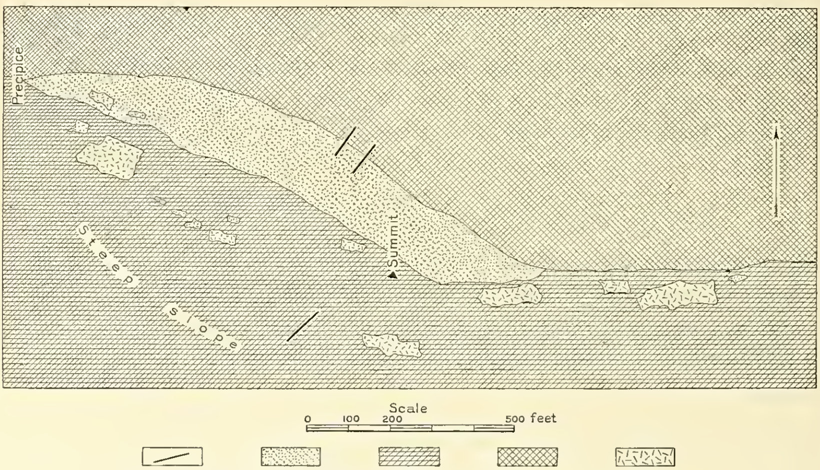


FIG. 1.—Sketch plan of intrusive rocks on Little Ascutney Mountain.

The rock is a very fine-grained typical aplite with a sugary, panallotriomorphic structure (spec. 60). The essential minerals are nearly the same as in the paisanite just described from the main mountain. Quartz is, however, quite prominent among the phenocrystic individuals which are otherwise composed of microperthite, either in separate crystals or in groups. The same constituents, with cryptoperthite and an alkali-iron hornblende identical in characters with that of the Windsor quarry rock, are the essentials in the groundmass. The quartz and feldspar "phenocrysts" are connected through all stages of transition with the same minerals of the groundmass, and it is probable that there has been but one generation of these essentials. The hornblende is strikingly poikilitic, as if corroded in the extreme. Biotite, oligoclase, magnetite, apatite, and zircon occur as accessories.

[a] Geology of New Hampshire, Vol. III, part 4, 1878, p. 202.

TABLE IX.—*Analyses of paisanites and other rocks.*

	1.	2.	3.	4.	5.	6.
SiO_2	73.69	73.03	77.14	66.50	73.35	70.19
Al_2O_3	12.46	13.43	12.24	16.25	14.38	11.96
Fe_2O_3	1.21	0.40	0.29	2.04	1.96	4.94
FeO	1.75	1.49	1.04	0.19	0.34	1.18
MgO	0.17	0.14	0.06	0.18	0.09	0.16
CaO	0.36	0.79	0.35	0.85	0.26	0.65
Na_2O	4.47	4.91	4.64	7.52	4.33	5.73
K_2O	4.92	4.54	4.47	5.53	5.66	4.06
H_2O above 110° C	0.24	0.35	[a]0.14	[a]0.50	--------	--------
H_2O below 110° C	0.14	0.18				
CO_2	Trace	Trace?	--------	--------	--------	--------
TiO_2	0.28	0.30	0.29	0.70	--------	--------
ZrO_2	0.14	0.06	--------	--------	--------	--------
P_2O_5	0.04	0.06	--------	Trace	--------	--------
Cl	0.02	0.03	--------	--------	--------	--------
F	0.05	0.08	--------	--------	--------	--------
FeS_2	--------	0.09	--------	--------	--------	--------
MnO	0.15	0.15	Trace	0.20	--------	0.48
BaO	--------	Trace	--------	--------	--------	--------
SrO	Faint tr.	Trace	--------	--------	--------	--------
Li_2O	Trace?	Trace	--------	--------	--------	--------
CuO	Trace	?	--------	--------	--------	--------
	100.09	100.03	100.66	100.46	100.37	99.94
O=F, Cl	0.02	0.04	--------	--------	--------	--------
	100.07	99.99	--------	--------	--------	--------
Total S	--------	0.05	--------	--------	--------	--------
Sp. gr	2.633	2.628	--------	--------	--------	--------

[a] Loss on ignition.

1. Hornblende-paisanite dike cutting Main syenite, Ascutney Mountain; analysis by Hillebrand.

2. Hornblende-paisanite dike cutting nordmarkite-porphyry, Little Ascutney; analysis by Hillebrand.

3. Lestivarite, Bass rocks, Gloucester, Essex County, Mass.; analysis by Washington, Jour. Geol., Vol. VII, 1899. p. 107.

4. Classic lestivarite, Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. III, 1898, p. 216; analysis by V. Schmelck.

5. Classic paisanite, Osann, Tscher. Miner. u. Petrog. Mitth., Vol. XV, 1896, p. 439.

6. Average grorudite, according to Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. I, 1894, p. 63.

The chemical analysis of this rock is given in Table IX, column 2, along with that of other rocks of related types. Their corresponding essential mineralogical composition is as follows:

1. Microperthite, soda-orthoclase, quartz, alkaline hornblende.
2. Microperthite, quartz, soda-orthoclase, alkaline hornblende.
3. Microperthite, other alkaline feldspar, quartz, hornblende, biotite.
4. Cryptoperthite, ægirine.
5. Microperthite, cryptoperthite, quartz, riebeckite.
6. Quartz, microperthite, microcline, albite, soda-orthoclase, ægirine, catoforite.

The molecular proportions for the Ascutney rock have been calculated as follows:

	Analysis.	Molecular proportions.
SiO_2	73.03	1.2165
Al_2O_3	13.43	.1313
Fe_2O_3	0.40	.0025
FeO	1.49	.0207
MgO	0.14	.0035
CaO	0.79	.0141
Na_2O	4.91	.0792
K_2O	4.54	.0484
TiO_2	0.30	.0036
ZrO_2	0.06	.0005
P_2O_5	0.06	.0004

If we suppose that the hornblende has 10 per cent lime, 3 per cent soda, and 40 per cent silica (not far from the proportions of those oxides in barkevikite), we can get an approximate idea of the quantitative mineral composition of the rock. On these suppositions the albite molecule would make up 40 per cent of the rock. The proportion of the same molecule would be 38 per cent if the hornblende were 5 per cent soda, and 41.5 per cent if all the soda were in the feldspar. The results of the calculation, based on an accurate knowledge of the composition of all the minerals, would not be far from the following:

	Per cent.
Albite molecule	40
Orthoclase molecule	27
Quartz	27
Anorthite molecule	2
Hornblende	3
Accessories	1
	100.0

A comparison of columns 1, 2, and 5 in Table IX shows at once the thorough similarity of this rock to classic *paisanite* and to the great aplite dikes on the northwest side of the main mountain. The last mentioned we have seen to be an acid representative of the porphyritic phase of the Main stock; in the same way the Little Ascutney paisanite, in its composition, evanescent color, and freedom from basic segregations, is closely allied to the granitic phase of the same stock. Both of the Ascutney paisanites are allied to grorudite (column 6) and to the "lestivarite" of Essex County (column 3) which, however, is a type considerably divergent from classic lestivarite (column 4).

BRECCIA MASSES ON LITTLE ASCUTNEY MOUNTAIN.

Inclosed in the green paisanite dike are 2 horses of breccia, the larger measuring in plan 25 feet (7.5 meters) by 8 feet (2.4 meters). In the older adjoining syenite-porphyry dike there are at least 16 similar horses exposed on the crest of the ridge, as indicated on the sketch map (fig. 1, p. 74). The largest of the horses in the porphyry is 180 feet (55 meters) in length by 55 feet (16.5 meters) in breadth. The smallest one mapped covers 8 (2.4 meters) or 10 (3 meters) feet square, though many smaller fragments of the same rock occur scattered through the porphyry.

These interesting bodies were first described by the geological survey of Vermont. In its final report Edward Hitchcock developed a theory of the Ascutney eruptives which is founded on the discovery of the breccia. It can best be expressed in his own words:

> * * * If we ascend Little Ascutney, near its west end, on the top, just where the southern slope begins, masses of a conglomerate of a decided character, several feet and even rods wide, appear on the side of the porphyry and granite. All traces of stratification in the conglomerate are lost and it passes first into an imperfect porphyry, and this into granite without hornblende, in the same continuous mass, without any kind of divisional plane between them. Where the conglomerate is least altered it is made up almost entirely of quartz pebbles and a larger amount of laminated grits and slate, the fragments rounded somewhat and the cement in small quantity. It is easy to see that a metamorphism has taken place in all the conglomerate and some of the pebbles might even be called mica-schist. In the cement also we sometimes see facets of feldspar. In short, it is easy to believe that the process of change need only be carried further to produce syenite, porphyry, or granite. One can not resist the conviction that the granite rocks of the mountain are nothing more than conglomerate melted down and crystallized, or at least that such was the origin of part of them.[a]

Van Hise has dissented from this view and briefly stated his opinion that these "pseudo-conglomerates" are flow breccias. He says: "The matrices of these rocks are thoroughly crystalline granular granite, syenite, or porphyry. Thus they are eruptives which have caught within them fragments of the rocks through which they have passed."[b]

The observations of the writer do not agree with Hitchcock's determination of the relation between the horses and the porphyry. There

[a] Geology of Vermont, 1861, Vol. II, pp. 565-566.
[b] Bull. Geol. Soc. Am., Vol. I, p. 236, footnote.

is no transition between the two, but instead a very clean-cut contact, which is just as distinct as that between the porphyry and the schists. The facts that lead to the rejection of Van Hise's theory of the breccia will also be briefly noted.

The horses do present in the field the general appearance of flow breccias (spec. 36). In thin section, however, the compact, dark greenish-gray cement resolves itself into an aggregate of clastic grains of quartz and feldspar in a secondary groundmass of argillaceous material, chlorite, biotite, and quartz. The biotite looks metamorphic and is concentrated about magnetite, which is comparatively abundant. Small garnets are also interspersed in the cement in great numbers, and, like the biotite, were, in all probability, formed in the partial alteration of the cement by the heat and mineralizers of the porphyry intrusion.

There can be no doubt that such a matrix is clastic, and the shape and nature of the inclosed fragments agree with that interpretation. They are subangular or angular and without visible stratification. In size they vary from those of microscopic dimensions to others having an area of a square foot or more. Usually the corners are sharp and plainly indicate that the fragments have not been worked over by water. As Hitchcock pointed out, these "pebbles" are of many different sorts.

The great majority of the fragments belong to the schists. A phyllite composed of quartz and sericite (occasionally with metamorphic biotite) as essentials, and of graphitic and iron ore with zircons as accessories, is very common. It is the slightly metamorphosed equivalent of the phyllite in the eastern half of the Ascutney area. The rocks of the contact aureole of the main mountain are also represented by many fragments that are still more altered forms of the phyllites than the type just mentioned. Certain of the dark, fine-grained blocks are made up essentially of cordierite rendered turbid by numerous microlitic inclusions, probably sillimanite. The gneissic fragments are usually of the varieties found in the fundamental formation at the foot of Little Ascutney. They are typical biotite-gneisses, often garnetiferous and sometimes charged with epidote. The mica-schist of the basal crystallines has a place in the breccia as a biotite-quartz-schist with little accessory material. An amphibolite, identical in composition with that described from the locality at the foot of Crystal Cascade, is likewise present among the blocks.

Quartz occurs as large, angular pieces from single crystals, as compact quartzite, and as a chalcedonic variety. Granular epidote with some quartz forms smaller fragments up to 1 inch (2.6 centimeters) in diameter, suggesting the equivalent of the metamorphosed limestone of the Ascutney contact zone. Large broken crystals of orthoclase are also common and are unquestionably fragmental in the same sense as the cement. So far as known, there is only one igneous rock among the breccia fragments, and it is one of the least abundant kinds. It is a typical granite-porphyry with an ideal development of idiomorphic quartz and feldspar phenocrysts. The only dark-colored constituent is biotite, the lamellæ of which are always grouped after the manner of segregations and never seem to form true phenocrysts. This is the only component of the breccia which is not to be found in crystalline schists surrounding Ascutney. The breccia cement itself may be regarded as the comminuted remains of the broken-up schists.

Each of these great horselike inclusions is now seen to have the composition, structure, and possible field relations of a true fault breccia. The most satisfactory explanation of them would attribute them to the disrupting action of vigorous and long-continued differential movements in an ancient zone of dislocation. That zone was perhaps nearly coincident with the present course of the two large dikes in which the horses are embedded. The faulting gradually prepared the material and recemented it into a new, tough, solid rock. Later, the invading eruptives carried off large masses of it as they forced their way along the old zone of dislocation and consequent weakness. The average specific gravity of the horses is about 2.79; that of the syenite porphyry, 2.646. It is reasonable to suppose that the immersed blocks of breccia sank to their present position rather than that they were carried up from below.

BIOTITE-GRANITE STOCK.

The second of the stocks which go to make up the main mountain is much the smaller of the two. The total area is about 1 square mile (2.6 sq. km.). The highly irregular contact line touches both syenite and phyllites (see Pl. VII).

That this rock (an *alkaline biotite-granite*) must be referred to a period of intrusion different from that of the Main stock was a matter of somewhat prolonged study in the field. An early examination of specimens and outcrops indicated that on the southeast side of the mountain along the contact with the schists there were two points where the igneous rock changed from a quartzless hornblende-bearing phase to a highly quartzose phase, devoid of all dark-colored essentials save an occasional shred or plate of biotite. This change was in all cases sudden, and each phase held its character for a long distance from their common contact with the schists. A second visit to the same localities explained the true relations. It showed that the granite is not of the nature of an acid flow streak on a large scale in the syenite, but that the former was intruded after the syenite had consolidated. A characteristic endomorphic zone that developed in the granite will be described below. A slight amount of alteration in the syenite itself may be detected. It is of the nature of the formation of a secondary granophyric structure among the feldspars of the once thoroughly granular syenite, but it is sufficient to emphasize here the granitic apophyses in the nordmarkite as a proof of the younger date of the more acid rock.

In one of these apophyses about 6 inches (15.2 centimeters) in width the walls of syenite must have been already solid when the granite was intruded, since out from them have been developed a large number of quartz prisms standing squarely on the walls and terminated with the usual planes at the free ends, which, of course, point toward the middles of the apophysis. The prisms average 3 or 4 centimeters in length by 1 centimeter in thickness. Other large crystals similar to these sessile ones are to be seen completely surrounded by the granitic matrix; they are doubly terminated. This apophysis, while thus allied to the pegmatites, is yet believed to be a true offshoot of the granite because of the identity of composition existing between its matrix and the material of the more normal apophyses. An analogy is to be found in a syenite dike cutting the classic laurvikite, wherein cryptoperthite crystals take the place of the large quartzes of the Ascutney dike.[a]

The granite has been mapped with a fairly close degree of accuracy. The very dense second-growth timber and a lack of outcrops prevented the discovery of the contact line in some places.

In three abandoned quarries situated in the southern lobe of the stock, about 250 yards (225 meters) from the schist contact, a more or less well-developed master jointage is to be seen. Its chief interest consists in the evident independence of this jointage and the present topography of the deep valley in which the quarries are situated. The latter lie on an east-west line. At the main quarry, in the middle, the joint planes dip about 15° south, or a few degrees east of south. At the eastern and western quarries they are found to swing into an easterly and westerly direction of dip respectively. In the western quarry the ground slopes east by south; in the eastern, west by south. In other words, the jointage is quaquaversal in the bottom of a steep-walled ravine or gorge. It must be said that such jointing can hardly be explained by the formation of concentric rift-planes through atmospheric changes of temperature. The conditions seem rather to confirm the more general view that the structure is an original phenomenon due to cooling.

The granite, excepting in a narrow contact zone, remains quite uniform in character throughout the stock. It is a typical pseudoporphyritic alkaline biotite-granite (spec. 2). The color is a light grayish pink, the grain medium to coarse, the structure hypidiomorphic granular in the groundmass. The phenocryst-like constituents are quartz, microperthite, orthoclase, and soda-orthoclase (with a specific gravity of 2.584 at 16° C.), accompanied by a small proportion of biotite individuals. These minerals have the same features as in

[a] Brögger, Zeit für Kryst., Vol. XVI, 1890, p. 193.

the nordmarkites. They compose the groundmass in which a considerable amount of multiple-twinned albite (near $Ab_8\ An_1$) and titanite with some magnetite, zircon, apatite also occur. The phenocrysts are not sharply separated from the groundmass in size, and it is likely that there has been only one generation of those constituents. The biotite is nearly uniaxial. The large amount of FeO in the analysis suggests that it is a lepidomelane. Titanite is beautifully crystallized with the ordinary rhombic outlines and well-developed prismatic cleavage. Its pleochroism is strong:

a, pale yellow.
b, yellow.
c, reddish yellow.
c>**b**>**a**.

Pseudomorphs of magnetite (ilmenite?) after titanite are not uncommon. In one out of seven slides made from this rock a single small individual of pale-green amphibole was discovered. Augite fails entirely. Here, as in the other stock rocks of the area, the quartz is rich in liquid and gaseous inclusions and in negative crystals arranged in lines and also provided with double bubbles of gas immersed in liquid.

The order of crystallization is the normal one:

1. Titanite, apatite, zircon, and magnetite.
2. Lepidomelane.
3. Albite and orthoclase.
4. Microperthite.
5. Quartz.

The essential oxides (see Table X, col. 1, p. 84) and their molecular proportions are noted in the following table:

	Analysis.	Molecular proportions.
SiO_2	71.90	1.1980
Al_2O_3	14.12	0.1382
Fe_2O_3	1.20	0.0070
FeO	0.86	0.0120
MgO	0.33	0.0082
CaO	1.13	0.0201
Na_2O	4.52	0.0723
K_2O	4.81	0.0511
TiO_2	0.35	0.0043
ZrO_2	0.04	0.0003
P_2O_5	0.11	0.0008

If all the TiO_2 be ascribed to titanite, and if we assume that the mica contains 10 per cent MgO, 8 per cent K_2O, and 40 per cent SiO_2, the analysis may be calculated and the quantitative mineralogical composition determined, with small degree of error, as follows:

	Per cent.
Albite molecule	37.9
Orthoclase molecule	27.0
Quartz	25.0
Anorthite molecule	3.9
Biotite	3.3
Magnetite	1.6
Titanite	0.9
Apatite	0.3
Zircon	0.1
	100.0

Chemically, this rock is an ideal equivalent, among the alkaline rocks, of granite among the nonalkaline eruptives, a biotite-granite characterized by a high total of alkalies with the soda and potash in nearly equal proportion. Iron, lime, and magnesia are all low. It is again to the Christiania region that we must go for the already described type nearest to this one. The "granitite" of Lier affords an analysis which is noted in column 4, Table X. In the Norwegian field, as at Ascutney, the biotite-granite is the youngest eruptive excepting the lamprophyres. A close and interesting correspondence between these two rocks is further illustrated in the character of the endomorphic contact phase. It is notably granophyric and miarolitic in the Norwegian occurrence, and, as we shall see, is in these respects similar to the Ascutney rock.

BASIC SEGREGATIONS IN THE GRANITE.

The homogeneity of the biotite-granite is affected by the presence of nodular basic segregations which, while not nearly so abundant as in the nordmarkites, are characteristic of the rock. They vary in color, composition, and size. Three classes may be distinguished, not only from each other, but, as well, from the metamorphosed schist inclusions, which occasionally appear within the mass of the stock.

The commonest segregation is of a more basic character than the other two kinds (spec. 1a). It is dark greenish gray in color, spherical, oval, or lenticular in form, and in the hand specimen sharply outlined against its host. In thin section, however, it is once more seen that this macroscopically sharp outline of a segregation does not forbid a very intimate interlocking of its minerals with those of the host. The size may vary from that of a pea to nodules as large as a man's fist. Under the microscope the nodule is seen to be a panallotriomorphic aggregate of much biotite, hornblende, and triclinic feldspar always close to and averaging the oligoclase, Ab_3An_1, together with smaller amounts of microperthite and orthoclase. Interstitial quartz, much titanite and apatite, and a remarkably small amount of magnetite comprise the accessories. The hornblende is not identical with that of the syenite nodules, as is shown by the pleochroism:

a, pale yellowish green.
b, olive-green (medium to strong absorption).
c, olive-green with a strong bluish cast (medium to strong absorption).
b>c>a.

The other constituents have the same properties as the parent rock. Often in this class of segregation there are small secondary nodules of nearly pure biotite and hornblende, some of which, by the concentration of the mica around the periphery, recall the kernels of the nordmarkites. On the other hand, the general continuity of the main segregation may be interrupted by light-colored spots composed chiefly of oligoclase, quartz, and idiomorphic hornblende.

But one example of the second type of segregation has been found. This is a gray, roundish mass about 7 feet (2.1 meters) in diameter occurring near the 2,100-foot contour close to the northern contact (with the syenite) of the great southwestern tongue of the granite (spec. 113). This large nodule is strongly alkaline, the predominant feldspars being microperthite, albite (pure or charged with the anorthite molecule up to the limit, Ab_8An_1), microcline, and probably cryptoperthite—named in the order of their abundance. Free quartz makes up probably as much as one-third of the rock. A hornblende that has not been observed in any other rock of the area is the remaining essential. It forms long, narrow, microlitic, irregularly terminated blades. It is pleochroic according to the scheme:

a, light greenish yellow.
b, deep brownish green.
c, deep brownish green with a strong bluish tinge.
b=c>a.

Much idiomorphic titanite, a few rare corroded plates of biotite, many crystals of magnetite, considerable apatite, and very rare zircons form the list of accessories. The structure is here hypidiomorphic granular.

Allied to the second type is a third class of the segregations, type analyses of which are given (Table X, cols. 2 and 3, p. 84). Here the biotite is much more common than the hornblende, the feldspars and accessories remaining the same in nature and relative abundance (spec. 1b). Quartz is not so abundant. The structure is the hypidiomorphic granular. The feldspars are somewhat altered, as is indicated in the chemical analysis. Calcite and a little muscovite are the secondary products. The microscopic diagnosis and the analysis agree in putting these segregations among the alkaline quartz syenites (åkerites). Again, it will be observed that there is an especially large amount of the mineralizer, fluorine, in the segregation.

TABLE X—*Analysis of biotite-granite.*

	1.	2.	3.	4.
SiO_2	71.90	59.27	56.01	75.74
Al_2O_3	14.12	15.76	[a] 15.19	13.71
Fe_2O_3	1.20	2.07	2.34	0.55
FeO	0.86	3.57	4.89	
MgO	0.33	3.04	4.67	Trace.
CaO	1.13	3.69	4.85	1.26
Na_2O	4.52	5.63	5.66	3.72
K_2O	4.81	3.33	2.16	4.69
H_2O above 110° C.	0.42	0.74	0.36	0.46
H_2O below 110° C.	0.18	0.23	0.90	
CO_2	0.21	0.30	Undet.	
TiO_2	0.35	1.12	1.13	0.17
ZrO_2	0.04	0.04		
P_2O_5	0.11	0.42	0.53	
Cl	0.02	0.03	Undet.	
F	0.06	0.42	Undet.	
FeS_2	Trace.	0.07	0.09	
NiO, CoO		Trace.	0.03	
MnO	0.05	0.37	0.40	
BaO	0.04	Trace?	Trace?	
SrO	Trace.	Faint tr.		
Li_2O	Trace.	Trace.		
	100.35	100.10	99.21	100.30
O=F, Cl	0.03	0.19		
	100.32	99.91		
Total S	Trace.	0.037		
Sp. gr	2.616	2.661	2.720	

[a] With ZrO_2.

1. Biotite-granite, Ascutneyville quarries; analysis by Hillebrand.
2. Basic segregation in the biotite-granite; analysis by Hillebrand.
3. Another sample of the last, containing more hornblende; analysis by Hillebrand.
4. "Granitite" from Lier, Christiania region; Brögger, Zeit. für Kryst., Vol. XVI, 1890, p. 72.

ENDOMORPHIC ZONE OF THE GRANITE.

The detection in the field of the actual plane of contact of granite and syenite is rendered comparatively easy on account of a conspicuous structural variation which characterizes the endomorphic zone. At the average distance of 20 feet (6.1 meters) from the contact the normal granite becomes much more porphyritic in appearance (spec. 105). The phenocrysts are chiefly quartz, which may either retain its dimensions in the normal rock or may form much larger doubly terminated crystals. The groundmass is much finer grained, though always holocrystalline, and is either granophyric or identical in general structure with the normal granite. Large terminated crystals of quartz may sometimes be seen projecting from the syenite into the granite in the same way as in the apophyses already described. Especially marked on the ledges of the contact zone are abundant roundish miaroles from 1 inch (2.6 centimeters) to 3 inches (7.8 centimeters) in diameter, either completely filled with crystalline matter or presenting cavities lined with well-formed crystals (spec. 106).

The usual occupants of the miaroles are quartz crystals showing the common terminal and prismatic planes and crystals of the same feldspars as occur in the granite proper. The feldspars are flesh colored or light brownish and, in thin section, turbid. They bear the planes (001) (010) (110) ($\bar{1}01$) ($\bar{2}01$) (021) and ($\bar{1}11$); (010) and (001) are especially well developed. The commonest of these feldspars seems to be a genuine microperthite. It illustrates in excellent fashion the rare Manebacher law of twinning and the murchisonite cleavage. The triclinic feldspar of the intergrowth is pure albite, giving an extinction angle of 19° on (010). Microcline and orthoclase crystals also occur in the miaroles. The latter has the small optical angle of sanidine. Finally, pseudomorphs of limonite after siderite completes the list of the minerals which have been found in the miaroles. Biotite seems to be absent. A close parallel to this endomorphic zone is furnished in the aplitic granophyre described by Brögger as the contact phase of the alkaline biotite-granite of Lier,[a] which in other respects resembles the Ascutney rock.

The endomorphic zone has been enriched by the incorporation of a certain amount of basic material evidently derived from the syenite. In the granophyric groundmass there are sporadic irregular granular areas impregnated with an alkaline hornblende near barkevikite and biotite. These are not found where the granite is in contact with the phyllites.

LAMPROPHYRES.

A number of dikes of lamprophyric habit cut the syenites at various points, and rocks of the same character intersect the Basic stock and the schists. No such dike has been discovered in the granite stock, but it is probable that they are all younger than that stock. They belong either to the class of camptonites or to the class of diabases. A similar association of the two groups in the same region has been described by Kemp as occurring on the Maine coast.[b]

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[a] Zeit. für Kryst., Vol. XVI, 1890, p. 72.

[b] Bull. Geol. Soc. Am., Vol. I, 1890, p. 32.

CAMPTONITES.

At the top of Little Ascutney a camptonitic dike cuts the nordmarkite-porphyry dike, the paisanite dike, a horse of the breccia, and the diorite. The rock is a very compact grayish-black mass, in which here and there a hornblende crystal and, more rarely, a feldspar appear as phenocrysts (spec. 57). In thin section it is seen to be an acid camptonite of the usual structure and composition. The hornblende phenocrysts are idiomorphic and measure from 1 to 3 millimeters in length. The pleochroism and absorption are those of a common basaltic hornblende:

a, pale brownish yellow.
b, deep, rich brown.
c, deep, rich brown.
$c \geqslant b > a$

The extinction on (010) is about 15° 30′.

The plagioclase is apparently very uniform in composition and averages the basic labradorite, Ab_2An_3, both in the rare phenocrysts and in the groundmass.

The rock is greatly altered, and this characteristic adheres to all the camptonites of the area. Chlorite, epidote, calcite, secondary quartz, and kaolin are the products of decomposition.

Analysis 1, in Table XI, represents the approximate composition of the average camptonite of the area (spec. 74). It was made from a type differing from that just described in containing a small proportion of augite in the groundmass and, more rarely, among the phenocrysts. The feldspar is here again the labradorite Ab_2An_3. The augite is much altered (into uralitic amphibole, chlorite, and the ores) from its original diopsidic condition. Dikes corresponding to this analysis were found cutting the syenite on the Windsor trail about 500 yards (457 meters) from the main summit of Ascutney Mountain, cutting coarse diorite in the saddle at the east end of Little Ascutney, and cutting gneiss east of the notch road and southwest of Brownsville.

While there is a noteworthy difference between this analysis and that of Hawes's classic camptonite, the former agrees well with the average analysis of camptonite as calculated by Brögger (cf. Table XI.)

TABLE XI.—*Analysis of camptonite.*

	1.	2.	3.
SiO_2	48.22	41.94	43.65
Al_2O_3	14.27	15.36	16.29
Fe_2O_3	2.46	3.27	----------
FeO	9.00	9.89	14.76
MgO	6.24	5.01	5.96
CaO	8.45	9.47	10.16
Na_2O	2.90	5.15	3.05
K_2O	1.93	0.19	1.50
H_2O above 110° C	1.66	3.29	----------
H_2O below 110° C	0.28		
CO_2	0.15	2.47	----------
TiO_2	2.79	4.15	4.63
ZrO_2	0.03	----------	----------
P_2O_5	0.64	----------	----------
Cl	0.10	----------	----------
F	0.05	----------	----------
FeS_2	0.36	----------	----------
NiO, CoO	0.03	----------	----------
MnO	0.20	0.25	----------
BaO	0.04	----------	----------
SrO	Trace.	----------	----------
Li_2O	Trace.	----------	----------
CuO	Trace.	----------	----------
	99.80	100.44	100.00
O=F, Cl	0.04	----------	----------
	99.76	----------	----------
Total S	0.19	----------	----------
Sp. gr	2.810–2.869	----------	----------

1. Camptonite dike, Ascutney Mountain; analysis by Hillebrand.
2. Classic camptonite, Campton Falls, N. H.; Rosenbusch: Elem. der Gesteinslehre, 2d ed., 1901, p. 244.
3. Average analysis of eight camptonite dikes; Brögger: Quart. Jour. Geol. Soc., Vol. L, 1894, p. 26.

The hornblende has not been analyzed; it is, hence, not possible to calculate the analysis. The specific gravity of these dikes varies from 2.810 to 2.869; on account of alteration, no two pieces, even from the same hand specimen, will agree in specific gravity.

DIABASE DIKES.

The second class of melanocratic dikes comprises compact, equigranular or porphyritic diabases of normal composition and structure, thus not differing essentially from the common dikes of the same rock occurring so abundantly up and down the Connecticut Valley (spec. 120). The feldspar is here also near the basic labradorite Ab_2An_3. Like the pale-green intersertal augite, it is much affected by weathering; the products of the change are the same as in the camptonites. A sulphide, probably pyrite, is visible in notable amount, even in the hand specimen. The magnetite is strongly titaniferous. Zircon and titanite are absent, and there is comparatively little apatite. The specific gravity was measured at 2.922. The total analysis is given in Table XII. It corresponds to that of a common, somewhat weathered diabase.

TABLE XII.—*Analysis of diabase (by Hillebrand)*

SiO_2	49.63
Al_2O_3	14.40
Fe_2O_3	2.85
FeO	8.06
MgO	7.25
CaO	9.28
Na_2O	2.47
K_2O	0.70
H_2O above 110° C	1.47
H_2O below 110° C	0.27
CO_2	1.36
TiO_2	1.68
ZrO_2	Trace?
P_2O_5	0.25
Cl	0.07
F	Trace
FeS_2	0.22
NiO, CoO	0.04
MnO	0.17
BaO	Trace?
SrO	Trace?
Li_2O	Trace
	100.17
O=F, Cl	0.02
	100.15
Total S	0.12
Sp. gr	2.922

SUMMARY.

The list of eruptive rocks in Mount Ascutney includes the Basic stock of gabbros and diorites transitional into one another and into an acid essexitic phase, ramifying dikes of younger diorite, dikes of a rock type not heretofore described and called "windsorite" from this Ascutney occurrence, the nordmarkite-porphyry dike-like stock of Little Ascutney, the pulaskite stock of Pierson Peak, the great paisanite dike of Little Ascutney, the variable nordmarkites of the Main syenite stock with granitic and monzonitic phases, the homogeneous alkaline biotite granite of the Ascutneyville stock, and the aplites and lamprophyres (diabase and camptonites) cutting nearly all the other bodies.

Chemically, the series of eruptives as a whole is characterized by normal silica, high alkalies, the potash slightly predominating, normal alumina, medium iron, low magnesia, low lime, and high titanic oxide. Mineralogically, they are rich in feldspar which is generally microperthitic, and are poor in biotite and bisilicates. Especially noteworthy is the extraordinary development of indigenous basic nodules of segregations and of "schlieren" in the different rock bodies, including both dikes and stocks. The abnormal abundance of the segregations is probably to be connected with the smallness of the conduit through which each irruption took place. Variations of temperature, abundance of foreign fragments, and the repetition of intrusion in the same conduit have all played their part in disturbing the normal process of crystallization.

Considering the small area occupied by the Ascutney intrusives, they must be considered as having an unusually wide range of composition (see list on p. 36). While dioritic types fail in the allied petrographical province of the Christiania region and nordmarkites and related alkaline rocks are absent in the Monzoni region, both of these classes are represented at Ascutney. The intimate association of independent bodies of such nonalkaline rocks as the gabbros and diorites of the oldest stock and of the older basic dikes, with the several bodies of typical alkaline syenites and granite, is to be particularly emphasized. That such an association is not rare, in America at least, is shown by its repeated occurrence in New York State[a] and in Essex County, Mass.[b] Not the least significant fact concerning the Ascutney eruptive group is the occurrence of rock types transitional between the nonalkaline and alkaline irruptives. Thus there is not only the most striking consanguinity among the respective members of each of these classes, but the two classes are themselves allied by a family relationship which is reflected also in many details of mineralogical and chemical composition.

Among the details described in connection with the irruptives, we may recall some which, while of greater or less importance to the general geology or mineralogy of the area, are not implied in the foregoing résumé of the intrusions. These include the evidence for the cylindrical character of the main controlling stock of Mount Ascutney itself, the remarkable tarnishing which slight exposure produces in the nordmarkite of the Windsor quarry and in the related paisanite of Little Ascutney, the great masses of breccia in the nordmarkite porphyry and paisanite dikes, and the interesting endomorphic phases, especially of the biotite-granite. Finally, the considerations relative to the mode in which the conduit has become occupied by the different intrusives will be summarized in the following chapter.

[a] Cushing, Bull. Geol. Soc. Am., Vol X, 1899, p. 177. Smyth, Ibid., Vol. VI, 1895, p. 263. Eakle, Am. Geol., Vol. XII, 1893, p. 35.

[b] Washington, Jour. Geol., Vol. VI, 1898 p. 799

CHAPTER V.

THEORETICAL CONCLUSIONS.

MANNER OF INTRUSION OF THE STOCKS.

Probably the most important question in connection with the dynamical geology of the mountain centers about the actual method of injection followed by each of the five largest eruptive bodies.

Hitherto it has been assumed that the Ascutney rocks belong to the category of genuine intrusives and that, for example, we have not here to do with a deeply eroded volcanic neck or pipe. This view will be still held in the further discussion of the rock bodies. The evidence, however, that the granitic rocks now exposed do not, after all, represent the deep-seated equivalents of magmas which, in the eruptive periods, escaped at the earth's surface as lava flows, is largely but negative. To exclude this volcanic hypothesis it is clearly not sufficient that the igneous bodies have all the characteristics of a plutonic origin and that there is in the vicinity, at present, lack of explosion breccias or lavas in any form. The complete removal of such products is only a question of the time allowed and the depth of denudation since the early period of the eruptions. Nor, again, and just as surely, is the general lack of flow structure showing a relatively rapid upward movement of the magma of distinct help in deciding the alternative.

The peculiar arrangement and form of the stocks, especially the lobate plan of the granite, seem to give greater satisfaction in the plutonic hypothesis. But a much stronger reason, affording cumulative evidence for its adoption, is doubtless to be found in the analogy of Ascutney Mountain with a score of other granitic areas in Vermont alone. There appears to be no evidence at all for the volcanic nature of these igneous bodies. Although the geological conditions are often, particularly in the smaller areas, very similar to those at Ascutney, extrusive rocks seem never to be organically associated with a single granitic mass. So far as known, there is no more reason to attribute a volcanic origin to any one of these smaller granitic bodies in Vermont than to the others; nor, indeed, than to the great massifs typified by the Barre granite. The transition in size from the smallest to the largest area is gradual, and mere size and shape will not suffice as a criterion of volcanic origin for any one. It is, perhaps, not too much to say that, if the Ascutney bodies occupy the vent of an ancient greatly eroded volcanic neck, the Barre granite itself, contrary to the received opinion of geologists, may be regarded as possibly of the same origin. In other words, it is reasonable to believe that the volcanic hypothesis for Ascutney Mountain has no stronger foundation in fact than it has for normal granitic areas the world over. In this view, the igneous rocks of Ascutney are all irruptive and each irruptive body assumed its present position and full volume only after some process had prepared the corresponding space within the country rock[a]. The problem before us relates to the manner in which that preparation was carried out.

APPLICATION OF EXISTING THEORIES TO THE ASCUTNEY INTRUSIONS.

It is held by some of our ablest masters in petrological science—perhaps by most of them—that stocks, sills, laccoliths, and dikes are, from the point of view of dynamical geology, of the same nature—i. e., that they vary only in size and form. Each is composed of a consolidated rock magma which has been injected into the country rock because of a previous or accompanying opening of cavities within the earth's crust. Displacements of folded and faulted rocks in mountain massifs are made responsible for the cavities or chambers. The latter may be supposed to antedate the eruption (plainly an inadmissible premise for the larger eruptive bodies) or to have been magmatically filled pari passu with the dislocation. In either case the adherents of this theory believe that no important assimilation of the country rock by the invading magma takes place, and that, therefore, the composition of the magma is not affected by such assimilation.

It is clear from the foregoing discussion of the Ascutney intrusives, as well as from the inspection of the map (Pl. VII), that none of the larger ones is laccolithic in character. The syenite-porphyry of Little Ascutney has apparently followed a zone of weakness, the contact of the gneiss and Basic stock. Though for this reason dike-like in its geological relations, it has so far enlarged its conduit as to assume the proportions of a stock. The other four bodies are true stocks. Each eruptive cuts across the schists, so that the igneous contact generally stands at a high angle to the strike of the schists. Only at the eastern end of the mountain are the two parallel, and it has already been noted that the surface of contact of the Main syenite stands nearly vertical, and is thus not coincident with the dip plane of the schists there any more than on the other slopes of the mountain. The facts show that a laccolithic origin can not be hypothecated for the Main syenite, much less for the granite.

The east-west elongation of the igneous area as a whole might suggest that the intrusions occupy a zone of dip faulting in the schists. But the transitional contact belt of the phyllitic and gneissic series is easily recognized on both the north and the south side of the moun-

[a] The term "country rock" is used in this report as a convenient expression denoting the terrane invaded by and thus in contact with an irruptive body.

tain, and it is quite as easily seen in the field that the belt has not been appreciably offset by a fault transverse to the strike. It is likewise in the highest degree improbable that displacements parallel to the strike of the schists can be safely called upon to explain the spaces now filled with the solidified magmas.

The facts derived from field study also speak strongly against the idea that all or any of these intrusions took place in consequence of the removal of the country rock en bloc by faulting. It might be conceived that faulting could have led to the transfer of the displaced schists upward, as if punched out by a huge die,[a] or to the foundering of the corresponding blocks, which would thus become buried deeply by the magma entering the resulting chamber. If such circling faults had occurred we should expect some evidence of them to be yet decipherable in the country rocks. Yet the latter show no sign of disturbance that can be traced to those particular movements. Even if the intrusion had taken place after this manner in one instance, it is in the highest degree improbable that so unusual a dynamic process should have been repeated three times in this limited area. The ground plan of the different stocks as expressed in the geological map can scarcely be explained on the hypothesis of circling faults. We must rather conclude, from a survey of the ground, that each of the stock bodies has actively displaced its country rock so as to find room for itself. The Basic stock has displaced the gneisses; the nordmarkite stock has displaced diorites and schists; the stock of Pierson Peak has displaced gabbros and diorites; the nordmarkite-porphyry of Little Ascutney has displaced gneisses and diorites, and the granite has displaced the syenite and a small amount of the phyllites.

A second commonly held view of many stocks and of many "batholiths" is that they have undergone their "mise en place" as a result chiefly of the caustic and assimilating property of the igneous magma in contact with the country rock. Thus, while Brögger regards the Predazzo-Monzoni area as illustrating in a thoroughgoing manner the process of differentiation in deep-seated chambers prepared by crustal movements, Fouqué finds in the same province an almost typical example of assimilation. It is here, as elsewhere, a question of the degree to which the process produces its effect, as every field geologist is bound to credit the assimilation of small foreign fragments caught in a molten magma and, as well, the local and subordinate digestion of the walls at certain of the eruptive contacts already described in geologic literature.

Stated in its usual form, the assimilation hypothesis also will hardly fit the facts recorded for the Ascutney eruptives. The oldest stock is quite basic, though it cuts a series of acid gneisses. The Main syenite shows no basification at its contact with the diorites. Its endomorphic contact phase is, on the contrary, there, as elsewhere, more strongly quartzose and has often even a smaller proportion of bisilicate than

[a] Recalling the "bysmalith" of Iddings, Mon. U. S. Geol. Survey, Vol. XXXII, Pt. II, 1899, p. 16.

the average syenite. The biotite-granite has, it is true, a hornblende among the constituents of its basic segregations; but the endomorphic zone, where the granite comes in contact with the older syenite, does not exhibit any special sympathy with that rock. Still more important is the complete lack of basification in the pulaskite of Pierson Peak which cuts the diorite and associated gabbro. That stock is of small dimensions. It is alkaline, and hence is composed of material which in its magmatic form must have been of specially caustic nature. The crystalline rock through which the magma found its way has a markedly different composition. There, if anywhere, we should, on the assimilation hypothesis, look for an endomorphic zone sensibly affected by the country rock. The failure of such a zone is as unquestionable as in the notable case of the shonkinite laccolith of Square Butte, Montana.[a] The Pierson Peak stock is made up of a homogeneous syenite which is indistinguishable, save for the absence of free quartz and the disappearance of much of the essential bisilicate, from an abundant phase of the Main stock of Ascutney Mountain proper. Both stocks are syngenetic with the stock-like dike of Little Ascutney. The occurrence of all three with essentially similar mineralogical and chemical properties, but with essentially diverse country rocks, seems to prove that they came from a single magma which persisted in nearly its pure form even after injection and notwithstanding the well-known solvent power of alkaline magma on both acid and iron-rich basic rocks.

SUGGESTED HYPOTHESIS OF THE MANNER OF INTRUSION.

Without considering other and less important views of the mechanics of intrusion, which, suggestive as they are, must yet be regarded as insufficiently supported by observations in nature, a somewhat detailed statement may be made of a third hypothesis which has forced itself upon the writer. It not only explains the facts as far as Mount Ascutney is concerned, but meets as well all the tests which have yet been applied to it from the results of experimental geology, from observations in other regions, and from the theory of igneous bodies generally.

Most geologists are agreed that intrusion on a large scale is not a sudden act, but occupies a period of time comparable to that required for complex folding in a mountain massif. This conclusion has been reached by those advocating the assimilation theory, as well as by those holding the rival theory of laccolithic and allied crustal displacement.[b] While the conclusion of any investigator as to the time required for a magmatic injection is itself in part a by-product of the intrusion theory ruling in his mind, it is yet noteworthy that the present exponents of the opposed theories accord in ascribing great duration to the time required for granitic intrusions at least. It will,

[a] Weed and Pirsson, Bull. Geol. Soc. Am., Vol. VI, 1895, p. 389.

[b] W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. II, 1895, p. 149.

then, be no antecedent objection to the hypothesis now to be proposed that it is based on a process of integration of small effects, and that the integration suffices for the geological work in hand only after the lapse of a long period between the beginning and end of the process.

The starting point of the hypothesis is found in the consideration of the phenomena of the contact belt belonging to each irruptive body. The present assimilation theory of Michel Lévy and others demands a study of the same belt as a test, rather than as the basis of formulation.

At many points in the internal contact zone of any one of the stocks numerous fragments of the country rock may be seen in the eruptive (Pl. VI). These are completely isolated, immersed in the crystallized magma, though often they are seen to have moved only a few feet or inches from the parent rock. As found in endomorphic zones of plutonics generally, the fragments are further quite normal in showing angular outlines and very sharp boundaries against the eruptive rock. There is usually, indeed, plain indication that these fragments have suffered little, if any, chemical solution by the magma. Recent experiments, however, have established beyond peradventure that, at temperatures but slightly above that of complete fusion of any silicate mixture, every important rock-forming mineral may be completely dissolved in that magma.[a] The conclusion seems unavoidable that, at the moment when a given foreign fragment was torn or floated off from its wall and thereafter, the immersing magma was relatively cool, and thus enfeebled in its solvent power. That its metamorphosing power was likewise diminished is suggested by the fact, borne out by microscopic study, that the recrystallization of the fragment is generally no more advanced than that of the country rock many feet from the irruptive.

But a still stronger proof of a comparatively low temperature at the moment of isolation of any one of the fragments is the fact that it is now to be seen floating, as it were, or, to be more accurate, suspended, in the magma. A brief consideration of certain experimental determinations shows that such suspension can occur in a normal magma invading rocks of average specific gravity only on the condition that the magma is highly viscous and near the point of consolidation. It has been established that, for each class of holocrystalline silicate rocks, the specific gravity of the corresponding glass is considerably lower than that of the natural rock, and that the specific gravity of the same rock when completely melted is still lower than that of the glass. No investigation has been made on these points for any of the Ascutney rocks, but it is fair to use the results for similar rocks from other parts of the world.

The most important case for consideration is evidently the relation

[a] Among other papers, cf. C. Doelter, Die Schmelzbarkeit der Mineralien und ihre Löslichkeit in Magmen: Tscher. Min. u. Petrog. Mitth., Vol. XX, 1901, p. 307; and Ueber einige petrogenetische Fragen: Centralbl. f. Min., Geol. und Pal., 1902, p. 545

between the specific gravity of the rocks in the Gneissic series and that of the diorite-gabbro magma; therein we must have the closest approximation in density between the material of any one stock and its staple inclusion. The specific gravity of the chemically analyzed diorite is 2.936. Similar determinations were made for the more basic gabbro phases collected at three different parts of the same stock; the values here ran from 2.95 to 3.19. The average for the gabbro is 3.08. We may take 3.10 as the approximate average specific gravity of the more basic parts of the oldest stock.

The most thorough and careful experiment bearing on this question is that made by Barus in the fusion of diabase.[a] He found that a sample of diabase at 20° C. had a specific gravity of 3.0178 and the glass produced by the dry fusion of the same rock had, at the same temperature, a specific gravity of 2.717. The density was much less in the molten state. Thus, at 1,400° C. the specific gravity was only 2.523, corresponding to an increase of volume of about 20 per cent. A critical discussion of many fusion experiments by Delesse and Cossa along the same line shows a close agreement in the behavior of the basic rocks treated in the older researches, as compared with that of the diabase of Barus's refined experiment.[b] One phase of the correspondence is shown in the following table:

Rock type.	1. Sp. gr. of rock at ca 20° C.	2. Sp. gr. of glass at ca 20° C.	3. Net decrease in density, rock to glass.	4. Net increase in volume, rock to glass.	5. Sp. gr. of rock molten at 1,400° C., calculated from Barus's fusion curve.
			Per cent.	*Per cent.*	
Diabase of Barus	3.0178	2.717	10.00	11.2	2.523
Average gabbro of Delesse	2.999	2.652	11.57	13.1	2.507
Average diorite of Delesse	2.859	2.657	7.07	7.6	2.390
Quartz-diorite of Cossa	2.667	2.403	9.90	11.1	2.229
Syenite of Cossa	2.710	2.430	10.33	11.5	2.266
Average granite of Delesse	2.684	2.438	9.16	10.0	2.243
Average of above			9.67	10.7	
Gneiss of Delesse	2.821	2.625	6.95	7,5	2.358

It is seen that these various independent investigations establish a tolerably constant ratio for the relative volumes of a holocrystalline, plutonic rock and of the glass produced by its fusion. Of special interest are the small differences among the results of Barus, Delesse, and Cossa on diabase, gabbro, and quartz-diorite. These are rocks related to various facies of the Basic stock at Ascutney Mountain.

[a] Philos. Mag., Ser. V, Vol. XXXV, 1893, p. 173; and Bull. U. S Geol. Survey No. 103, 1893. Cf. Joly, on fusion of basalt, Trans Roy. Dublin Soc., Ser. II, Vol. VI, 1897, p. 298

[b] Delesse, Bull. Soc. Géol France, Ser. II, Vol. IV, 1847, p. 1380; Cossa, ref. by Zirkel, Lehrbuch der Petrographie, Vol. I, 1893, p 681

The behavior of all basic rocks under fusion has, unfortunately, not been tested for high temperatures, but, for reasons well established by Barus and derivable from a survey of this particular field of research, it is admissible to apply the fusion-curve of Barus to any rock of allied composition. On this supposition, at one atmosphere of pressure, the specific gravity of the Ascutney gabbro would fall from 3.10 to 2.59 at 1,400° C. and that of the average diorite from 2.94 to 2.46. At this temperature the rock would remain highly fluid even at the depth of 5 miles in the earth's crust. The specific gravity of the normal gneisses occurring near the Basic stock ranges from about 2.69 to about 2.76, with a probable average of 2.73.

To determine what these would be if fragments with the corresponding densities could be kept solid and obey the law of expansion for solid rock, at 1,400° C., it is permissible to use Reade's expansion coefficient for granite without incurring serious error.[a]

Barus has shown that pressure simply elevates the melting point in the normal type of fusion without interfering essentially with the value of the coefficient determined at ordinary temperatures and pressures.[b] The average gneiss would have, as a result of the application, a calculated specific gravity of 2.63. It must be remembered, too, that contact metamorphism here, as generally elsewhere, would raise this value still higher, and that any acidification of the magma in contact with the gneiss would lower the density of the magma. Now, the beautiful experiments of Barus in the fusion of various carbon compounds under varying pressures show that, in thermal expansibility and in compressibility, they behave in a manner extremely similar to the few silicates on which any studies in fusion have been made. He has shown that naphthalene, a substance obeying, like diabase, the normal law of fusion, is slightly more compressible as a liquid than as a solid.[c] The fusion curves indicate that, for the same increase of pressure, liquid naphthalene gains in specific gravity about twice as fast as solid naphthalene. The compressibility of a fused silicate rock is probably, then, approximately twice that of the same rock when solid. But his diabase curve demonstrates that the thermal expansibility of the liquid rock is 1.9 as rapid as that of the solid rock. Thus a block of cold solid gabbro immersed in a deep-seated molten magma of the same chemical composition would be less condensed by the pressure than the molten rock, but the effect on relative densities would be partly compensated by the relative rate of expansion due to any superheating of the magma. A block of gneiss would behave in a manner closely similar to that of a block of gabbro. It is believed that the pressure of several thousand atmospheres would not affect seriously the contrast in densities which experiment would lead us to expect if a fragment of the Ascutney gneiss were completely immersed in the fused gabbro at plutonic pressures. If this be true, only one

[a] Origin of Mountain Ranges, London, 1886, p. 110. [b] Philos. Mag., Vol. XXXV, 1893, p. 306.
[c] Am. Jour. Sci., 3d ser., Vol. XLII, 1891, p. 140.

conclusion can be drawn. Since uniform pressure affected both gneissic fragment and magma when the former was parted from the parent country rock, the difference of density of the two would prevent the suspension of the fragment as a mere matter of flotation. Further, the fragments, like the basic segregations, could remain in the positions in which they may now be seen only if the magma possessed a high viscosity at the time when they were rifted off.

If we are forced to this view of the conditions in the Basic stock, still more surely may we have confidence in it as explaining the presence of even more numerous schist fragments in the syenitic and granitic stocks. The following table shows that, even in the holocrystalline state, each irruptive rock has a specific gravity lower than its country rocks. It indicates further that the inequality increases in the same sense the greater the degree of exomorphic change in the invaded schist.

Eruptive rock.	Specific gravity.	Corresponding country rocks.	Approximate specific gravity.
Main stock	2.616 – 2.683; average, 2.65	Normal sericitic schist	2.70
		Average of three specimens from phyllite of contact zone.	2.84
		Average of Basic stock	3.05
Nordmarkite-porphyry of Little Ascutney.	2.633	Average of Basic stock	3.05
		Average of gneisses	2.73
Pulaskite, Pierson Peak	about 2.63	Average of Basic stock	3.05
Granite stock	2.616	Normal sericitic schist	2.68
		Average of hornfels from phyllitic contact.	2.84
		Average of Main syenite	2.65

Delesse found that, in melting down granite to a glass, the specific gravity was lowered about 10 per cent on the average.[a] Accepting his figure, the biotite-granite of Ascutney would afford a glass with a specific gravity of about 2.35.[b] A block containing 1,000 cubic feet of the porphyritic phase of the Main syenite would tend to sink in a magma of the latter specific gravity by virtue of a downward pull equal to the weight of at least 5.3 tons of rock in the air, and evidently, from Barus's results, still faster in the thinly fluid granite itself. It is in the highest degree probable that this difference of density would not be significantly altered by the great pressures reigning at the moment when such a block would become detached from the wall of the granite body. Nothing less, then, than a very unyielding, highly viscous

[a] Annales des Mines, Ser. II, Vol. IV, 1847, p. 1380.

[b] Cf. granite, specific gravity 2.63; obsidian, 2.3 to 2.4.

condition of any one of the Ascutney magmas can account for the presence of the foreign blocks in the immediate vicinity of their homes in the invaded formations. The viscosity probably approached that of the Archean granitic magmas, which, according to Lawson, were capable, under enormous dynamic stresses, of shearing and attenuating foreign blocks suspended in those magmas near the moment of consolidation of the latter. Lawson has also suggested that, although the viscosity was so great, the temperatures may have been high enough to melt up the more basic foreign fragments completely.[a] Whether solid or molten when sheared or pulled out, such blocks could not sink in the magma, because of its thick, pasty condition.

At Ascutney Mountain, as elsewhere, the magmas that formed the stocks were capable of forcing their way through fissures a few inches or but a fraction of an inch in width, for distances of hundreds of feet or yards from the respective main eruptive mass. These are clearly offshoots from the stocks, though the junction with the latter may not be seen in many instances. Each magma must have been very fluid when it filled its own set of these narrow fissures.[b] That conclusion accords with the results of the recent careful experiments of Doelter.[c] He has shown that there are but comparatively small differences among the temperatures at which a granitic rock or an artificial mixture of silicates is softened by heat, becomes thinly molten, or solidifies from that molten condition. Thus he found that a foyaitic mixture (of orthoclase, elæolite, and ægirine) became soft at 1,070° C., thinly fluid at 1,110–1,115°, and then solidified at 980–1,000° C. The corresponding figures for a basaltic mixture (of labradorite, augite, olivine, and magnetite) are 1,120–1,125°, 1,140–1,150°, and 980–1,000° C. Predazzo granite and Remagen basalt became softened at respective temperatures of 1,150° and 992° C.; completely molten at, respectively, 1,240° and 1,060° C. But a slight restoration of heat, therefore, would be necessary to reconvert a cooled and toughly viscous endomorphic zone, yet hot enough to quarry blocks from the invaded formation, into a highly mobile state. It can not be denied that there must occur a loss of at least that small amount of heat in the closing stage of stock intrusion. The magnitude of plutonic pressures puts no difficulty in the way of accepting this conclusion as to high fluidity. Oetling has proved, on the contrary, that the temperature point of consolidation of melted rocks and silicate mixtures is lowered by pressure. He, in fact, shares the view of Amagat, that, if the pressure be sufficiently high, solidification can not occur at all.[d] Moreover, it

[a] Geol. Rainy Lake Region, Ann. Rept. Geol. and Nat. Hist. Survey Canada, 1887, Part F, pp. 131-2-3-8, etc.

[b] There is no contradiction between this statement and the previous one of high viscosity in the main magma which isolated and suspended foreign blocks. As implied in a following paragraph, it would simply mean that the apophysal tongues were injected before the magma had come in contact with the present walls of its main chamber.

[c] Tscher. Min. u. Petrog. Mitth., Vol. XX, 1901, pp. 232 and 307

[d] Ibid., Vol. XVII, 1897, p. 370.

is coming to be generally accepted that pressure induces mobility in plutonic magmas by retaining water and mineralizers.[a]

In summary, then: Field observation and experiment agree in attributing a thinly fluid condition, except at the moment of final crystallization, to such magmas as those from which the Ascutney stocks were derived.[b]

High fluidity must have two important results: First, it would facilitate the formation of apophysal tongues, often intersecting; secondly, it would entail a downward strain on any disjointed blocks in the roof contact of the stock body. Following joints, planes of stratification, schistosity, or slipping, the apophyses must seriously impair the strength of the roof and walls. The same planes of weakness, even without the aid of the irruptive wedge, already form a menace to the integrity of the walls and roof, especially the latter; this on account of the gravity component already demonstrated as a result of a difference of density between the solid rock and the magma beneath. Moreover, a shattering of the country rock may be expected by reason of the differential temperature strains induced by the magma.

When, from these causes, a block becomes dislodged and completely immersed in magma, it must sink, and sink rapidly.[c] The space formerly occupied by the block is now filled with magma. In the same manner an indefinite number of blocks may be removed by this natural stoping. New surfaces will continually be presented to the invading magma, and so long as the stated conditions persist there will be greater and greater destruction of the country rock. It is simply a question of time whether the advance of the magma shall be so great as to fashion the chamber of an Ascutney stock or of a great batholith.

A brief statement of this central idea of the stoping hypothesis has been given by Lawson in a review of certain of Brögger's writings. So far as known to the present writer this noteworthy paragraph contains the only clear enunciation of the doctrine to be found in geological literature, and is worthy of quotation in full:

> The essential features of the assimilation hypothesis were formulated by the reviewers some years ago, before the publication of Michel Lévy's views, and urged as a satisfactory explanation of the remarkable relations which obtain between the Laurentian granites and gneisses and the upper Archean or Ontarian metamorphic rocks. These intrusive granites and gneisses occupy vast tracts of the Canadian Archean plateau, and there seems to be no escape from the view that they bear a batholitic relation to the crust which they invaded from below. Portions of the crust were absorbed, but there are two possibilities as to the method of absorption, viz: 1, by fusion; 2, by sinking into the magma. The numerous blocks of rock scattered through the granites lend much probability

[a] Doelter, Tscher. Min. u. Petrog. Mitth., Vol. XXI, 1902, p. 218.

[b] See the general statement by Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. III, p. 338.

[c] Johnston-Lavis has seen a piece of compact lava sink quickly in a flowing lava stream from Vesuvius. Proc. Quart. Jour. Geol. Soc., Vol. XXXVIII, 1882, p. 240.

to the latter having played a part in the process. Such batholites were doubtless accompanied by laccolitic satellites.[a]

The hypothesis of natural overhead "stoping" accords with the facts known with regard to other kinds of igneous intrusion. Even in the case of those great granitic massifs organically associated with master lines or zones of dislocation (e. g., the tonalite and the "Judicarienlinie" of the Tyrol), the magma chamber may have been largely opened by overhead stoping. The same process may similarly greatly enlarge the deep-seated cross section of a volcanic neck. Yet no one can deny its practical insignificance in the intrusion of sheets or dikes, nor, for obvious reasons, does that fact injure the strength of the proposed hypothesis when dealing with vastly larger igneous bodies. The latter must be much longer molten by reason of their size, and have more direct communication, through convection and other currents, with the earth's interior. The same remark applies in general to laccoliths, although it is possible that, in limited degree, laccolithic magmas may carry on independent stoping, and therewith assimilation, in their hot interiors.

The hypothesis, it will be observed, is allied in one respect to the assimilation theory of Kjerulf, Michel Lévy, Lacroix, and others. According to each of the two views, the plutonic chamber occupied by stock or batholith has been formed by the activity of the magma itself along the internal contact. But, in the older theory, the assimilation at the contact is essentially caustic and chemical; in the newer view the assimilation there is essentially mechanical. The former attempts to explain in one step the opening of the space now filled with eruptive material and the disappearance of the corresponding mass of country rock; the latter has still to give account of the multitude of larger or smaller blocks sunken in the magma. What becomes of them? How far will they sink? What is their fate when they come to rest?

ABYSSAL ASSIMILATION.

It is at once evident that such questions are most difficult to answer in detail; perhaps the second is always destined to remain unanswered. It is evident, too, that we are now many removes nearer the realm of speculation than in any previous explanatory step. Yet it can not be considered a fatal objection to any theory of intrusion that it must refer ultimately to the unexplored interior of the earth. The attempts to solve the plutonic problem with attention rigidly kept on the accessible part of the earth's crust must have but partial success. If experiment, analogy, and the considerations of cosmical physics can aid in explanation, they should be employed. The field geologist has only the earth's outer skin to study; yet granite, with all its relatives, is a product of physiological processes occurring, as it were, in the vital organs of the earth.

The cardinal fact of fluidity in plutonic magmas needs to be viewed

[a] Science, new series, Vol. III., 1896, p. 637.

in relation to the equally certain fact of the earth's rigidity and to the necessity of finding some mechanical explanation for the support of the roof over the igneous body during intrusion. A complete discussion of the former topic would carry us farther afield than the scope of the present report warrants. Suffice it here to note that the same problem confronts every modern theory of intrusion.

In the case of the Ascutney stocks it is believed that the strength of the roof over each irruptive mass was doubtless sufficient to prevent its foundering en masse in the less dense magma. Other and larger stocks and batholiths must be studied in this regard each by itself. As the underpinning of the schist cover of the Ascutney igneous area as a whole was demonstrably aided by a progressive consolidation of the partial magmas, so it is conceivable that there may be a lateral progression of solidification in the homogeneous magma of a much larger body with a corresponding strengthening of its roof. In all such intrusions there will also be the continued presence of country-rock buttresses still remaining unassimilated.

Whether a stoped-out block sinks in the magma but thousands of feet or miles from its former position in roof or wall, that block must undergo an increase of pressure, and, with the greatest probability, an increase of temperature.[a]

The added pressure would have, according to the experiments and field studies of Barus, Doelter, Daubrée, Fouqué, Michel Lévy, and others, the secondary effect of increasing in the magma the capacity of retaining water and other solvents, even at very high temperatures.[b] So important are other experiments in this connection that a brief résumé of certain results accruing from them must be given.

The solubility of rock-forming minerals in silicate magmas has been shown by fusion experiments to depend on (*a*) the temperature of the magma; (*b*) the chemical composition and fluidity of the magma; (*c*) the fusibility of the minerals, and (*d*) on pressure. Doelter has been able to prove that, under one atmosphere of pressure, all the common types of rock-forming minerals are completely soluble in certain representative magmas at temperatures only slightly above those of the respective consolidation points of the latter. These magmas were made from granite, obsidian, common basalt, limburgite, phonolite, foyaite, leucite-basalt, leucitite, hornblende-andesite, and nepheline-basalt—a magmatic range so wide as to demonstrate the practical certainty that all silicate magmas have similar solvent properties. He further shows that the melting point of a silicate rock occurs at about the average temperature of fusibility of its constituent minerals. Long before, Bischof easily dissolved clay-slate in fluid lava, using a bellows furnace for fusion.[c] These important deductions

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[a] Perhaps the block would sink to the zone of pressure-solid magma.

[b] Among the more recent papers, cf. C. Barus, Am. Jour. Sci., Vol. XXXVIII, 1889, p. 408, and Vol. XLI, 1891, p. 110; C. Doelter, Centralbl. f. Min., etc., 1902, p. 550, and Tscher. Min. u. Petrog. Mitth., Vol. XXI, 1902, p. 218.

[c] Chem. u. Phys. Geol., Supplement, 1871, p. 98.

from laboratory investigations correspond to the facts of outdoor nature. Well-known practical examples may be found in the fused and greatly corroded granite inclusions in the basalts of the Auvergne, and again in the complete disappearance by fusion of the "floating islands" in the caldera of Kilauea.[a] The high fluidity of the normal plutonic magma would likewise facilitate the complete solution of foreign fragments, as experimentally proved by Doelter.

It is true that the direct influence of pressure is directed toward elevating the melting points of silicate mixtures, though probably not in a degree proportional to the amount of the pressure.[b] Yet that effect on the solvent power of the magma may be much more than counterbalanced by the indirect effect of pressure in retaining water and other solvents. Once molten, pressure tends to keep silicate magmas molten, since it lowers the temperature point of consolidation.[c] In determining the solvent power of a plutonic magma, temperature furnishes here, as in fixing the melting point, the "coarse adjustment," as pressure furnishes of itself the "fine adjustment."

In conclusion, then, it seems legitimate to regard the conditions of the abyssal portions of plutonic magmas as conspiring toward the perfect digestion of a submerged foreign rock fragment during all the time of intrusion except during the short period preceding final consolidation. Even so uncompromising an opponent of the theory of contact digestion by stock magmas as Brögger admits that such assimilation can be, in the greater depths, exceedingly important, "ausserordentlich bedeutend."[d]

Since it is probable that magmas are more or less completely saturated solutions,[e] there would doubtless be a volumetric increase on the fusion of each block at whatever depth it attained, an increase comparable to that demonstrated in fusion experiments at 1 atmosphere of pressure. The question at once arises as to what compensation can be made for the increased bulk of rock matter below the earth's surface incident to abyssal assimilation on a large scale. Two possibilities suggest themselves in the face of the hydrostatic problem involved. Either volcanic outflow elsewhere or secular upheaval in the region would satisfy the conditions. The latter would seem to be more likely of fulfillment in regard to stocks and batholithic intrusions generally. It is to be noted that magmatic stoping would tend to weaken the earth's crust immediately above the intruding body, and there secular elevation of the surface would be particularly looked for. There may, in this way, be found one cause of the huge buckles filled with the "central granites" of Alpine mountain chains. This implies

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[a] J. D. Dana, Characteristics of Volcanoes, New York, 1891, p. 176.

[b] Doelter, Tscher. Min. u. Petrog. Mitth., Vol. XXI, 1902, p. 221.

[c] Oetling, op. cit., p. 370.

[d] Die Eruptivgesteine des Kristianiagebietes, Vol. III, 1898, p. 350.

[e] Lagorio, Tscher. Min. u. Petrog. Mitth., Vol. VIII, 1887, p. 504. Cf. Delesse, Bull. Soc. Geol. France, ser. ii, Vol. IV, 1847, p. 1393.

that the doming of the great intrusive masses of the Christiania region, attributed by Brögger to laccolithic injection, may, in reality, be due to this crustal weakening and buckling by magmas working up from the "ewige Teufe," but at present it must remain only the suggestion of a possibility, as the writer has no personal knowledge of the region.

It is, moreover, worthy of inquiry whether this sort of live energy of intruding granitic magma may be responsible for many of the well-known cases where the secondary structure planes in the invaded formations wrap around their respective intrusive bodies. Examples are seen in the highly developed peripheral cleavage and schistosity parallel to the outlines of such magmas in the Rainy Lake region[a] and in the Black Hills.[b] Such structures could certainly be produced by the force of magmatic expansion, provided that force be sufficient in amount, for it must be exerted always normal to the chamber walls.

If the foregoing reasoning is correct, the preparation of the chambers within which the stock bodies of Ascutney Mountain now rest was carried out by mechanical, piecemeal disruption of each invaded terrane by the attack of the magma on the main contacts. This physical action was accompanied by chemical assimilation at greater depths. Consequently, at those depths the magma must become more and more mixed as the result of assimilation. Each successive eruption from the magma basin beneath may be expected to show indications of the gradual alteration of the magma by the incorporation of foreign substance. This important corollary has to do with the great question of the origin of the igneous rocks, a subject which, in spite of all its complex difficulties, must here be dwelt upon so far as to show agreement or disagreement with the hypothesis just outlined. But a less important, although significant, test of the hypothesis may first be noted.

The hypothesis of rifting not only gives adequate reason for the very general sharpness of contact between an irruptive and its country rock, but also goes far to explain the observed lack of enrichment of the endomorphic zone with the material of the country rock. The blocks would be likely to suffer most from solution in the magma after they had begun their rapid downward journey. They would yield up their substance along the whole path. There would thus be a tendency toward an equal distribution of the absorbed material throughout the magma. In any case, there would be far less impregnation of the endomorphic zone with the substance of the invaded formation than that demanded by the supposition of the slow digestion of the latter in place. In so fluid a magma convection currents would tend still further to destroy any contrast of composition between the endomorphic zone and the body of the intrusive.

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[a] Lawson, Ann. Rept. Geol. and Nat. Hist. Survey Canada, 1887, Part F, map.

[b] Van Hise, Sixteenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, pp. 637 and 815.

EVIDENCES OF DIFFERENTIATION.

In turning to the main problem still awaiting us, the relation of the hypothesis of rifting, overhead stoping, and abyssal assimilation to the sequence of the eruptive rocks at Ascutney Mountain, it must be be stated in advance that differentiation in the usual sense of that term has, it is believed, been operative in the production of these rocks. This illuminating principle seems to win added credibility every year, as the petrological facts concerning consanguinity, complementary dikes, etc., become more numerous and more clearly ascertained. Without entering further into the general question, the course of our argument demands that some of the concrete evidences for the value of the principle be noted as the result of a study of Ascutney Mountain.

Direct witness to the fact of differentiation is found in the abundant and remarkable basic segregations from most of the stocks and dikes. Moreover, the "blood relationship" in mineralogical and chemical composition of the main rock bodies of Little Ascutney, Pierson Peak, and Ascutney Mountain proper, occurring as they do in so strikingly different geological associations, and the close agreement in composition with the distant syenitic rocks of Essex County, Mass., Killington Peak, the Adirondacks, Rigaud Mountain, Quebec, and the eastern townships of Quebec, seem to indicate that strict chemical and physical laws, and not fortuitous similarity in the products of assimilation, govern the particular groupings of metals and oxides found in the respective intrusives. The occurrence of nordmarkites in all of these regions must be regarded as the result of the independent assertion in each region of one and the same set of laws of attraction and concentration in an originally more complex rock magma rather than the result of multiplied consolidations of one great nordmarkitic magma underlying all this part of North America.

Further, the conclusion that mere assimilation of the invaded sedimentary terranes by a magma can not be used to explain the intrusives of this part of the world is rendered all the more probable by a detailed comparison of the Ascutney eruptives with those of Mount Shefford, as described by Dresser.[a] The Canadian intrusives named in the order of injection are essexite, nordmarkite, pulaskite, camptonite, and bostonite. The first of these is considerably more alkaline than the Ascutney diorite analyzed, but is probably close chemically to phase *e* of the Basic stock. Macroscopically, the Ascutney diorite and the Shefford essexite are remarkably alike in general habit, and the writer has seen a coarser phase of the latter which has the poikilitic bisilicates and other detailed features of the Ascutney gabbros. As striking similarity characterizes the green nordmarkites of the two mountains. These facts seem to prove conclusively that definite chemical and physical laws have governed the formation of

[a] Am. Geol., 1901, Vol. XXVIII, p. 203.

each special magma which crystallized after irruption into the rock bodies now exposed to view. There has been some post-eruptive differentiation in the Shefford intrusions, as they possess basified endomorphic zones. Dresser holds that the essexite, nordmarkite, and pulaskite form the filling of a laccolithic space in the Lower Silurian sediments of Shefford Mountain. Accepting his view of the mode of intrusion, preeruptive differentiation from a magma originally composed of a mixture of these special magmas, might be credited with a full explanation of the Shefford rocks, though even then the possibility is quite open that the original complex magma had been formed by the considerable digestion and assimilation by a still earlier magma, of the Trenton slates and other sediments through which the eruptions took place. On the other hand, the fact of some kind of assimilation preparatory to differentiation at Ascutney can hardly admit of doubt.

The differentiation of the alkaline rocks in the area, on the hypothesis outlined for Ascutney, would be local and confined to a magma which had been more or less strongly affected by the "mise en place" of the Basic stock. If we have anywhere an igneous formation approximately representing the main magma which underlay the region before the intrusion began, it must be found in that stock. All subsequent intrusions might, on account of the intermixture of assimilated schists, be expected to show a divergence from the original magma that would be the stronger the later the corresponding intrusive appeared in a series of eruptions. In other words, the windsorite dikes, the nordmarkites, pulaskite, monzonite, paisanite, granites, and aplites are, by the hypothesis, regarded as the product of the deep-seated assimilation of the schists followed or accompanied by the differentiation of these related magmatic types from the mixture due to subcrustal digestion. The high silica, potash, and alumina of the micaceous and quartzose phyllites and gneisses would explain the increasing acidity, the alkalinity, and feldspathic character of these differentiated products, though other features must be credited to differentiation alone.

Just how differentiation takes place is still to be reckoned among the mysteries of geology. There is no doubt that several determinative factors must be taken into account. Without in any way wishing to question the validity of the other causes, the writer will here briefly instance one of them as seeming to be of more general application. Rosenbusch has published the view that the separation of differentiated products may be due in part to the gravitative effect, whereby the more acid and lighter constituents of a complex magma become segregated and float upon the more basic and heavier residue.[a] It is supported by the valuable observations of Morozewicz in synthetic experiments and in the study of glass furnaces.[b] Doelter

[a] Mikroskopische Physiographie d. Min. u. Gest., Vol. II, 1896, p. 552.
[b] Tscher. Min. u. Petrog. Mitth., Vol. XVIII, 1898, pp. 170 and 233.

has pointed out that such results adhere to exceptional cases, both in his own experiments and in those of the Russian investigator; yet their significance is still great, since they agree with Gouy and Chaperon's theoretically deduced principle of gravitative stratification in saline solutions,[a] as well as with some positive field observations. For example, Sir A. Geikie describes the separation of a lower layer of picrite and an overlying layer of olivine-basalt in the same lava flow, and finds it probable that similar differentiation has taken place in basic sills.[b] It is at least worth while to apply the gravitative theory to the Ascutney magmas, so far as to state briefly the course of events entailed.

By the separation of the differentiated products, the uppermost layer would, by the antecedent addition of the abundant silica from the digested schists, become more and more acid as the assimilation progressed. The aplites and granite would appear as the latest products (excepting the complementary dikes) of a differentiation dependent on the assimilation for its final expression.

Opposed to the hypothesis is the more usual view of simple differentiation as explanatory of the eruptive sequence. The latter has been well expressed by Brögger for the similar sequence in the Christiania region. He points out the general harmony existing between the theoretical order of differentiation, the order of eruption in the province, and the order of crystallization in the various rocks.[c] On the same principle the oldest Ascutney stock would be regarded as of the nature of a gigantic basic segregation which had absorbed into itself the basic orthosilicates and metasilicates of lime, magnesia, and iron before the crystallization, from the same original magma, of the syenites and granite where the dark-colored constituents are so poorly represented.[d] The possibility of mere differentiation (without assimilation) producing the Christiania rock bodies is due, according to Brögger, to the peculiar laccolithic nature of the intrusions in that province. The preparation of free space for the play of chemical reactions leading to differentiation is quite in contrast with that hypothecated for the Ascutney area, though many of the rock types of the two regions are extremely similar. Brögger has pronounced against the assimilation theory of Kjerulf and Michel Lévy, largely for the reason that it fails to meet the controlling test, the proof of chemical sympathy between the formation invaded and the igneous body supposed to have performed the digestion. Thus the granite of the Christiania region contains scarcely 0.5 per cent of CaO, although the Cambrian and Silurian beds through which the intrusions occurred contain as large an average as 24.5 per cent of the same oxide.[e] The objection does not, however, apply to the modified assimilation

[a] Ann. de Chimie et de physique, 6th ser., Vol. XII, 1887, p. 384.

[b] Ancient Volcanoes of Great Britain, London, 1897. Vol. I, pp. 419 and 442, and Vol. II, p. 310.

[c] Die Eruptivgesteine des Kristianiagebietes, Vol. II, 1895, p. 175.

[d] Cf. Zeit. für Kryst., Vol. XVI, 1890, p. 86.

[e] Die Eruptivgesteine des Kristianiagebietes, Vol. II, 1895, p. 129.

hypothesis as outlined in this chapter. Brögger's own cross sections would imply that the Cambrian and Silurian limestones were deposited on Archean crystalline schists. The vertical thickness of this formation is probably several times as great as the thickness of all the Lower Paleozoic limestones combined. Differentiation working on the magma produced by the mixture of the digested material of both limestones and schists might very well give a granite with a low content of lime. Be the method of intrusion what it will, the similarity of the Norwegian and Vermont rocks seems to point unmistakably to the truth of the main principle of differentiation—the tendency toward definite chemical and mineralogical segregation in a silicate magma, irrespective of how that magma was prepared.

As the specific gravity of the acid magmas must in every case be lower than that of the original basic magma, the latter would tend to rid itself continually of the foreign substance being dissolved from the sunken blocks. We have seen that the latter would sink deeply. Whether this gravitative cleansing be perfect or not at a moderate depth of, perhaps, a mile or two below the original magma surface, the magma might there still be quite basic. If we now imagine a prolonged period during which the overlying acid-alkaline intrusives were completely crystallized and, afterwards, a limited fracturing of the whole compound terrane, we can secure some explanation of the final series of basic dikes. They would represent the product of renewed eruptive activity from the deep-lying, still molten magma pressed upward along the easy paths of the fractures. The common occurrence of the diabase dikes and lavas through the whole length of the Connecticut Valley and in many parts of the Appalachian system suggests correlation with this hypothetical explanation. Possibly the camptonites are nothing more than dikes of diabase which have absorbed a small amount of ferrous iron and alkalies from the syenites through which they have found their way. Nevertheless, in spite of the difficulty of determining the place and exact manner of the differentiation of complementary dikes in general, the possibility that these youngest dikes correspond to the basic poles of secondary differentiation can not be excluded. Nor is it necessary to the hypothesis of abyssal assimilation that either alternative be established, for the hypothesis must be linked with the belief in secondary differentiation.

THE PETROGENIC CYCLE.

Finally, it should be observed that the whole series of events leading from the beginning of the invasion of the oldest stock to the irruption of the youngest stock and dikes might, after the solidification of the last of these, be followed by a resumption of plutonic activity. There might thus be repeated the sequence of changes memorialized in the existing rock bodies—basic to acid through intermediate types. Or any part of the cycle might be repeated, whereby relatively basic irruptions into the schists would be followed by more acid ones. Or, thirdly, the cycle represented in the unsqueezed igneous rocks of the present mountain might have been preceded by an older cycle, the records of which are still buried deep within the schistose formations in the neighborhood. Such an earlier cycle would account for the amphibolites and aplitic sheets which antedate the last great period of folding and dynamometamorphism in the schists.

SUMMARY AND GENERAL APPLICATION.

In order to bring this hypothesis of overhead stoping, abyssal assimilation, and differentiation into relation with the general problem of the plutonic rocks, it will be expedient to recapitulate (I) the essential facts of observation in the Ascutney area, (II) the results of experimental investigation on the specific gravity of the Ascutney rocks and on silicate magmas, and (III) the conclusions won from the correlation of both groups of considerations.

(I) The Ascutney irruptive bodies exhibit the following characteristics:

A series of true stocks ranging from the oldest, most basic, and least alkaline to the highly alkaline, youngest, and most acid, followed and accompanied by groups of aplitic and lamprophyric dikes.

Two of the stocks (Basic stock and Main stock) characterized by a noteworthy heterogeneity; the other three by just as striking homogeneity.

An almost entire lack of sympathy between the structural planes in the country rocks and the form of each intrusive body.

Conclusive evidence that the different magmatic chambers were not prepared by circumferential faulting.

In each stock a decided lack of any enrichment of the endomorphic zone by substance dissolved from the invaded formations; a general freedom from foreign inclusions in the interior, with a characteristic abundance of angular inclosures near the contacts; an exceedingly sharp line of contact with the country rocks; equally sharp contacts of the foreign fragments and their respective hosts; lack of direct sympathy between the composition of the intrusive stocks and of their respective country rocks.

The existence of many long and narrow, apophysal offshoots from each stock, betokening their high fluidity at the time of intrusion.

The presence of many basic segregations in four out the five stocks.

The mineralogical and chemical characters of the stock rocks which, compared among themselves and with the rocks of other petrographical provinces, compel belief in some kind of differentiation of the Ascutney igneous bodies from a common magma.

(II) The experiments of Barus, Delesse, Daubrée, Doelter, Oetling, Morozewicz and others have shown—

That representative natural or artificial silicate mixtures at ordinary atmospheric pressure become thinly molten at a temperature only slightly above that of solidification.

That, in every instance, a great increase of volume characterizes the change from the solid to the molten state.

That the corresponding difference of density is, no doubt, essentially preserved under plutonic conditions.

That the chief rock-forming minerals are soluble in all of the melted silicate mixtures yet investigated and at the temperatures ruling when those mixtures are thinly molten.

That pressure aids the solubility indirectly by retaining water and other mineralizers in the magma, but retards it, probably in much less degree, by raising the temperature of fusion for silicate minerals.

That there is evidence of differentiation in molten silicate magmas by gravitative effect.

Numerous specific gravity determinations on the solid Ascutney rocks show that the lightest of these would, under the same conditions of pressure as the densest of the magmas (that of the Basic stock), sink on immersion in that magma.

(III) The conclusions necessitated, it is believed, by these facts are:

1. That the various chambers now occupied by the igneous bodies were not opened by bodily movements in the earth's crust, but by some kind of assimilation of the invaded formations.

2. That this assimilation did not take place, except in subordinate degree, by caustic solution on the main contacts.

3. That, even in its relatively inactive state near the moment of final consolidation, each magma was capable of rifting off numerous large and small blocks from the walls with which it came in contact—blocks now visible because the magma was then so toughly viscous as to support them in suspension.

4. That during the much longer period of high fluidity each magma was capable of still more powerful rifting action.

5. That throughout that period there must have prevailed a more or less steady rain of the rifted blocks downward into the lower depths of the magma and a corresponding enlargement of the magma chamber, the size of which would depend on the time during which the action continued; independent testimony may be had of the high probability that the time taken in all plutonic intrusion is very great.

6. That in the abyssal region the blocks must undergo active solution by the magma, which would thus become mixed and gradually more complex.

7. That some compensation for the increased volume of the rock digested must be made—suggesting either surface extrusion from another part of the same magma basin or secular upheaval of the earth's crust above the basin.

8. That the original magma was at least as basic as the gabbroitic phase of the oldest stock.

9. That there would be a tendency for the mixed magma to become more and more acid by reason of the assimilation of the schistose terranes.

10. That this magma would be expected to differentiate by slow gravitative action, through which the lighter, more acid submagmas would float on the heavier basic residues.

11. That such differentiation must be supplemented by other causes, real and universal, though at present ill understood, leading to a comparatively definite splitting of the main magma; thus homogeneous rock bodies would be produced similar to those in other parts of eastern North America and elsewhere.

12. That the Ascutney stocks are the crystallized product of such differentiation from an ever-changing magma constantly enriched by assimilation.

13. That the series of petrogenic events at Ascutney constitute a cycle that might be repeated either as a whole or in part within the same area.

14. That the later basic dikes may be explained as the beginning of a second petrogenic cycle, or as the basic poles of a secondary differentiation.

Now, the facts of field observation at Ascutney Mountain, with two possible exceptions, correspond to possible characteristics of most of the granitic intrusions of the world. The heterogeneity of the Basic stock and of the Main stock is doubtless of a higher order, and the basic segregations in the latter are more numerous than in the normal granitic mass. Yet these contrasts may be largely explained by the action of secondary differentiation. The experimental results of investigation on melted silicate mixtures are manifestly capable of general application. There is, accordingly, reason to believe that the hypothesis summarized in the list of conclusions concerning the Ascutney eruptives may be applied to most stocks and batholiths.

THE UNIVERSAL EARTH MAGMA.

If this hypothesis be accepted for stocks and batholiths generally, and if dikes, sheets, and laccolithic intrusions (including all such as have been conditioned by the action of hydrostatic pressure on a magma entering spaces opened by bodily crustal movements) are the results of the eruption of submagmas differentiated from the deeper-lying and greater magma produced by the incorporation of invaded formations, the further inquiry as to the original composition of such assimilating magma thus becomes a matter of special interest. The required space can not here be taken for a full discussion of this question, even if only the limited number of facts now known concerning the subject were given full statement. Special diffidence may be felt in approaching this most difficult theme. Yet certain preliminary considerations are offered, primarily those which, in the opinion of the writer, do not at the present time receive the full share of attention that they should have in the problem of the earth's interior; taken together, they seem to form, in a measure, a test of the foregoing hypothesis.

The evidence is accumulating that the normal order for the eruption of plutonic rocks is that of from most basic to most acid. That the same order may be preserved, on the large scale, in extrusions of lava at volcanic cones is illustrated by Sir Archibald Geikie in his treatise on The Ancient Volcanoes of Great Britain.[a] It seems established, moreover, that the oldest eruptive in the majority of petrographical provinces approximates a gabbro or basalt in composition. Yet the oldest intrusive, by the foregoing hypothesis, is that one which should most nearly represent the original magma, modified as the latter tends to become by the assimilation of the more siliceous crystalline schists and sedimentary terranes.

Again, in those conduits where escape of igneous rock from the earth's interior to the surface takes place to such an extent as to build large volcanoes, we should expect the sequence of eruption to be completed by an effusion of lava more nearly representing the original magma than the antecedent flows. This for the reasons, first, that assimilation (deep-seated digestion of the overlying crust) in the immediate vicinity of the vent would, in that late stage in the development of the volcano, have progressed so far as to have enlarged the conduit to a size suitable to the large cone; secondly, that the vent would by the long continuance of the volcanic activity have become freed from the products of such digestion, and, thirdly, that the latest flows would be derived from the original magma practically unaffected by assimilation. Now, it is a significant fact that the latest extrusive product of our greatest volcanoes, such as Etna, Fusiyama, Chimborazo, Cotopaxi, etc., is without known exception, either basalt or andesite. The unnumbered lofty volcanoes which spring from the floor of the deep Pacific and Indian oceans are, with but few exceptions, capped with basalt or andesite. Indeed, such basic lava seems to be the only igneous rock exposed in oceanic areas making up at least one half of the whole surface of the globe.

Not less important is the equally indisputable fact that the great fissure eruptions of the globe give birth to only one kind of lava, again basaltic. The familiar examples in Iceland, Northwestern Europe, India, the Northwestern United States of America, and the Hawaiian Archipelago, tell no uncertain story concerning the nature of the vast reservoir from which they have derived their enormous volumes of lava. The more acid flows which occur in any one of these regions are insignificant in bulk when compared to the total basic output. The former could be explained, in accordance with the present hypothesis, as the product of differentiation acting on the universal magma influenced by the assimilation of the continental rocks, which are characteristically more acid than that magma. Further,

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[a] Vol. II, 1897, p. 477.

we should expect assimilation to be less active in determining the composition of fissure eruptives than in preparing the secondary magmas erupted in volcanic cones or injected in the intrusive form. From the nature of the geological dynamics rendering possible the rapid expulsion of the voluminous flows at great fissures, it is clear that the corresponding magma had, in each case, relatively easy access to the earth's surface, and had not to work its way through the crust. The plateau lavas accordingly merit particular notice in the search for the general earth magma. Too little attention has been paid to the volume, relative abundance, and geological occurrence of the different eruptive types in the extant discussions of the origin of igneous rocks. Those questions must always be of prime importance in deciding on the question of assimilation.

For different reasons, excepting that derived from the enormously greater abundance of basaltic lavas on the earth, Dutton came to this same conclusion as to the nature of the "primordial matter." He has rightly emphasized the importance of the fact that basalt is a "synthetic or comprehensive type of rock." His theory of the derivation of other igneous rocks by simple fusion of sedimentary formations, derived in their turn by atmospheric agencies from this "primordial matter," takes insufficient account of the facts of differentiation learned since 1880. Yet his theory has a suggestive relation to the one proposed in these pages.[a]

Thus, partly by the induction of known facts, partly by the deduction of certain conclusions which are explanatory of a considerable number of related phenomena, we have been led to the view that there is, all round the earth and not far from its present surface, a single fundamental magma of a composition allied to basalt. This magma must probably be regarded as molten only potentially and to uncertain depth by the local relief of pressure. It has been implied that all other rocks may have been indirectly derived from such a magma, though the possibility is not excluded that part of the normal continental intrusive (acid-alkaline) rocks may form the more or less pure equivalent of primal matter differentiated at the surface of the original crust of the earth. It is, of course, evident that we are now face to face with other principal earth problems, most of which are nothing more nor less than true riddles. The nature of the earth's original crust, the antiquity of the ocean basins, the duration and geological history of the Archean era during which most of the siliceous material of the crust was prepared in nearly its present form, the origin of the crystalline schists, the preponderance of potash among the alkalies of continental formations, the explanation of the high soda content of sea water, are among those problems bearing on the hypothesis. It can only be said that the writer has not yet met with insurmountable objections to the hypothesis in the partial solutions now attained for them.

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[a] Cf. C. E. Dutton, The High Plateaus of Utah: U. S. Geol. and Geog. Surv. Rocky Mountain Region, Washington, 1880, p. 125 et seq.

The probability that the combined variety and type constancy of the continental igneous rocks are due to both abyssal assimilation and magmatic differentiation is taught not only by a detailed study of a small area like Ascutney Mountain, but as well by a review of the earth's igneous output as a whole. Perhaps the hypothesis founded on this conviction may do something toward removing the difficulty that is felt by most students of igneous rocks; it is the dilemma once well described to the writer by a leading petrologist: "As a geologist, one must believe in assimilation; as a petrographer, he must declare against it."

APPENDIX.

TABLES, LIST OF SPECIMENS, ETC.

TABLE XIII.—*Mineralogical and structural constitution of the Ascutney eruptives.*

	Essential feldspars.	Other essential constituents.	Accessory.	Structure.
Camptonite	Basic labradorite (Ab_2 An_3).	Hornblende Augite.	Titaniferous magnetite. Pyrite. Apatite. Decomposition products: Chlorite, epidote, calcite, secondary quartz, kaolin.	Panidiomorphic porphyritic.
Augite-gabbro	do	Augite.	Biotite. Hornblende. Pyrite. Ilmenite. Titanite. Apatite.	Hypidiomorphic granular.
Diabase	do	do	Titaniferous magnetite. Pyrite. Apatite. Decomposition products: Chlorite, epidote, calcite, secondary quartz, kaolin.	Ophitic.

TABLE XIII.—*Mineralogical and structural constitution of the Ascutney eruptives*—Continued.

	Essential feldspars.	Other essential constituents.	Accessory.	Structure.
Hornblende-biotite-augite gabbro.	Basic labradorite ($Ab_2 An_3$).	Hornblende. Biotite. Augite.	Ilmenite. Pyrite. Titanite. Apatite.	Hypidiomorphic granular.
Biotite-hornblende-diorite.	Av. basic oligoclase ($Ab_2 An_1$).	Biotite. Hornblende.	Quartz. Ilmenite. Pyrite. Apatite. Titanite. Zircon.	Do.
Biotite-augite-hornblende-diorite.	do	Biotite. Augite. Hornblende.	Quartz. Ilmenite. Pyrite. Apatite. Titanite. Zircon.	Do.
Essexite	Andesine ($Ab_5 An_3$). Microperthite. Orthoclase.	Hornblende. Biotite.	Quartz. Augite. Ilmenite. Apatite. Titanite. Zircon.	Do.
Monzonite	Microperthite. Orthoclase. Labradorite ($Ab_1 An_1$).	Hornblende. Augite. Biotite.	Quartz. Titaniferous magnetite. Apatite. Pyrite. Zircon.	Do.
Windsorite	Microperthite. Orthoclase. Basic oligoclase ($Ab_2 An_1$).	Biotite.	Quartz. Augite, hornblende. Ilmenite. Apatite. Zircon. Titanite?	Do.

TABLE XIII.—*Mineralogical and structural constitution of the Ascutney eruptives*—Continued.

	Essential feldspars.	Other essential constituents.	Accessory.	Structure.
Pulaskite	Microperthite. Orthoclase.	Biotite	Titaniferous magnetite. Quartz. Titanite. Hornblende. Augite. Apatite. Zircon.	Hypidiomorphic granular.
Nordmarkite	Microperthite (cryptoperthite). Orthoclase. Microcline. Acid oligoclase.	Hornblende. Biotite. Augite. Quartz.	Quartz. (Allanite.) Titaniferous magnetite. Apatite. Pyrite. Zircon. Monazite. Garnet.	Hypidiomorphic granular. Porphyritic. Trachytic.
Biotite-granite	Microperthite. Orthoclase. Microcline. Acid oligoclase.	Biotite. Quartz.	Magnetite. Titanite. Apatite. Zircon.	Porphyritic.
Paisanite	Microperthite. Soda-orthoclase.	Quartz. Hornblende.	Titanite. Ilmenite. Pyrite. Zircon. Apatite.	Panallotriomorphic porphyritic.
Muscovite-aplite.	Orthoclase. Albite.	Quartz. Muscovite.	Microperthite.	Panallotriomorphic.

TABLE XIV.—*Chemical analyses.*

[Analyst, W. F. Hillebrand.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
SiO_2	52.12	55.28	64.62	65.43	64.88	56.51	73.69	56.53	73.03	71.90	59.27	56.01	48.22	49.63	90.91	58.35	45.30
Al_2O_3	16.35	17.23	16.46	16.11	16.24	16.59	12.46	16.47	13.43	14.12	15.76	a 15.19	14.27	14.40	4.18	21.30	30.51
Fe_2O_3	3.68	1.54	1.82	1.15	1.37	1.35	1.21	1.58	.40	1.20	2.07	2.34	2.46	2.85	.22	.30	.24
FeO	6.02	6.23	2.14	2.85	2.70	6.59	1.75	5.40	1.49	.86	3.57	4.89	9.00	8.06	1.27	6.00	8.80
MgO	4.14	2.69	1.10	.40	.89	2.52	.17	2.67	.14	.33	3.04	4.67	6.24	7.25	.37	2.10	3.11
CaO	7.25	5.60	2.39	1.49	1.92	4.96	.36	4.90	.79	1.13	3.69	4.85	8.45	9.28	.22	.85	.90
Na_2O	3.65	5.42	4.57	5.00	5.00	5.15	4.47	5.59	4.91	4.52	5.63	5.66	2.90	2.47	.77	1.60	1.65
K_2O	2.34	2.12	5.21	5.97	5.61	3.05	4.92	3.80	4.54	4.81	3.33	2.16	1.93	.70	.58	5.63	4.84
H_2O above 110° C.	.88	.71	.39	.39	.46	.71	.24	.60	.35	.42	.74	.36	1.66	1.47	.74	.86	1.05
H_2O below 110° C.	.25	.20	.13	.19	.19	.21	.14	.23	.18	.18	.23	.90	.28	.27	.06	.31	.26
CO_2	.07	.04	.11	Tr.?	None.	.33	Tr.	.05	Tr.?	.21	.30	Undet.	.15	1.36	.18	None.	Tr.?
TiO_2	2.10	1.64	.81	.50	.69	1.20	.28	1.40	.30	.35	1.12	1.13	2.79	1.68	.28	.87	1.48
ZrO_2	.02	Tr.	.03	.11	.13	.04	.14	.03	.06	.04	.04	--------	.03	Tr.?	.02	None.	None.
P_2O_5	.89	.73	.21	.13	.13	.41	.04	.27	.06	.11	.42	.53	.64	.25	.05	.18	.12
SO_3	None	None.	None.	None.	None.	None.	None.	None.	None.	None.	None.	--------	None.	None.	None.	None.	.04
Cl	.09	.07	.05	.05	.04	.07	.02	.07	.03	.02	.03	Undet.	.10	.07	Tr.	.03	.04
F	.03	.28	Undet.	.08	.08	.24	.05	.19	.08	.06	.42	Undet.	.05	Tr.	Tr.	Undet.	.04
S (FeS_2)	.24	.07	.19	.07	None.	.06	None.	Tr.	.09	Tr.	.07	.09	.36	.22	.11	.19	.36
Fe_7S_8	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	.53	.96
NiO, CoO	Tr.	(?)	None.	(?)	None.	Tr.?	None.	Tr.	(?)	None.	Tr.	.03	.03	.04	None.	.03	.02
MnO	.17	.24	.12	.23	.14	.24	.15	.20	.15	.05	.37	.40	.20	.17	Ft. tr.	.13	.20
BaO	.04	.06	.03	.03	.06	.03	None.	Tr.	Tr.	.04	Tr.?	Tr.?	.04	Tr.?	Tr.	.05	.03
SrO	Tr.?	Ft. tr.	Tr.	Tr.	Ft. tr.	Tr.	Ft. tr.	Tr.	Tr.	Tr.	Ft. tr.	--------	Tr.	Tr.?	None.	Tr.	Tr.
Li_2O	Tr.	Tr.	Tr.	Str. tr.	Tr.	Tr.	Tr.?	Tr.	Tr.	Tr.	Tr.	--------	Tr.	Tr.	Str. tr.	Str. tr.	Str. tr.

a Including ZrO_2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
CuO	(?)	(?)	Tr.	(?)	(?)	(?)	Tr.	(?)	(?)	(?)	(?)	--------	Tr.	(?)	(?)	Tr.	(?)
C	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	--------	(?)	(?)	a.10	b.40	c.17
	100.33	100.15	100.38	100.18	100.53	100.26	100.09	99.98	100.03	100.35	100.10	99.21	99.80	100.17	100.06	99.71	100.12
O=F, Cl	.03	.13	.01	.04	.04	.11	.02	.09	.04	.03	.19	--------	.04	.02	--------	--------	.02
	100.30	100.02	100.37	100.14	100.49	100.15	100.07	99.89	99.99	100.32	99.91	--------	99.76	100.15	--------	--------	100.10
Total S	.13	.038	.10	.036	None.	.03	None.	Tr.	.05	Tr.	.037	--------	.19	.12	.056	.31	.19
	2.936	2.822	2.666	2.659	2.683	2.849	2.633	2.756	2.628	2.616	2.661	2.720	{2.810- 2.869}	2.922	2.678	2.673	2.835

[a] Another sample gave 0.06 carbon and 0.42 CO_2. [b] Another sample gave 0.03 carbon and no CO_2. [c] Another sample gave 0.03 carbon and 0.04 CO_2.

1. Biotite-augite-hornblende-diorite from the Basic stock; Notch road.
2. Basic segregation from the quartz-orthoclase-microperthite-bearing hornblende-biotite-diorite; Little Ascutney Mountain.
3. "Windsorite" dike cutting the Basic stock; Little Ascutney Mountain.
4. Nordmarkite with granitic structure; Windsor quarry, north side of Ascutney Mountain.
5. Nordmarkite with porphyritic structure; east end of Ascutney Mountain.
6. Basic segregation in No. 5.
7. Paisanite dike cutting No. 4; northwest side of Ascutney Mountain.
8. Basic segregation in No. 7.
9. Paisanite dike cutting nordmarkite-porphyry dike of Little Ascutney.
10. Alkaline biotite-granite; Ascutneyville quarry.
11. Basic segregations in No. 10.
12. Basic segregations in No. 10; containing more hornblende than No. 11.
13. Camptonite; Ascutney Mountain, near summit.
14. Diabase dike; Ascutney Mountain, north slope.
15. Quartzitic phyllite; cliff west of Ascutneyville.
16. Cordierite-biotite-microperthite-hornfels; north slope of Ascutney Mountain, 100 feet (31 meters) from contact with syenite.
17. Cordierite-corundum-pleonaste hornfels from the same cross section of the exomorphic zone as No. 16; 25 feet (8 meters) from the contact.

TABLE XV.—*List of the more important specimens studied.*

No. 1a and 1b. Basic segregation in biotite-granite.
2. Biotite-granite.
5. Metamorphosed limestone of contact-zone, bearing grossularite.
24. Sericitic quartzite.
32. Biotite-hornblende-diorite.
34. Granite; phase *h* of Main syenite stock.
36. Breccia of Little Ascutney.
42. Green nordmarkite; Main syenite stock (phase *f*).
57. Camptonite dike; Little Ascutney.
59. Microperthite-bearing hornblende-biotite-diorite.
59a. Basic segregation in 59.
60. Paisanite; Little Ascutney.
61. Hornblende-biotite-augite-gabbro.
62. Pulaskite; Pierson Peak.
66. Basic segregation in porphyritic phase *g* of Main syenite stock.
74. Augite-camptonite.
76. Nordmarkite-porphyry; Little Ascutney.
77. "Windsorite" dike; Little Ascutney.
100. Metamorphosed limestone of contact zone, bearing epidote, etc.
105. Endomorphic zone of biotite-granite.
106. Miarolitic phase of 105.
111. Monzonite; phase *i* of Main syenite stock.
113. Segregation in biotite-granite.
114. Unaltered siliceous limestone.
115. Porphyritic phase *g* of Main syenite stock.
120. Diabase dike.
122–136, inclusive. Metamorphosed phyllite of contact zone about the Main stock.
139. Paisanite of Main stock.
141. Basic segregation in 139.
145a. Augite-biotite-diorite dike; Little Ascutney.
147. Augite-biotite-hornblende-diorite; Little Ascutney.
175. Altered aplite.
184. Augite-biotite-diorite.
191. Muscovite-aplite.
192. Augite-gabbro.

INDEX.

O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 209.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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