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THE GABBROS

AND

ASSOCIATED HORNBLENDE ROCKS

OCCURRING IN THE

NEIGHBORHOOD OF BALTIMORE, MD.

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NOTE.—These figures were all drawn with the aid of a camera lucida, the aim being to represent some particular spot in a given section as accurately as possible, without attempting to combine the interesting points of several sections or of different portions of the same section.

GABBROS AND ASSOCIATED HORNBLLENDE ROCKS.

BY GEORGE H. WILLIAMS.

INTRODUCTION.

Considerable attention has been devoted during late years to the metamorphism of igneous rocks, and it can now be regarded as placed beyond reasonable doubt that such rocks may be changed to more or less schistose masses, which often closely resemble crystallized sediments.¹ This possibility has heretofore been largely ignored, owing doubtless to the extensive obliteration of those characteristics which are generally regarded as most typical of eruptive rocks. Schistose or banded structure, however, can now hardly be considered as necessarily an indication of sedimentary origin. The minerals which are most characteristic of the so-called crystalline schists have been repeatedly shown to be derived from the alteration of igneous as well as of aqueous formations. These minerals only represent the final and most stable combination of certain elements under certain conditions, and are quite independent of the earlier combinations in which these elements may have existed. A lava bed and a clay bank, if the two may be supposed to have originally had the same chemical composition, might, under the influence of the same metamorphic agencies, ultimately give rise to the same rock in spite of original differences in structure or mineralogical composition. Stratification may be obliterated by metamorphism, while foliation, or even a banded structure, may, by the same means, be secondarily induced. Neither structure nor mineral composition can be taken as an infallible guide in determining the origin or the age of rocks.

It would seem but reasonable to suppose that eruptive rocks were more abundant in the early periods of the earth's history than at any time since. The conditions to which such masses have subsequently

¹ Probably the first to study and call especial attention to the metamorphism of eruptive rocks was that admirable and careful geologist, Prof. K. A. Lossen, of Berlin, who, since 1869, has emphasized this point in many papers scattered through the *Zeitschrift der deutschen geologischen Gesellschaft*, the *Sitzungsberichte der Gesellschaft der naturforschenden Freunde zu Berlin*, the *Jahrbuch der preussischen geologischen Landesanstalt*, and through his explanations of various sections of the geological map of the Harz Mountains. His efforts to follow unaltered intrusive rocks in fossiliferous strata into highly dislocated regions, where both they and the sediments have been very much metamorphosed, are deserving of the most careful study. For a full list of his papers on this subject, see *Jahrbuch der preuss. geol. Landesanstalt*, 1883, p. 619.

been subjected, however, must have differed far more widely from those under which they were formed than from those under which sediments were deposited. Might we not, therefore, reasonably expect that igneous rocks would be more readily subject at least to molecular and chemical changes than aqueous formations?

The primary cause of regional or, as Lossen calls it, "dislocation" metamorphism is the action of the orographic or mountain-making forces, which in all geological epochs have been upheaving and crumpling one portion or another of the earth's crust. Where the rocks are most disturbed, there they are most changed. The enormous pressure has completely altered their structure, while the increased circulation of heated waters and mineral solutions through the crushed and twisted strata has everywhere facilitated chemical reactions and the formation of new compounds.

The present paper is intended as a contribution to our knowledge of a particular phase of metamorphism in eruptive rocks, i. e., that one which is dependent on the secondary development of hornblende by the paramorphism or pseudomorphism of pyroxene. This is a change the frequency of which renders it of fundamental geological importance. It has already received considerable attention from many eminent geologists, but no locality heretofore studied seems to have afforded opportunities for tracing out every stage in the process of alteration superior to those offered by the area of massive rocks west and northwest of the city of Baltimore. Here, covering a district of over fifty square miles, the unchanged pyroxene rock and its resultant hornblendic equivalent occur in the most intimate relations. Exposures of both rocks in situ are numerous, and the opportunity of following out the gradual transition of one into the other is proportionately great.

Many other localities in this country will doubtless be found to display the same changes on an equal scale, as, indeed, certain observations by Hawes,¹ in New England, and by F. D. Chester,² in Delaware, already seem to indicate.

It has not yet been possible for the present writer to study other allied areas in connection with the one near Baltimore. The results already obtained, however, will probably be found to have a widespread application in other regions, and it is in this hope that they are communicated.

This investigation, which, with many interruptions, has extended over a period of nearly two years, was commenced in the fall of 1883 at the Johns Hopkins University, Baltimore, where it has since been carried on. The writer would express his sincere thanks to Dr. Leroy McCay, of the Green School of Science, Princeton, N. J.; to Mr. W. G. Brown, of Charleston, S. C.; and to Mr. W. S. Bayley, of the Johns Hopkins University, for their kindness in furnishing many careful analyses necessary to throw light on some of the most interesting points of the in-

¹ Mineralogy and Lithology of New Hampshire, 1878, p. 228.

² Proceedings Philadelphia Academy of Natural Science, October 14, 1884, p. 244.

vestigation. He is also under obligation to Profs. C. H. Hitchcock, of Hanover, N. H., and F. D. Chester, of Newark, Del., for the loan of thin sections of rocks closely allied to those occurring near Baltimore.

SUMMARY.

For the benefit of those to whom the details contained in this paper might not prove of especial interest, as well as to furnish those who purpose to read it with a résumé of its contents, a brief statement of the most important results secured is herewith appended.

Chapter I gives the mode of occurrence and distribution of the rocks investigated. These are principally the dark, trappean-looking masses which occupy an irregularly oval area, nearly fifty square miles in extent, immediately west and northwest of the city of Baltimore. They are externally enough alike to be all included under the local designation of "niggerhead;" but nevertheless, as a closer examination shows, they really comprise three quite distinct types. The first of these is a fine-grained, purplish-black aggregate of hypersthene, diallage, and plagioclase, to which the name *hypersthene-gabbro* is applied; the second is a dark-green rock, composed of fibrous hornblende and plagioclase, which the writer has designated as "*gabbro-diorite*;" while the third is a group of rocks characterized principally by the large amount of olivine which they contain, and on this account to be referred to the family of *peridotites*.

Chapters II and III contain detailed descriptions of the first two of these rock types, their macroscopic appearance, their mode of occurrence, their microscopic structure, and their chemical composition being given at length.

Chapter IV is devoted to the principal point of the paper, viz, the attempt to clearly show that the hypersthene-gabbro and the gabbro-diorite are geologically identical masses, and that the latter has been derived from the former by the secondary alteration of its pyroxene constituents to fibrous hornblende.

§ 1 gives the relations of these two rocks as observed in the field. Wherever they both form part of the same exposure, as may be seen at numerous localities within the area, the one rock always grades imperceptibly into the other; nothing resembling a sharp line of contact is anywhere observable.

§ 2 contains a comparison of the chemical composition of these two rocks. As might be expected from the varying proportions in which the constituents are present in different specimens of the gabbro, chemical analyses of this rock from different localities vary considerably. The results of the chemical examination made of the gabbro-diorite all fall within the limits found in different specimens of the hypersthene-gabbro. In order that a still more satisfactory comparison might be instituted, samples of average composition were obtained in the case of both rocks by powdering together chips of equal size, taken from all the represent-

ative specimens of each which had been collected within the entire area. The close agreement between the analyses of these two powders strongly indicates that, in spite of local variations, the two rocks are essentially identical in chemical, if not in mineralogical, composition.

§ 3. The most conclusive evidence in favor of the derivation of the diorite from the gabbro was obtained from the microscopic examination of the zone occurring as a transition between the two rocks. In thin sections from this zone, the pyroxene could be seen in the actual process of alteration to fibrous hornblende. This mineral surrounds the pyroxene in the form of a fringe or border, which gradually increases in width as the diorite is approached, until it finally entirely replaces both diallage and hypersthene. The process of alteration is somewhat different in the case of the two minerals, as might be supposed from the differences in their respective compositions. The diallage may change directly to fibrous green hornblende, as is so often observed in gabbros from all localities. The hypersthene, however, is deficient in both the lime and the alumina necessary to form the hornblende, and appears only to change to this mineral when these constituents are furnished by the adjacent feldspar. This process is quite similar to that observed by Professor Törnebohm in the case of the corresponding unisilicate olivine. The fibrous green hornblende of the gabbro-diorite, which replaces the hypersthene, must, therefore, be regarded as the product of a reaction which has taken place between the substance of this mineral and a plagioclase. This conclusion is substantiated by chemical analyses of all the isolated components of a specimen in which this process of alteration was far advanced.

§ 4 mentions other areas in Europe and America in which changes have been observed similar in character to those here described. It also contains suggestions relative to the conditions and causes necessary to produce uralitization.

Chapter V contains descriptions of the third or olivinitic rock type, which is abundantly associated with the gabbro and gabbro-diorite. These rocks are younger than the gabbro, since they break through it in the form of dikes. They are rarely rich in feldspar and are sometimes altogether free from it. By a gradual loss of olivine they seem also to grade into another massive rock composed almost wholly of diallage and hypersthene. These masses are all very rich in magnesia and readily give rise to the serpentinous hornblendic and talcose rocks which are everywhere abundant in and about the Baltimore gabbro area. As far as could be observed the olivine seems always to form serpentine, and the pyroxene (no matter what be its form), hornblende. This latter mineral often suffers a further alteration to talc, its lime separating out in the form of calcite. In this manner the hornblende serpentines, like those of the Bare Hills, have been derived from original eruptive aggregates of olivine and bronzite, similar in character to many rocks which are still to be found near them in a quite unaltered condition.

CHAPTER I.

THE LIMITS OF THE GABBRO AREA NEAR BALTIMORE AND THE GENERAL CHARACTER OF THE ROCKS COMPOSING IT.

The geological situation of Baltimore is in many respects similar to that of several other of the most important cities on the Atlantic border. Like New York, Philadelphia, Washington, and Richmond, it lies on the wide belt of crystalline strata which follows the coast from Maine to Georgia. How little has thus far been discovered regarding the real age of these rocks, the many rival theories as to their origin but too plainly indicate. At present it seems only possible to regard them, on account of their freedom from all organic remains and their highly crystalline character, as upper members of the pre-Cambrian or Archean formation, although they doubtless include rocks which future study may show to differ widely both in origin and age.

This belt extends from Pennsylvania and Delaware in a south-south-westerly direction across the eastern part of Maryland, into Virginia. The rocks composing it are highly crystalline, for the most part feldspathic, and have a strike which generally conforms to the direction of the belt, though local variations are frequently observed. There is none of the homogeneity or of the granitoid massiveness of the Laurentian formation in Canada or in New York, but on the contrary a finely banded and schistose structure is quite universal. Micaceous, hornblendic, chloritic, and epidotic layers constantly alternate with various kinds of gneiss.

Owing to the absence of glacial action in Maryland, these rocks are almost always more or less decayed to a considerable depth below the surface. This may also be the case even when they appear to the eye quite fresh, as is shown by the rapid disintegration which takes place where apparently unaltered rocks are exposed by railroad cuttings or in quarries. Some bands of gneiss, however, like those quarried on Jones Falls, north of the city line, seem to have resisted the general tendency to decompose, and by their real freshness present a marked contrast to the more altered rocks around them. On account of the readiness with which these gneissoid rocks disintegrate and form soil, blocks or boulders are but rarely met with on their surface.

The city of Baltimore itself lies on the extreme eastern edge of this crystalline belt, just where it is overlaid by Mesozoic and Tertiary sands, gravels, and clays which everywhere along the eastern

shore of the United States compose the strip of territory between the crystalline rocks and the ocean. This covering of sedimentary deposits gradually thins out as the land rises toward the northwest, so that its exact boundary is difficult to trace. Long after the crystalline rocks appear, detached areas of it may be found, occupying levels where it has been sheltered from erosion. The higher and more inland of these unconsolidated deposits, like those of New Jersey, Delaware, and Virginia, are to be assigned to the Jurassic-Cretaceous formation. These, in their turn, farther to the east and south, are overlaid by still younger Tertiary deposits. The boundary of both of these divisions is approximately given by Philip T. Tyson on his geological map of Maryland, published in 1860.¹

The above-mentioned belt of crystalline rocks includes within its limits in Maryland, as in other parts of its extent, many areas of crystalline limestone and serpentine. These are sometimes quite irregular, sometimes lenticular in their shape, and are extensive and numerous enough to form a very considerable proportion of the entire formation.

Huge veins of a coarse-grained pegmatite, which both in their form and in their structure closely resemble intrusive rocks, are also frequently found intersecting the schists and gneisses.² As far as my observation extends, the character of these granites seems quite independent of the rock in which they occur. Whether in the lightest, most acidic gneiss or in the darkest hornblende-schist, the coarse-grained aggregate of muscovite, microcline, albite, and quartz appears in all respects the same.

Nor are these rocks—the limestones, the serpentines, and the granites—the only ones which are included in the Archean belt. Massive rocks of a most basic character, and in all probability exotic in their origin, are also occasionally encountered, and it is to the consideration of such an area that the contents of the present paper is devoted.

Immediately west and northwest of the city of Baltimore is situated an irregularly oval district, somewhat over fifty square miles in extent, within which the rocks exhibit a marked contrast to the surrounding gneisses. On his geological map of Maryland, Philip Tyson designated a portion of this area as “trap,” an appellation which the character of the rocks here exposed does indeed seem abundantly to warrant.

Wherever along the border of this region the line of contact with the surrounding rocks is not concealed by the overlying Mesozoic deposit, there is a sudden and abrupt transition from the light-colored, well-foliated gneisses and schists to heavy, black, massive rocks in which a schistose structure is exceptional and, when present at all, mostly confined to the periphery of the mass. Perhaps, however, the most striking contrast is presented by the resistance offered by these dark rocks to the action of atmospheric influences. Instead of readily disinte-

¹ First annual report of P. T. Tyson, State agricultural chemist, to the house of delegates of Maryland. 1860.

² Johns Hopkins University Circulars, No. 38, p. 65. March, 1885.

grating like the gneiss, they break up, in consequence of their jointed structure, into huge polygonal blocks which strew the surface of the ground in countless numbers wherever they have not been carefully removed by the farmers.

The entire area is characterized by the substitution of black stone walls for the usual rail fences.

The large blocks, which, on account of their color, weight, and hardness, are locally known as "niggerheads" or "ironstone," are sometimes rounded, but generally angular in shape. In some exposures of the rocks, where the blocks have never been removed from their original position, complete decomposition to a deep-red, clay-like substance may be seen to have taken place along the cracks and fissures formed by jointing, although at a distance of less than a quarter of an inch from this material the rock retains its original freshness. When first taken from the ground the blocks of this rock are generally covered with a coating of this same decomposition product, which, however, is soon washed away by rain, leaving the natural color exposed.

The deep-red color of the soil in some portions of the area occupied by these rocks seems to be due to this decomposition, although in other localities, on account of variations in composition—to which, as we shall see further on, these rocks are especially subject—the same alteration produces a soil of a light buff color.

The contact between these dark rocks and the surrounding gneisses is rarely well exposed; even where it is concealed, however, the limits of the area may, in most cases, be quite accurately determined either by the sudden change in the color of the soil or by the number of angular blocks which at once appear as soon as the "niggerhead" region is entered. This, of course, is not true where the overlying covering of Mesozoic sand and gravel buries the contact far below the surface, as is the case in the southern portion of the region.

Where the contact between "niggerhead" and gneiss is exposed, as in the railroad cutting south of Melvale on the Northern Central Railroad or in that on the Western Maryland Railroad near Highland Park, it is rarely a sharp line. As a rule the two rocks alternate with each other for some little distance, as though dikes of the darker rock had penetrated the gneiss around the border of the main mass.

North of the Franklin road, which runs out of the city toward the west, the boundary of the area in question has been located with considerable accuracy, and is given upon the accompanying map¹ (Plate IV). Starting

¹The map upon which the limits of the areas occupied by the "niggerhead" and serpentines near Baltimore are traced, is a portion of the more extensive one recently compiled and edited by Mr. Albert L. Webster, at the request of the trustees of the Johns Hopkins University. This map, which covers an area 25 miles square, with the city hall of Baltimore as its center, was intended primarily for the use of the University Naturalists' Field Club. It has already rendered valuable service, although, being merely a compilation from existing materials, it contains many errors and no topography.

just north of Calverton Heights it runs in a northeasterly direction, crossing the Western Maryland Railroad south of Highland Park Station. It passes a short distance northward of Druid Hill Park to the village of Woodberry, where a tongue of it crosses Jones Falls. Returning to the west side of the Falls between Woodberry and Melvale, the boundary extends in a sinuous line as far north as Mount Washington. Here it turns quite abruptly to the west, following very closely the direction of Smith's avenue as far as Pikesville. Beyond Pikesville the line bends slightly toward the south until it reaches a point about one mile east of Randallstown, where it takes a southward course, crossing the Patapsco River a short distance north of Hollofields Station. It soon, however, recrosses the river, but returns again farther south and sends a narrow belt for a considerable distance westward into Howard County. South of this point the limits of the area cannot be traced with any accuracy, owing to the rapidly-increasing thickness of the Mesozoic deposits. A few exposures of the black rock may be seen at North Bend, on the Frederick turnpike, on the new road leading from Orange Grove to Catonsville, and at several points on the Baltimore and Ohio Railroad in the Patapsco Valley. In the latter case, however, it is only found at a few places imbedded in the prevailing gneisses and schists, so as to resemble tongues or dikes, which stretch southward beyond the southern limits of the main mass.

The relations of several areas of black but schistose rocks, lying outside of the region whose limits have here been traced, will be mentioned beyond.¹

At any characteristic exposure within the limits of the area above outlined, it takes but a superficial examination to detect the presence of two rocks, mineralogically altogether distinct, although they are everywhere so intimately associated as to be geologically inseparable.

Both rocks are so heavy, dark, and massive as to be included under the local designation of "niggerhead," but the purplish tinge of one is alone sufficient to distinguish it from the dark-green color of the other. A closer examination with the aid of a pocket lens discloses the fact that the purplish-black rock is composed of a glistening, striated feldspar and pyroxene, the latter constituent being almost always present in two readily distinguishable forms, diallage and hypersthene. The greenish-black rock, on the other hand, which is much the commoner

¹ A compact, massive rock, which, from its mode of occurrence or from a macroscopical examination, cannot be distinguished from the typical rock of the "niggerhead" area, is found in the gneiss, at a point near McDonogh, some distance north of Pikesville, and so outside of the limits above outlined (No. 180). It is interesting to note, however, that the microscope shows this rock to be altogether different from the other, having nothing, as regards either structure or mineralogical composition, in common with it. The McDonogh rock agrees in all respects with the normal Mesozoic diabase of the Atlantic border, with which, as we shall see, the Baltimore "niggerhead" has nothing to do.

of the two, is made up of the same feldspar and a green hornblende with a satiny luster.

On account of the purely granular structure of the first rock, as well as on account of the physical properties of its two pyroxenic components, it must, in accordance with the most generally accepted rules of petrographical nomenclature, be designated as a *hypersthene-gabbro*. The second, greenish rock, in consideration of its close association with the first rock and probable derivation from it, we may call a *gabbro-diorite*.¹

As has already been stated, these two rocks are everywhere so intimately associated that no geological separation of them is possible; nevertheless they are mineralogically altogether distinct. It will therefore be expedient to give a somewhat detailed description of the two types in their most characteristic forms, based upon the microscopic study of a large number of thin sections prepared from specimens collected at all accessible localities. Afterward the mutual relations of these two rocks will be discussed from a geological, chemical, and petrographical standpoint, and finally the general conclusions derived from such a discussion will be stated.

Another class of basic, massive rocks may be here mentioned as occurring in and around the gabbro area, although it is, both geologically and mineralogically, quite distinct from the one just described. Small dikes and lenses of a dark-brown rock are frequently encountered which apparently intersect the gabbro and gabbro-diorite, and are hence younger than these. This rock is composed of olivine, diallage, and bronzite, with varying quantities of a basic, triclinic feldspar. When the latter constituent is abundant the rock must be designated as an *olivine-gabbro*, but the small amount of this mineral commonly present would consign it, with almost an equal right, to the family of the *peridotites*.

Resulting from the undoubted alteration of these rocks are certain others containing hornblende or serpentine, which are in all respects identical with still other masses in which no trace of the original minerals is longer to be found. These olivine rocks, with their associates and derivatives, are considered in the final chapter.

¹ This name is assigned in accordance with the usage of Prof. A. E. Törnebohm, of Sweden (Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, 1877, p. 391), as being the one which conveys the most information regarding both the mineralogical composition and the origin of the rock in question. In their most typical development these rocks are diorites, except that the hornblende is more than usually satiny and fibrous. Many of them resemble the "*Epidiorit*" of Gümbel, from Belgium and Bavaria. In a preliminary notice of the Baltimore gabbros (Johns Hopkins University Circulars, No. 30, April, 1884), they were called by the present writer *anorthite-amphibolites*, in accordance with the usage of some German authors. Similar rocks have also been designated in Germany as "*Diorit*," "*Dioritschiefer*," "*Amphibolschiefer*," &c. In this country they were called by Dr. G. W. Hawes "*metamorphic diorites*." Zirkel early suggested calling all anorthite-hornblende rocks "*corsite*," but in this he does not appear to have been generally followed. The name gabbro-diorite was also independently employed by Maj. T. B. Brooks in 1879 (Geol. of Wis., Vol. III, p. 522).

CHAPTER II.

PETROGRAPHICAL DESCRIPTION OF THE HYPERSTHENE-GABBRO.

The first-mentioned purplish-black rock of the Baltimore "nigger-head" area, on account of its granular structure and mineral components, can only be classified as a gabbro. It nevertheless possesses a compactness of texture, a fineness of grain, and a freshness which are very exceptional in rocks generally considered as most typical of this family. It furthermore gains an additional interest from the large amount of hypersthene which it contains, inasmuch as the presence of this constituent makes it a connecting link between the true gabbros and the norites.

The number of localities within the United States where gabbros are thus far known to occur is quite small, although this is undoubtedly due rather to the fact that these rocks have not yet been recognized than to their really limited distribution. In the year 1876, Zirkel described the first American gabbro from Iron Mountain, Laramie Hills, Wyoming.¹ During the following year, Streng made known the hornblende-gabbros occurring on the St. Louis River, Minnesota,² and in 1878 appeared Dr. George W. Hawes's account of the gabbros of New Hampshire.³ Still more recently Prof. R. D. Irving has studied the gabbros occupying enormous areas in Wisconsin, Michigan, and Minnesota.⁴ In these rocks hypersthene was not observed except in one instance, at Waterville, N. H.⁵

The presence of this mineral in such abundance in the Baltimore rock renders its relation at once apparent to the hypersthene rocks occurring near Peekskill, N. Y., called by H. Credner "hypersthenite,"⁶ and by Prof. J. D. Dana norite.⁷ Numerous unpublished observations made on sections of similar rocks from many localities in Pennsylvania and Delaware seem to indicate a hitherto unsuspected distribution of this mineral in the so-called "traps" of the Archean formation. This fact is especially interesting when considered with reference to the

¹ Microscopical Petrography, Washington, 1876, p. 107.

² Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, pp. 113-117. 1877.

³ Mineralogy and Lithology of New Hampshire, 1878, pp. 165-173.

⁴ Geology of Wisconsin, Vol. III, p. 168, 1880. Copper-Bearing Rocks of Lake Superior, Monographs of the United States Geological Survey, Vol. V, pp. 37-57.

⁵ Mineralogy and Lithology of New Hampshire, 1878, p. 54.

⁶ Zeitschrift der deutschen geologischen Gesellschaft, XVII., p. 390. 1865.

⁷ American Journal of Science (III), XX, p. 194, Sept., 1880.

coarser-grained masses of the Norian system in New York and Canada, in which hypersthene has long been known to be an almost universal constituent.

In Europe gabbros are very common rocks, while even those which contain an orthorhombic pyroxene are not rare. They are known among other localities, in Saxony, Silesia, the Harz Mountains, and Scandinavia. There are many points of resemblance between the Baltimore gabbro and the "*Trapgranulit*" of Saxony, although the American rock is free from garnet.¹

Professor Törnebohm has proposed to restrict the old and much-abused name "*Hyperite*" to certain gabbros which contain hypersthene.² His descriptions indicate a close similarity between the Swedish and Baltimore rocks.³

Excellent exposures of the hypersthene-gabbro are very abundant within the Baltimore area, especially in the northern portion of it. Among the localities where this rock may be seen to advantage in position may be mentioned the Western Maryland Railroad between Oakland Station and Howardville; the region around Franklin, Powhatan Mills. and Wetheredville, and west of these places on the old Liberty and Windsor Mill turnpikes; in Gwynn's Falls, north of the Windsor road bridge; in Jones Falls, north of Woodberry; along the road leading northward from Ellicott City, in Howard County. Perhaps the best place to obtain fresh and typical specimens is at Mount Hope Station, on the Western Maryland Railroad, although they may be secured from the huge boulders which strew the surface at almost any spot within the area.

This rock is always very massive in appearance, rarely exhibiting the banded and nowhere the schistose structure which is frequently seen in the associated hornblendic rocks. Its irregular polygonal blocks are often covered with a thin coating of a deep red color due to decomposition, beneath which, however, as has already been mentioned, the rock is surprisingly fresh.

The mineral constituents of the gabbro which are discernible with the unaided eye are plagioclase, diallage, and hypersthene. A black hornblende, which is brown in transmitted light, is also sometimes seen in good-sized crystals and has every appearance of being a primary component. Magnetite and apatite are shown by the microscope to be universally present, although in varying quantities. Olivine was observed in only one specimen, collected near Orange Grove. With the exception

¹This resemblance is even much closer in the case of certain rocks occurring at Claymont, Del., which are much like those at Baltimore. Here the garnet is present, as in the Saxon rocks.

²Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 379. 1877.

³Still closer is the resemblance to the hypersthene-gabbro from Ekersund, in Norway, recently described by Prof. H. Rosenbusch (Nyt Magazin for Naturvideskaberne, XXII, pp. 304-309, 1882).

of certain indeterminable inclusions no other minerals were discovered in the wholly unaltered rock. (Plate I, Fig. 1.)

The grain of the hypersthene-gabbro is, as a rule, uniform and fine, the component minerals averaging from one to two millimeters in diameter. Exceptionally, however, the grain becomes coarser; in a few specimens the individuals of pyroxene and feldspar measured from twenty-five to thirty-five millimeters in length. The coarsest varieties are rarely altogether fresh.

The feldspathic constituent of the hypersthene-gabbro is *bytownite*, corresponding to a mixture of six molecules of anorthite with one of albite. A comparative study of this mineral in many different specimens of the rock showed the greatest constancy in its composition and physical properties. Stauroscopic measurements on the feldspar extracted from a Mount Hope specimen of the gabbro (No. 56)¹ gave extinction angles (measured against the cleavage lines) of -16° to -19° on OP (001) and of -28° to -30° on $\infty P \propto$ (010).

	I.	II.	III.
SiO ₂	46.17	48.94	46.5
Al ₂ O ₃	35.23	33.26	34.6
CaO	16.29	15.20	17.3
Na ₂ O	22.31	2.30	1.6
Total	100.00	100.70	100.0

α Difference.

In the above table of analyses, I is of the pure feldspar powder extracted from the Mount Hope specimen. It was made by Mr. W. S. Bayley in the chemical laboratory of the Johns Hopkins University. II is an analysis by Ludwig of what Tschermak regards as a typical bytownite from N  r  dal in Norway.² III is the theoretical composition, calculated by Schuster, for a mixture of six anorthite molecules with one of albite.³

The specific gravity of the powder used in analysis I was determined by means of the Thoulet solution to be 2.74, which agrees very well with the results of the optical and chemical investigations.

In the above-mentioned specimen of gabbro from Mount Hope the feldspar constitutes somewhat over one-half of the entire mass. This may perhaps be regarded as a fair average, although great variations in the proportions of the component minerals cause the analyses of specimens of the gabbro from different localities to differ widely, as will be shown in the sequel.

¹ The numbers given with the succeeding descriptions are those attached to specimens in the Johns Hopkins University collection.

² Sitzungsberichte der k. Akademie der Wissenschaften. Bd. L. Wien, 1 Juli 1869.

³ Mineralogische und petrographische Mittheilungen, III., p. 153. 1881.

The feldspar individuals are generally quite irregular in shape, giving rise to the granular structure which is characteristic of gabbro in contrast to diabase. Rarely, however, a lath-shaped crystal indicates a slight tendency toward the ophitic structure.

When seen between crossed nicols, the feldspar appears, as a rule, finely striated. Sometimes two systems of striae are seen to intersect at an angle of nearly 90° . In other cases the striations are very coarse or altogether wanting, in which case the extinction is more or less undulatory and irregular.

The minute, dust-like inclusions, which are so common in the feldspars of the older basic rocks, are admirably developed in the Baltimore gabbros. They answer very well to the descriptions given of them in rocks from other localities by Zirkel, Hagge, Hawes, and other investigators. When viewed with a low magnifying power the plagioclase appears to be covered with a fine black or brown dust, which, under the highest magnifying power, is resolved into a mass of very minute opaque dots and lines. The arrangement of these inclusions is such that the needles occupy the center of the crystal; this is surrounded by a zone where only the dots or globulites are to be seen. The exterior of the crystal is generally free from inclusions of any kind. Frequently the acicular bodies are altogether absent and then the minute dots are arranged in lines which indicate the position of the twinning lamellæ. An occasional inclusion of another kind, like a fluid cavity, an apatite crystal, or a grain of magnetite, is surrounded by a narrow zone which is quite free from the dust-like particles. (See Plate I, Fig. 1.) Neither a microscopical nor a chemical examination served to give any clew to the mineralogical nature of these minute bodies.

The diallage is the constituent of the gabbro next in order of importance to the feldspar, although in some specimens it is not so abundant as the hypersthene. A chemical analysis of this mineral, isolated by means of the Klein solution, from a Gwynn's Falls specimen (No. 148), was made by Mr. W. G. Brown, lately of the University of Virginia, with the following result:

SiO ₂	51.414
Al ₂ O ₃	4.323
FeO	9.307
MnO	0.043
CaO	20.600
MgO	15.138
	<hr/>
	100.825

The specific gravity as determined by the Klein solution is 3.26.

In hand specimens the diallage appears black, but when seen by transmitted light in thin sections it has a light-green color and exhibits no appreciable pleochroism. This constituent, like all the others,

shows no indication of a crystal form; it is present only in rounded or irregularly-shaped grains, and appears to have crystallized somewhat later than the feldspar. The prismatic cleavage and the parting parallel to the orthopinacoid are both well developed; frequently a second parting parallel to the clinopinacoid is also present. In sections approximately parallel to either OP (001) or $\infty P \infty$ (100) an optical axis—not a bisectrix—appears, when the examination is made with converged polarized light. Clinopinacoidal sections exhibit an extinction angle as large as 40° .

Twins, according to the ordinary law for augite, where the orthopinacoid is both twinning plane and composition face, are quite common. Instances where the twinning trace is inclined from 25° to 35° to the cleavage lines, as described by Cohen,¹ Rosenbusch,² and others, have been also not infrequently observed. The explanation of these twins recently suggested by Mr. George F. Becker³ does not appear to be applicable in the case of the Baltimore gabbros, inasmuch as the extinction for both portions of the crystal is nearly simultaneous. It can be seen that this could not be so if the section were really one of an ordinary twin cut parallel to a very acute pyramidal face.

Other systems of fine striations, visible only between crossed nicols, are very often seen traversing the individuals of diallage in several directions. They are by no means always straight in their course nor continuous across the crystal, but appear to be due to some molecular disturbance produced by pressure, to which, as is well known, this mineral is peculiarly sensitive.⁴

In its freedom from inclusions the diallage, as a rule, presents a contrast to the hypersthene, although when such inclusions are exceptionally present they do not appear materially to differ from those of the rhombic pyroxene.

Hypersthene is a constant component of the Baltimore gabbros, although its amount varies widely in different specimens. It is readily detected in the rock by its bronzy luster, and may be often seen spangling a section with metallic-looking spots even before it is brought under the microscope. This effect is, however, altogether due to inclusions in the hypersthene; and, since these may be wanting, the absence of the metallic reflection is of itself no proof that this mineral is not present.

¹ Geognostische Beschreibung der Umgegend von Heidelberg, p. 69. 1881. Sammlung von Mikrophotographien, etc., Taf. XXVIII., Fig. 4. 1881.

² Mikroskopische Physiographie. Vol. II. Die massigen Gesteine, p. 410. 1877.

³ Geology of the Comstock Lode, Monographs of the United States Geological Survey, Vol. III, 1883, p. 113, Pl. IV, Fig. 28. See, also, the elaborate explanation of these apparently anomalous twins given by F. Becke in the Mineralogische und petrographische Mittheilungen, VII. Bd., p. 98. 1885. This explanation is essentially the same as that of Becker.

⁴ Van Werveke: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II, p. 97. 1883.

A chemical analysis of this hypersthene, which was isolated from the above-mentioned specimen (No. 148), yielded Mr. Brown the following results:

SiO ₂	52.12
Al ₂ O ₃	1.69
FeO	20.94
CaO	3.20
MgO	21.56
Total	99.51

The specific gravity of the powder analyzed was 3.35.

Under the microscope this mineral exhibits no better crystalline form than the diallage, from which, however, it is easily distinguished by its marked trichroism. The ray which vibrates parallel to the brachydiagonal axis ($\tilde{a} = \alpha$) is brownish-red; the one vibrating parallel to the macrodiagonal ($\tilde{b} = \beta$) is light greenish-yellow, while that one which vibrates parallel to the vertical axis ($\tilde{c} = \gamma$) is green. The absorption is $\alpha < \gamma < \beta$, γ being very nearly equal to α . This agrees with the results of F. Becke's examination of the hypersthene from Bodenmais, in Bavaria,¹ although Haidinger, Tschermak, Rosenbusch, Fouqué, and other authors give the absorption of this mineral as $\gamma < \alpha < \beta$.

The cleavage parallel to the unit-prism ∞P (110) is well developed; but even more pronounced is a parting parallel to both pinacoids $\infty P \propto$ (100) $\infty P \propto$ (010), which renders it possible to readily place the orthorhombic character of the mineral beyond a doubt.² If the isolated hypersthene powder be brought under the microscope, numerous cleavage pieces parallel to the orthopinacoid (recognized by their green and yellow dichroism) are observed, which, in converged polarized light, show a bisectrix with both axes in the field. Basal sections also show a bisectrix in converged light. All sections in the prismatic zone show in parallel polarized light an extinction parallel to the cleavage lines, which, together with the above-mentioned interference figures, is abundant optical proof that the mineral is really orthorhombic and not a pleochroic diallage. The fact that the brachydiagonal axis is the acute bisectrix and the optical angle comparatively small is sufficient indication that it is hypersthene, and not enstatite or bronzite, with which we have to deal.

The peculiar inclusions so generally characteristic of hypersthene are, as a rule, present in great perfection. They have been so often described that no extended notice of them is here necessary, especially as nothing new regarding their arrangement or nature can be added to what has already been stated by Kosmann³ and Hagge.⁴ Suffice it to

¹ Mineralogische und petrographische Mittheilungen, III., p. 65. 1880.

² H. Rosenbusch: Gesteinsarten von Ekersund. Nyt Magazin for Naturvideska-berne, XXII, p. 305. 1882.

³ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 532. 1869.

⁴ Mikroskopische Untersuchungen über Gabbro- und verwandte Gesteine. Inaug. Dis., p. 10. Kiel, 1871.

say that they were found to be in all respects identical with the inclusions in the well-known hypersthene (paulite) from the coast of Labrador. They are composed of fine needles arranged parallel to all three crystallographic axes and of little plates of a reddish-brown color lying parallel to the brachypinacoid. To these latter the peculiar metallic reflection seen in many sections is due. They vary considerably in thickness, as may be seen by the different depths of color which they possess. These plates all extinguish simultaneously with the hypersthene, which may be due to their extreme thinness or to the fact that they have their axes parallel to those of their host. Kosmann was inclined to regard these inclusions as brookite. Although generally abundant,¹ they are sometimes entirely absent from the hypersthene.²

A yellowish-brown hornblende, undoubtedly of primary character, is sometimes met with in the hypersthene-gabbro. Such a constituent is mentioned by many writers as an accessory in gabbros from other localities. In this way a series of rocks is formed which is related to the normal gabbros in the same manner as the "proterobase" of Gümbel is related to the normal diabase. This primary hornblende is, in the Baltimore gabbros, strongly pleochroic. The α ray, approximately parallel to the clinodiagonal axis, is light-yellow; the β ray, coinciding with the axis of symmetry, is brownish-yellow; while the γ ray, inclined about 12° to the vertical axis, is yellowish-brown. The absorption is, as usual in hornblende, $\gamma > \beta > \alpha$ or $\gamma = \beta > \alpha$.

This hornblende is sometimes so full of minute black inclusions as to be nearly opaque, even when in very thin sections. These interpositions are, however, not evenly distributed, but are massed in irregular patches. No trace of external crystalline form is ever discernible. This mineral appears to have been the last to crystallize from the magma, a single individual often covering a considerable space and inclosing smaller grains of both pyroxene and feldspar. It is not infrequently intergrown with pyroxene in such a manner that the orthopinacoids of both minerals are coincident. On the whole this hornblende appears to be in all respects identical with that occurring so plentifully in the augitic and hypersthene rocks of Dana's "Cortlandt series" near Peekskill, N. Y.

The occurrence of this hornblende in the least altered specimens of the gabbro, its compact structure, and the other marked contrasts which it presents to the green, fibrous amphibole to be hereafter described are all a sufficient warrant for its original character.

Of the other constituents occurring in the hypersthene-gabbro, the magnetite and the apatite present no peculiarities worthy of mention. The former is never very abundant, the latter rarely so, although in

¹ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 501. 1871.

² Regarding the original nature of these and similar inclusions, so generally found in the constituents of the older massive rocks, the writer has expressed his views in the American Journal of Science, XXXI (3), p. 33, January, 1886.

one specimen (No. 56) from Mount Hope, it was found to compose 12 per cent. of the entire mass of the rock.

Olivine was detected in only one specimen (No. 69), found near Orange Grove Station, on the Baltimore and Ohio Railroad.¹ Here it was only sparingly present in small, irregular grains, which, however, were remarkably fresh. Wherever it is in contact with the feldspar, the olivine is surrounded by the peculiar border of fibrous amphibole, first described by Törnebohm and attributed by him to a reaction between the substance of the two minerals.²

Accidental minerals are rare in the Baltimore gabbros. At some localities vein-quartz—evidently a secondary infiltration into existing cracks and fissures—is abundant. Long crystals of black tourmaline, forming radiating groups sometimes two feet in diameter, are found imbedded in this quartz at Gwynn's Falls, near the Windsor road bridge, and near Wetheredville; also, in Jones Falls, a short distance north of Woodberry.

Associated with this quartz, west of Mount Hope Station and along Gwynn's Falls, north of the Liberty road, are many blocks of a coarse-grained muscovite granite or pegmatite, which is to all appearances identical with that occurring so abundantly in the gneisses. (Johns Hopkins University Circulars, No. 38, page 65, March, 1885.) This rock is composed of a flesh-colored microcline, white albite, quartz, and muscovite; garnet and tourmaline are also not rare constituents. The occurrence of this pegmatite, so rich in alkalis, in the center of the gabbro area may be regarded as a fact in favor of its exotic nature so far as it shows that this rock is not dependent upon the nature of the inclosing mass, as might naturally be expected to be the case with segregation veins.

The most striking feature in the texture of the unaltered gabbro is the repeated and abrupt change in the coarseness of the grain which is seen at some localities. This phenomenon, as is well known, is often frequently observed in very ancient massive rocks which cover considerable areas. It was undoubtedly caused by some irregularity in the cooling of the original magma from a molten state, for which it is now difficult to find a satisfactory explanation.

The coarsest-grained varieties of the Baltimore gabbro occur in the neighborhood of Wetheredville, and there these sudden changes in texture are most apparent. Irregular patches of the coarsest kinds lie

¹ The percentage of silica (44–46 per cent.) in these Baltimore rocks is so low for a normal gabbro that the absence of olivine is striking. Possibly the place of this mineral is here supplied by the corresponding bisilicate hypersthene, as has been shown by Hague and Iddings to be the case with many of the basalts when they become slightly more acidic. (*American Journal of Science* (3), XXVI, p. 244. September, 1883.)

² *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, p. 383. 1877. See, also, F. D. Adams: *American Naturalist*, November, 1885, p. 1087; and the writer: *American Journal of Science*, January, 1886, p. 35.

imbedded in those of the finest grain, without regard to any order. In other cases, a more or less pronounced banded structure is produced by an alternation of layers of different grain or by such as have one constituent developed more abundantly than the others. Such bands are not, however, parallel, but vary considerably in direction and show a tendency to merge into one another, as though they had been produced by a motion in a liquid or plastic mass.

One peculiar structure was observed in a huge block of gabbro discovered in Jones Falls, near Woodberry (No. 156). The main body of the rock, which was entirely massive, was composed of a grayish gabbro, in which were numerous dark-brown, lenticular patches, some two inches in length, arranged with their longest axes parallel in direction. This remarkable mottled appearance was due, as the microscope showed, to the replacement, in the darker colored spots, of the pyroxene of the gabbro by the primary brown hornblende above described.

The color of the hypersthene-gabbro is on the whole uniform, although it may vary from a purplish-black to gray. The latter varieties show an almost entire absence of the inclusions from the pyroxene constituents and produce by their decomposition a light-buff instead of the more common dark-red soil.

Chemical analyses of the hypersthene-gabbro are given and discussed in connection with those of the gabbro-diorite, in Chapter IV, section 2, p. 37.

CHAPTER III.

PETROGRAPHICAL DESCRIPTION OF THE GABBRO-DIORITE.

The very intimate association of the hypersthene gabbro near Baltimore with a greenish, more or less schistose rock, to which the name gabbro-diorite has been applied, has already (p. 17) been mentioned. In its typical development, this rock may readily be distinguished from the gabbro, so that it will be advantageous to describe it in some detail before considering the relations of the two rocks to each other. As regards their distribution the diorite is much the commoner, for, whereas it frequently occurs over considerable areas alone, the gabbro is always accompanied by the hornblende rock.

In typical specimens the color alone is enough to distinguish the gabbro from the diorite; intermediate varieties, however, often occur, which cannot by this means be certainly identified.

A closer examination of the diorite shows it to be composed of a fibrous, green hornblende, possessing a satiny luster, and an opaque white feldspar, which, on account of its altered condition, is more prominent in this rock than in the gabbro. In blocks which have been long exposed this feldspar is often completely weathered out on the surface, giving the rock a peculiarly pitted appearance.

Frequently the diorite is not less massive than the gabbro; but in other cases it exhibits a pronounced schistose structure, which, as far as observed, is conformable with the foliation of the adjacent gneisses. The same direction is often indicated by the arrangement of the rock constituents, even where no proper foliation is present. The hornblende is interspersed with long dashes of feldspar, which follow the general direction of the lamination. In other cases the two principal constituents are disposed in parallel bands.

Other minerals than the feldspar and amphibole are rarely visible to the unaided eye. Occasional grains of pyrite and crystals of red garnet¹ are almost the only exceptions. The microscope disclosed in addition epidote, apatite, magnetite, and rarely rutile and sphene.

¹ This mineral was observed in exceedingly sharp dodecahedral crystals, often measuring several millimeters in diameter, in the diorite near the center of the long railroad cutting at Mount Hope.

The hornblende is the usual green variety common in massive diorite and crystalline schists. It almost never occurs in well-defined crystals, but in confused aggregates of imperfectly developed individuals. The extinction angle, measured, as proposed by F. Becke,¹ on splinters parallel to the prismatic cleavage plane, gave an average value of about 13° . The pleochroism is very pronounced and of the character usual in hornblende, i. e., the α ray, nearly parallel to the clinodiagonal axis, is light-yellow; the β ray, coincident with the orthodiagonal, yellowish-green; and the γ ray, dark bluish-green. The absorption is here as in all hornblende $\gamma > \beta > \alpha$.

As has already been mentioned, the green hornblende of the diorite is rarely present in compact individuals of any size. As a rule many minute crystals are crowded together in a confused aggregate, giving rise to the characteristic satiny appearance which this mineral possesses in hand specimens. In some cases this subdivision is carried so far that even the microscope is unable to resolve the hornblende into its ultimate components. This, which is a truly fibrous hornblende or uralite, is composed of the finest possible needles, whose axes are only approximately parallel, so that between crossed nicols the crystal can never become at one time perfectly dark. (No. 12, collected north of Druid Hill Park.)

Another curious and interesting structure is occasionally encountered in the hornblende of this rock. Each individual is externally quite homogeneous and compact, but internally is composed of an irregular mixture of hornblende needles and quartz grains. The former generally have their crystallographic axes nearly parallel, although they may have an altogether different orientation from the external hornblende rim. The rim itself may also differ in its optical orientation at different points.² (See Plate III, Fig. 1.)

No other occurrence of quartz was observed as a true constituent of the gabbro-diorite.³

The specimens which exhibited this remarkable structure to the best advantage were found in the Western Maryland Railroad cutting at

¹ Mineralogische und petrographische Mittheilungen, IV., p. 235. 1882.

² Exactly this same structure was seen in a rock, called by Professor Törnebohm "hyperite-diorite," from Ölme, in Sweden. This investigator regards it as undoubtedly due to the alteration of the pyroxene constituent of a hyperite or gabbro which is found in considerable quantity associated with it. This rock is represented by slide No. 21, in the collection of Swedish rock sections prepared by R. Fuess, of Berlin. It is described in the Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 385, 1877, by Törnebohm, who mentions that it also contains garnet, like its American equivalent.

³ Large veins of quartz are even commoner in this rock than in the gabbro. At Mount Hope these are especially well developed. The hornblende seems to be massed in a black rim at their edge, and frequently large, well-defined crystals of this mineral lie wholly imbedded in the quartz. Black tourmaline and pyrrhotite occur in the same connection.

Mount Hope (Nos. 92, 93, and 103*b*). They contained small but sharp dodecahedrons of red garnet.

The ordinary hornblende of the diorite is quite free from inclusions, but in certain specimens crystals much larger and more compact than the average occur, in which minute black needles are so abundant as to render the mineral quite opaque, no matter how thin the section may be. These needles are short and stout, being often so rounded as to present an elliptical outline. They vary considerably in size, but even the largest are not more than $\frac{1}{25}$ mm in length and $\frac{1}{500}$ mm in width. In prismatic sections of the hornblende they are seen to be arranged parallel to the vertical axis, and also in two directions, making an angle of about 45° with this. In basal sections they appear to follow for the most part the prismatic cleavage lines, though they are also less frequently disposed in other directions, especially in that parallel to the clinodiagonal axis.

These inclusions furthermore are always central in their arrangement, the periphery of the hornblende crystal being free from them. When particularly abundant, the smaller needles appear to run together, forming irregular, opaque masses, much resembling magnetite. That these inclusions are in reality magnetite is indicated by the fact that such crystals of hornblende as contain them most abundantly are attracted by the magnet while others are not.

Both the compact structure and the inclusions of this green hornblende are points of close resemblance to the brown variety of this mineral mentioned in connection with the hypersthene-gabbro. Whether that here described is a primary or a secondary product it is difficult to say, although all appearances indicate the former supposition as the more probable. It seems as though the compact green variety might represent the primary brown hornblende of the gabbro, which has undergone no other change than that of its color.

Specimens showing this mineral to the best advantage were collected near Mount Hope. (Nos. 95, 96, and 110.)

The feldspar of the diorite is identical with that of the gabbro. For examination this component was separated from a very typical diorite specimen from the neighborhood of Pikesville (No. 64). Stauroscopic measurements under the microscope were not altogether satisfactory on account of the very minute size of the grains. A large number of trials made upon this isolated powder gave upon such particles as showed twinning lamellæ—i. e., those parallel to OP (001)—values varying from 22° to 28° , while upon those without lamellæ—i. e., those parallel to $\infty P \propto$ (010)—extinction angles as high as 36° were observed.

These results indicate that the feldspar is slightly more basic than that in the Mount Hope gabbro (No. 56) described in the preceding chapter (p. 20).

A chemical analysis of the feldspar powder of No. 64, by Mr. W. S. Bayley (I in the following table), fully agrees with the results obtained by optical methods:

	I.	II.	III.
SiO ₂	45.06	45.24	45.7
Al ₂ O ₃	35.69	35.61	35.1
CaO	18.30	18.20	18.0
Na ₂ O	*.95	.95	1.2
	100.00	100.00	100.00
Sp. gr	2.74	2.739	2.747

* Difference.

No. II is the analysis recently communicated by Kloos¹ of the feldspathic constituent of the Ehrberg diorite, which occurs in the southern part of Baden, intimately associated with gabbro. It is here quoted on account of its remarkable similarity to that of the Baltimore diorite. No. III is the theoretical composition of a mixture of eight molecules of anorthite with one of albite as calculated by Schuster.²

This feldspar melted readily in the flame of a Bunsen burner and was completely decomposed by being digested for a considerable time in concentrated hydrochloric acid.

Although the two analyses here given show the feldspars of the gabbro and diorite to be An₆ Al₁ and An₈ Al₁, respectively, still, since such slight variations in composition are well known to be common in any rock, there seems to be no reason whatever for not regarding the two feldspars as practically identical.

Under the microscope the feldspar of the gabbro-diorite exhibits finely developed twinning lamellæ, brilliant interference colors, and large extinction angles, all facts indicative of its basic character.

Inclusions are sometimes altogether absent from the feldspar; frequently, however, the same indeterminable, dust-like particles are present which have been described as occurring in the feldspar of the gabbro. Actinolite needles, evidently secondary in their origin, as well as fluid cavities containing movable bubbles, were also observed in many instances.

The fact that the feldspar is more prominent in hand specimens of the diorite than in those of the gabbro has already been mentioned. Instead of being fresh, glassy, and transparent, and therefore appearing dark from its abundant inclusions or from the color of the underlying minerals, the feldspar of the diorite is generally an opaque white, due to its more or less complete alteration to saussurite. In most cases this change is only in an incipient stage, but exceptionally the devel-

¹ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, p. 16. 1884.

² Mineralogische und petrographische Mittheilungen, III., p. 153. 1881.

opment of zoisite—to which, as Cathrein has shown, the formation of saussurite is due,¹—has been so extensive that it is only with the greatest difficulty that the mineral can be made transparent. (Nos. 17, 74, 102.)

Closely related to the above-mentioned alteration of the feldspar is the extensive development of epidote in some specimens of the gabbro-diorite. It is especially abundant in those sections from Mount Hope, already mentioned, on account of the black inclusions contained in some of the hornblende. (Nos. 95, 96, and 110.) Sometimes the epidote crystals are scattered irregularly through the feldspar, but far more commonly they are arranged, just at the contact between the feldspar and the hornblende, in such a manner as to form a continuous border around the former, the terminated ends of the crystals projecting into the feldspar substance, as is shown on Plate III, Fig. 2.

Under the microscope, the epidote is readily distinguished from the feldspar by its wide black edge, due to its high refractive index. Between crossed nicols it exhibits the usual very brilliant interference colors. The extinction is parallel to the longest axis of the crystals and to the cleavage lines, because, although a monoclinic mineral, the individuals are, as is generally the case with this species, elongated in the direction of the axis of symmetry (orthodiagonal). The optical axes lie in the clinopinacoid $\infty P \infty (010)$, i.e., in the plane at right angles to the longest axis of the crystal. Ordinary long sections, therefore, show in converged polarized light the interference figure of either an optical axis or a bisectrix. One exceedingly distinct section cut parallel to the clinopinacoid is reproduced on a large scale in Fig. 1. The absence of

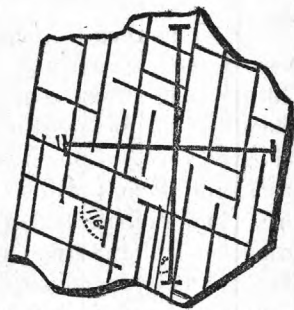


FIG. 1.—Epidote cross-section. (Slide No. 95.)

any interference figure in converged polarized light indicated the crystallographic orientation of this section. Two distinct sets of cleavage lines, parallel to $OP (001)$ and $\infty P \infty (100)$, respectively, intersect at an angle of 116° . The extinction angle is 5° when measured against the pinacoidal and 59° when measured against the basal cleavage. All of these observations agree so closely with the well known physical properties of epidote as to place the nature of this mineral beyond a doubt.

The true epidote of the gabbro-diorite is distinguished from the closely

¹ Zeitschrift für Krystallographie, VII., p. 234. 1883.

allied zoisite, mentioned above as a component of the saussurite, by its more pronounced crystal form, its peculiar mode of arrangement, the larger size of its individuals, but especially by its color and pleochroism. Moreover, the monoclinic character of this mineral, though not generally apparent, is proven by the cross-section above described and figured.

The color of the epidote is very light, and the pleochroism is proportionately weak; nevertheless both are distinctly visible. The ray vibrating parallel to the orthodiagonal axis (\bar{b}) is colorless, while that vibrating at right angles to it is a light greenish-yellow. Absorption, \bar{b} ($=\bar{b}$) $<$ $c=a$, which corresponds with that of a similar epidote recently described by H. Reusch as occurring in a diorite from Drontheim, in Norway.¹ No twinning lamellæ, however, like those mentioned by Reusch, were observed in the Baltimore rock.

From its position the epidote of the gabbro-diorite would appear to have resulted from the alteration of the feldspar, as has been so often observed by other investigators. Its peculiar position at the contact between the feldspar and the hornblende would furthermore indicate that the latter mineral had also participated in its formation. A similar relation was suggested by Zirkel in 1876 for epidote observed by him in certain propylites from Washoe.²

The other occasional constituents of the gabbro-diorite, like garnet, magnetite, apatite, rutile, sphene, &c., have already been mentioned by name and are so accessory in their character as to need no detailed description.

As regards the structure of the gabbro-diorite, it is in many respects identical with that of the hypersthene-gabbro. Where both rocks are equally massive there are the same abrupt changes in grain, the same banding produced by alternate layers richer in one or another of the mineral constituents, and the same very coarse pegmatitic varieties. Indeed, there are many localities where the color is the only macroscopical guide as to whether a given rock-specimen is gabbro or diorite.

In other cases, however, the hornblendic rock possesses a well marked schistose structure, which the true gabbro never exhibits. This is on the whole most common near the periphery of the area, especially in its southern part, although it is by no means confined to this portion. When thus foliated the rock cleaves with greater or less readiness along one plane, which, so far as observed, appears to be parallel to the foliation of the adjacent gneisses. Where this structure is most eminently developed all traces of the gabbro disappear, and the diorite has much more the appearance of one of the so-called crystalline schists than of a massive rock.

¹ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II., p. 179. 1883.

² Microscopical Petrography, p. 112, vol. VI of the Reports of the Geological Survey of the 40th Parallel under Mr. C. King. (I am indebted to Mr. J. P. Iddings, of the United States Geological Survey, for the information that nearly all of the mineral described by Zirkel in these rocks as epidote is in reality chlorite.)

CHAPTER IV.

GENETIC RELATIONS OF THE HYPERSTHENE-GABBRO AND THE GABBRO-DIORITE.

The connection existing between the two rock types which, in their most characteristic development, have received a somewhat detailed description in the preceding chapters is an exceedingly intimate one. Mineralogically they are quite distinct, but geologically they are inseparable. Everywhere the two extremes, which we have called gabbro and diorite, are bound together by intermediate varieties whose presence seems only explicable on the supposition of the original identity of the two main types. It is to this close association, which undoubtedly possesses a wide geological significance, that the principal interest of the Baltimore gabbro area attaches. To make this clear was the main object of the investigation the results of which are here communicated. The accomplishment of this necessitated, first, a careful study of the field relations of the rocks; secondly, a consideration of their chemical composition; and, thirdly, a microscopical examination of the intermediate and transitional varieties. The results of this work will be stated in the first three sections of this chapter, while a fourth will contain the conclusions regarding the origin of the rocks in question which seem best in accord with the facts observed.

§1. GEOLOGICAL RELATIONS OF THE GABBRO AND DIORITE TO EACH OTHER AND TO THE SURROUNDING ROCKS.

In spite of the close similarity in the structure between the gabbro and the gabbro-diorite which a prolonged study of these rocks in the field disclosed, their petrographical and mineralogical differences are so great and the recognition of typical specimens of either is so easy that their association at first appeared to be only accidental.

From the intimate manner in which loose blocks of both types were mingled on the surface, it was natural to suppose that the more massive of the two—the gabbro—occurred as intrusive masses breaking through the diorite, which, on account of its frequently well developed schistose structure, was at first regarded as a member of the gneissic series. To support this view it was, of course, necessary to discover some point where the contact of the two rocks was well displayed. Careful search was therefore made at all exposures within the area studied, but nowhere could any sharp line of demarkation between the two rocks be found.

Natural and artificial exposures along the streams, highways, and railroads west and northwest of the city exhibit many admirable sections, in not a few of which both rocks are present in their most typical development. In every case, however, they grade into each other by almost insensible transitions; anything like a sharp line of contact is out of the question. Between any two points where the rocks in situ can be certainly identified as belonging to one type or the other, there is a space which cannot be referred to either. In other words, a typical occurrence of the gabbro is connected with a typical occurrence of the diorite by a rock which forms a perfectly gradual passage between them. Nowhere is there any break in the continuity of the mass; geologically both rocks must be regarded as the same.

One excellent exposure where these transitions between the gabbro and gabbro-diorite are especially well exhibited is the excavation on the Western Maryland Railroad just beyond Mount Hope Station. It was made the subject of extended study and is perhaps deserving of especial description, inasmuch as it is very typical of what may be seen at almost every gabbro exposure within the entire area.

This point, which is not over five miles northwest of the city, is easy of access by train. The railroad here runs slightly north of west. The excavation, locally known as the "Blue Cut," commences 200 yards beyond the end of the station platform and exposes just 1,000 feet of rock, which, on account of the depth to which it has been blasted, is remarkable for its freshness. The huge blocks thrown out beside the road afford admirable specimens of all varieties of the gabbro.

The first exposure is on the north side, 600 feet from the station, where a typical hypersthene-gabbro appears (No. 101); this is, however, soon covered by a dark-red soil, and is not again visible for 95 feet, when it reappears as gabbro-diorite. Five feet farther on this is again replaced by the hypersthene-gabbro, and here the first contact, or rather transition, from one rock to the other may be seen. At one point the diorite is in position, and directly below it, not two inches away, is the typical gabbro. Between the two the mass is quite continuous and composed of a rock of intermediate character, which will be more particularly described beyond. (No. 105, gabbro; No. 106, diorite; Nos. 103*a*, 103*b*, and 104, transition stages taken from one large hand specimen.)

For 50 feet on the north side beyond the last-mentioned point, the typical massive gabbro is exposed, when another change to diorite is observed. The transition here takes place in a solid wall, from 10 to 12 feet in height, whose perfect continuity is beyond a question. The two rocks alternate with each other in every direction—horizontally and vertically—in the most perplexing manner, and it is frequently impossible to tell on the spot whether a given specimen is gabbro or diorite.

On the south side of the cutting the only rock exposed, as far as this point (750 feet from the end of the station platform), is diorite. At

759 feet, however, there is a change to gabbro in a solid rock wall, exactly like that just described on the north side.

Other points where similar transitions occur are: 869 feet, south side; 910 feet, north side, where the gabbro continues for only about 6 feet; and 1,000 feet, north side (Nos. 91, 92, and 93), where the diorite once more gives place to the gabbro, which continues throughout the remaining 600 feet of the cut.

Just west of the bridge which crosses this cutting the gabbro shows a decided tendency to spheroidal weathering, so often characteristic of basic massive rocks.

Both gabbro and diorite are traversed at four points by bands of a pulverent, green material, derived from the alteration of dikes of certain highly magnesian rocks, which will be more particularly mentioned in the succeeding chapter. These bands, which are like others occurring at many points within the gabbro area, here vary in width from two to thirty feet and strike northeast.

The diorite at the Mount Hope locality is, as a rule, massive. More or less distinct indications of a banded structure are observable in both rocks, the layers having a steep southeast dip and a northeast strike and being thus conformable with the direction of the above-mentioned pulverent, green beds. This structure is due only to the arrangement of the rock constituents; any signs of a true foliation are very rarely encountered in the diorite.

The principal importance of the section at Mount Hope lies in the conclusive evidence which it affords of the geological identity of the hypersthene-gabbro and the gabbro-diorite. Precisely the same evidence may be obtained at almost any characteristic exposure of the rocks. The numerous outcrops along the old Liberty turnpike or on the Windsor road, at Powhatan or at Woodberry, or at any of the other cuttings on the Western Maryland Railroad, show the same intimate association and constant alternation of the gabbro and diorite, although not always so satisfactorily as the exposure at Mount Hope. At North Bend, on the Catonsville turnpike, the diorite is admirably exhibited in a section of some length, toward the eastern end of which the gabbro may be seen passing gradually into the amphibole rock in every direction.

The huge blocks and boulders which are so abundant in the bed of Gwynn's Falls near the Windsor road bridge may often be plainly seen to be composed partly of one rock and partly of the other, and hand specimens can even be obtained which show the entire transition.

The relation of the rocks of the gabbro area to those which surround them has already been alluded to in Chapter I. The western, northern, and northeastern limits of the area are comparatively well defined, both because the rocks lie near the surface, being covered only by the soil formed by their own decomposition, and also because the surrounding rocks here differ very much from them in appearance and character.

At some points where the contact is well exposed, as in the Western Maryland Railroad cuttings near Highland Park, dikes of the gabbro appear to diverge from the main mass and to penetrate the surrounding schists.

The limits of the gabbro area toward the south and southeast are very difficult to locate: first, because of the thickness of the overlying Oretaceous deposits and, secondly, because certain of the adjoining schists so closely resemble the most foliated forms of the gabbro-diorite.

At numerous points around the gabbro area—as, for instance, in the bed of Jones Falls, within the city limits; on the Northern Central Railroad, south of Woodberry; along the Maryland Central (Delta) Railroad, north of Guilford; on the Belan road; and on the Baltimore and Ohio Railroad, between Avalon and Orange Grove—heavy, black, schistose rocks are exposed, which the microscope shows to be composed of feldspar, compact green hornblende, quartz, epidote, and other accessory minerals. To assume that all these rocks are alteration products of the gabbro seems at present unwarranted, since they are interbedded with and pass by gradual transitions into typical biotite-gneiss. In the quarries of this latter rock on Jones Falls, just north of the city, narrow bands of this same hornblende schist may be seen to be regularly interstratified with the gneiss—an additional proof that metamorphism can produce the same ultimate result from materials originally altogether different.

Thus far no trace of either pyroxene or really fibrous hornblende has been discovered in these hornblende schists, so that no opinion whatever can be expressed regarding their relations. Nevertheless they often resemble the true gabbro-diorite so closely that when the two rocks are in contact it is impossible to say where the one begins or the other ends. They appear to pass into one another by insensible gradations, and even the microscope fails to detect any infallible characteristics by which they may be separated. The close resemblance of these hornblendic schists and gneisses to the gabbro-diorites has given rise to the greatest difficulty encountered in fixing the limits of the gabbro area, and the uncertainty regarding the exact relations of these rocks still leaves it extremely doubtful where this line should be drawn.

A similar difficulty was found by Phillips in his studies of the metamorphosed diabases of Cornwall. He says: "There can be no doubt, however, that, under certain conditions, rocks of igneous origin acquire a degree of schistosity which is often exceedingly puzzling to the geologist, as it is sometimes impossible to determine where foliated traps cease and where metamorphosed slates begin."¹

Seriously as the existence of these hornblende schists may affect the locating of the exact boundary of the gabbro area, it fortunately has nothing whatever to do with the main question here at issue, viz, the geological identity of the hypersthene-gabbro and the gabbro-diorite as

¹ Quarterly Journal of the Geological Society, Vol. XXXIV, p. 495, 1878.

portions of one continuous mass. There is sufficient evidence at many localities within the area to convince any one who will take the pains to carefully examine it that the two rocks differ only in the form of their bisilicate constituent.

§ 2. CHEMICAL RELATIONS OF THE GABBRO AND THE GABBRO-DIORITE.

The chemical examination of these two rock types led to the same conclusions regarding their essential identity as were reached through the study of their field relations.

The analyses given in the following table, with the exception of Ia and II, were made by Dr. Leroy McCay, of the Green School of Science, Princeton, N. J., for whose uniform kindness in rendering every possible assistance to this investigation the writer would express his feeling of deep obligation:

	I.		Ia.	II.	III.	IV.
SiO ₂	44.10	44.12	45.31	45.35	46.85	46.68
TiO ₂ .....					.30	
Al ₂ O ₃	24.86	24.55	24.11	16.11	20.02	17.12
Fe ₂ O ₃	7.89	7.89	8.24	3.42	2.30	2.18
FeO	6.53	6.51	6.47	3.50	4.60	7.61
MnO	Trace	Trace			Trace	Trace
CaO	11.90	12.01	8.08	18.04	13.84	12.46
MgO	3.89	3.78	4.49	12.32	10.16	10.34
Na ₂ O	1.66	1.68	1.66		1.32	1.75
K ₂ O .....	.24	.19	.27	} a1.26	Trace	Trace
H ₂ O .....	.60	.59	.70		.88	.88
P ₂ O ₅ .....		.51			Trace	Trace
Total	101.67	101.83	99.33	100.00	100.27	100.02
Sp. gr	3.044			2.992	2.996	3.069

a Difference.

No. I gives two parallel analyses of a remarkably fresh specimen of hypersthene-gabbro from the Mount Hope Cut (No. 56). It is, as may be seen from the analysis as well as from the inspection of a thin section, unusually rich in feldspar and magnetite. A calculation of the average of these two analyses, assuming the theoretical composition of the different constituents given by J. Roth, yields the following result:

	Per cent.
Bytownite (An ₆ Al ₁)	65.55
Diallage	15.28
Hypersthene	8.03
Magnetite	11.43
Apatite	1.12

101.41

The constituents of this rock, which were separated as completely as possible by means of Thoulet's and Klein's solutions, gave proportions by weight agreeing very closely with those obtained by calculation, viz:

	Per cent.
Feldspar	64.2
Pyroxene and apatite	23.3
Magnetite	12.5
	<hr/>
	100.0

Ia is an analysis of a Swedish rock from Tiberger, which is exactly analogous in mineralogical composition to the Baltimore gabbro, containing as it does plagioclase, diopside, hypersthene, apatite, a little biotite (altogether wanting in our rocks), and much magnetite. It is called a "hyperite" by Törnebohm, whose analysis is here quoted on account of its very striking resemblance to I.¹

Analysis No. II, by Mr. W. S. Bayley, of the Johns Hopkins University, is of another specimen of hypersthene-gabbro (No. 85), containing much less feldspar and almost no magnetite. Its color is much lighter than that of No. 56, though it is not less fresh. It was found as a boulder in the bed of Gwynn's Falls near the Windsor road bridge. So small an amount of magnetite is present that nearly all the iron is probably in the ferrous state. If this assumption be made, a calculation of this analysis gives nearly equal proportions of feldspar and of pyroxene, a result which was also obtained by a separation of the constituents.

The very great differences between the analyses I and II, especially as regards the percentages of alumina, lime, iron, and magnesia, plainly indicate what important local variations in mineralogical composition even typical specimens of the hypersthene-gabbro may exhibit. These variations are, however, due to the proportions of the ingredients present, not to any change in their nature. They would, of course, be much greater should analyses of layers visibly richer in one or another component be compared.

Analyses III and IV are of two different specimens of the gabbro-diorite. The former (No. 64) was collected at a point midway between the Western Maryland Railroad and the village of Pikesville, the latter (No. 87) from the Windsor road beyond Forest avenue. Both represent the mean of two parallel analyses. While they differ far less than those just given of the gabbro proper, they nevertheless show considerable variation in the proportions of alumina and iron, owing to the presence of more feldspar in the one and of more hornblende in the other. It will be observed that both of these analyses fall entirely within the limits of I and II.

¹ Ueber die Geognosie der schwedischen Hochgebirge. Bihang till k. Svensk. Vet.-Akad. Handlingar. I. Stockholm, 1873 (see review, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 657, 1873). Quoted also by J. Roth in his Petrographische Beiträge (Analyses) for 1879, p. xxxviii.

The specific gravities given in the foregoing table were determined by means of the Thoulet solution and a Mohr's balance, as suggested by Cohen.¹

On account of the great differences which specimens of both the gabbro and the diorite were found to exhibit in their chemical composition, an attempt was made to arrive at a fair average for each. For this purpose chips of about an equal size were taken from twenty-three of the most typical specimens of gabbro, which had been collected in every part of the entire area. These were powdered together and thus a sample of fair average composition was secured. Nineteen of the most representative specimens of the gabbro-diorite were treated in the same manner, and both powders were then analyzed by Dr. McCay, with results which are given below (V, gabbro, and VI, gabbro-diorite):

	V.	VI.
SiO ₂	46.85	48.02
Al ₂ O ₃	19.72	17.50
Fe ₂ O ₃	3.22	1.80
FeO	7.99	7.83
CaO	13.10	13.16
MgO	7.75	10.21
Na ₂ O	1.56	1.48
K ₂ O .....	.09	Trace
H ₂ O .....	.56	.79
Total	100.84	100.79

While slight differences in the proportions of alumina and magnesia are still noticeable, it will be at once seen that the agreement is much closer than when individual specimens are compared. It would seem reasonable to suppose that even these would, however, disappear, if the number of specimens employed in obtaining the average sample had been sufficiently increased, inasmuch as they have been so considerably lessened in the present case.

It will be observed that the two former analyses of the diorite (Nos. III and IV) are by no means so far removed from the average composition of this rock (VI) as are those of the gabbro. This can, however, hardly be regarded as more than a coincidence, since just as great variations were noticed in different specimens of one rock as in those of the other.

The identity of the feldspathic constituents of both of these rocks has already been shown on page 30. From the analyses of the rocks themselves presented in this section it seems warrantable to regard them as chemically identical, each, however, on account of differences in the proportions of its constituent minerals, being subject to variations within wide limits.

¹ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II., p. 87. 1883.

§ 3. MICROSCOPICAL RELATIONS OF THE GABBRO AND THE GABBRO-DIORITE.

The microscopical study of the intermediate zone, which has already been described as always occupying a position between the hypersthene-gabbro and gabbro-diorite wherever these rocks occur in close proximity, has disclosed facts of great importance in regard to their genetic relations. This zone varies considerably in width, but nowhere shows any break in the continuity of the rock mass.

Specimens of the coarser-grained varieties of the gabbro (No. 148 and others) sometimes have their pyroxenic constituents—hypersthene and diallage—surrounded by a fibrous border, which is plainly visible to the unaided eye, especially upon a weathered surface. This border is generally of a dark-green color on its outer edge and a lighter green or even white within.

The microscopical examination of thin sections prepared from the intermediate zone discloses the universal presence of this green fringe, which is only rarely macroscopically visible. Sometimes it is wholly green; sometimes it is composed of an exterior green and an interior white portion. In some cases it is most finely fibrous; in others, comparatively compact. The microscope readily shows that this border is composed, in all cases, of hornblende, differing in no respect from that which forms the most characteristic component of the gabbro-diorite. A detailed study of any intermediate zone furthermore discovers a steady increase in the width of this hornblende fringe as the diorite is approached, until the one rock finally gives place to the other by the gradual metamorphism of the pyroxenic constituents into amphibole.

Both diallage and hypersthene appear ultimately to give rise to the same product, but the process of the alteration presents important points of difference in the two cases.

The grayish or green, non-pleochroic diallage is sometimes surrounded by a very narrow rim of compact green hornblende, possessing a perfectly homogeneous, crystalline structure; in other cases the diallage is accompanied by grains and needles of hornblende having no recognizable regularity in their arrangement; but far more frequently the amphibole is finely fibrous in its structure and penetrates the diallage individual, especially in the direction of its cleavage, in such an intimate manner as to leave little doubt that it has resulted from the latter's alteration.

All three of these forms of hornblende may be observed in the interior of diallage crystals as well as around their edge. In all cases, however, there seems to be a comparatively sharp line of separation between the two minerals, no gradual transition of the substance of one into that of the other having been observed.

In some instances the diallage is intergrown with such compact,

sharply defined hornblende crystals,¹ the two minerals having no crystallographic connection, that it would appear as though they both must have originally crystallized simultaneously. Nevertheless even these most compact forms of the green hornblende are so intimately connected by every conceivable transition with those finely fibrous forms, undoubtedly of secondary origin, that the study of a long series of sections served only to strengthen the first impression into a conviction that the two cannot be separated.

Almost precisely the same relations have been recently found by J. H. Kloos to exist between the diallage and the hornblende of the gabbro occurring near Ehersberg, in the Black Forest, in Baden.² This investigator regards the fibrous hornblende as undoubtedly an alteration product of the diallage; but all that has a compact structure, whether it forms a fringe about the edge of the pyroxene or is present in its interior, is considered as an original crystallization, partly simultaneous with, partly subsequent to, the formation of the diallage itself. Such an assumption is, however, unwarranted in the case of the Baltimore rocks, because the forms are connected by every possible intermediate stage.

Moreover, Streng has made an elaborate chemical study of the diallage and hornblende which occur in similar relations in the gabbros of Harzburg, in the Harz Mountains,³ the results of which show that their composition is nearly identical. If this be true, the supposition that the diallage and the hornblende are simultaneous formations necessitates the possibility of the same chemical compound crystallizing in two different forms under exactly the same conditions. This idea is rendered even more improbable in the present case by the fact that our gabbro often contains a compact brown hornblende, of undoubted original character, but probably differing considerably in composition from the diallage.

Another reason for regarding all of the green hornblende as a secondary product is the fact that, as will be shown below, the hypersthene never contains inclusions of this mineral, as would be expected if both had crystallized simultaneously. In case the green hornblende is an original constituent, we must assume that the hypersthene first crystallized from the magma, this process having been completed before the formation of the hornblende commenced. The crystallization of the diallage, on the contrary, must have progressed along with that of the hornblende; and yet not one fact could be discovered that seemed to indicate that the hypersthene was the older constituent of the two.

¹ Microscopic section No. 139, from a specimen collected on the Baltimore and Ohio Railroad near Gray's bridge. Diallage is also intimately intergrown with the compact primary brown hornblende, as may be seen in section No. 138, from the same locality.

² Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, pp. 24-33. 1884.

³ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, pp. 943, 948, and 950. 1862.

Their relations to each other and to the other minerals point to an equal age for both.

On the supposition of the secondary nature of the hornblende, however, these facts become at once intelligible. The chemical composition of the diallage is such as to allow its direct change by paramorphism to hornblende, and this can therefore take place as readily in one portion of the crystal as in another; in the case of hypersthene, on the other hand, the addition of certain other chemical constituents, such as alumina and lime, is necessary, and these must be furnished by the feldspar, as will be shown below. Hence it is possible for the hypersthene to change to hornblende only where it is in contact with the feldspar, i. e., around its external edge.

The secondary nature of hornblende which accompanies the hypersthene is much more evident than of that occurring in connection with the diallage. This is always composed of two distinct zones, of which the inner one is made up of fine, colorless fibers, while the outer one is dark green in color, decidedly pleochroic, and comparatively compact in structure. The appearance of this fringe is represented in Plate I, Fig. 2.

The interior colorless zone is too finely fibrous to become entirely dark between crossed nicols, but the individual needles may nevertheless be seen with a high power to have a slightly inclined extinction angle. They are generally arranged with their longest axes approximately perpendicular to the edge of the hypersthene, although they are sometimes grouped irregularly or show signs of a radial arrangement. On the one side they grade so imperceptibly into the hypersthene that there can be no doubt about their having originated from its substance. These needles are so fine that no decision based on crystal form could be arrived at in regard to their nature. Their relation to the exterior green zone renders it, however, exceedingly probable that they are some form of hornblende.¹

This exterior portion of the fringe is often quite compact for a considerable distance and displays all the characteristic features of hornblende—cleavage angle, pleochroism, extinction, &c.—in perfection. Generally with a high power a tolerably sharp line may be seen to separate these two zones; but not infrequently a single crystal may be seen to belong to both, being white at one end and green and pleochroic at the other.

It is interesting to note that the process of alteration here described shows the closest analogy with that well known to take place around the olivine in many ancient massive rocks, although, so far as I know,

¹ The color of this hornblende is invariably influenced by the proximity of a grain of magnetite. Here it becomes a much deeper green, showing that this mineral has contributed something to its composition, a fact which still further indicates its secondary nature. Magnetite grains are sometimes themselves fringed with a border of dark-green hornblende.

it is here described for the first time in the case of the corresponding bisilicate, hypersthene.

Professor Törnebohm, in his description of the diabases and gabbros of Sweden, states that the olivine of the "hyperite" occurring near Ölme is always surrounded by a double zone of secondary hornblende, the outer one being green and the inner one colorless, on which account he considers it tremolite.¹

F. Becke describes the same phenomenon in the olivine-gabbro of Langenlois, in Lower Austria,² as well as in that from Rosswein, in Saxony.³ This author regards the interior colorless zone as probably bronzite in the first instance and as anthophyllite in the second.

Both of these writers noticed that these bordering rims were only present where the olivine came in contact with the feldspar, on which account a reaction was naturally assumed to have taken place between the substance of the two minerals, resulting in the production of a silicate of intermediate composition.

No essential difference could be observed between this change of the olivine and that exhibited by the hypersthene of the Baltimore gabbro. The fringing rims occur along the contact between the hypersthene and the feldspar, and even where the latter mineral is no longer visible they seem to occupy the place where it once existed. After the study of a number of sections under the microscope this joint action of the two minerals became so evident that a chemical examination of the composition of all the different constituents was undertaken, with a view of ascertaining how nearly the secondary hornblende agreed with the diallage in composition and how far it was intermediate between the hypersthene and the feldspar.

For this purpose a moderately coarse-grained specimen from near the Windsor road bridge, over Gwynn's Falls (No. 148), was selected, in which the alteration of both pyroxenic minerals was plainly visible to the unaided eye. Under the microscope all the phenomena above described were seen to be present in great perfection.

This rock was pulverized to such a fineness that, by sifting, a powder was obtained whose grains measured from $\frac{1}{160}$ to $\frac{1}{160}$ of an inch in diameter.⁴ This was then separated, by repeated treatment with the Thoulet and Klein specific gravity solutions, into four portions, each one being composed of one of the four rock constituents in a nearly pure state. Of these, I possessed a reddish-brown color and a metallic luster, and was made up, as the microscope showed, almost wholly of hypersthene; II was brownish-gray in color and contained the diallage. It was only possible to separate these two constituents by means of the

¹ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 384. 1877.

² Mineralogische und petrographische Mittheilungen, IV., p. 355. 1882.

³ *Ib.*, p. 450.

⁴ Bolting-cloth is found to be very serviceable in preparing rock powders for the separation of the constituents.

borotungstate of cadmium (Klein's solution) at a high temperature. III was green in color, and could be seen under the microscope to be composed of fibrous hornblende, both white and green. IV was pure white and contained only the feldspar.

Chemical analyses of these four powders were kindly furnished at my request by Mr. W. G. Brown, lately of the University of Virginia, who has spared no pains to render them as accurate as possible. His results are as follows:

	I.	II.	III.	IV.
SiO ₂	52.12	51.414	49.240	45.32
Al ₂ O ₃	1.69	4.323	9.010	35.45
Fe ₂ O ₃ .....				.99
FeO	20.94	9.307	10.584	.....
MnO .....		.043	.035	.....
CaO	3.20	20.600	14.364	16.51
MgO	21.56	15.138	15.839	.50
Na ₂ O				2.41
K ₂ O .....				.06
Total	99.51	100.825	99.072	101.24
Sp. gr.	3.35	3.26	3.09	2.73

These analyses are not perfectly conclusive, because we have no means of knowing that the green hornblende associated with the diallage is exactly identical in composition with that which surrounds the hypersthene. A hornblende of just the composition of the diallage would be quite possible, but in powder No. III all of this mineral present in the entire rock is mixed together.

If, however, we assume that all the hornblende does possess the same composition, as seems reasonable from the agreement in all of its physical characters, we have between the diallage (II) and the hornblende (III) only such slight differences—increase in the latter of alumina and loss of lime—as have been noted by Dr. George W. Hawes¹ and Prof. B. Harrington² as being the frequent accompaniments of uralitization, or perhaps even its conditioning cause.

In the case of hypersthene, however, the circumstances are altogether different. Here the hornblende is intermediate in composition between the hypersthene (I) and the feldspar (IV). For it the former must have furnished the necessary iron and magnesia, while the latter supplied the alumina and lime. Thus the chemical examination of the different constituents fully bears out the interpretation already put upon the facts observed under the microscope.

(It is worth while to notice the close resemblance of the feldspar analysis (IV) made from specimen No. 148 to that of the same mineral extracted from the Mount Hope specimen (No. 56) given on page 20.)

¹ Mineralogy and Lithology of New Hampshire, 1878, p. 65.

² Report of Progress of the Canadian Geological Survey, 1878, Appendix G, p. 22.

The process of alteration of both diallage and hypersthene to hornblende continues until finally all traces of the original minerals disappear and their place is wholly occupied by an irregular aggregate of needles which are large enough to be easily determinable as amphibole. In some cases (No. 103a) the needles in the center of such an aggregate are colorless, while those around the edge are green and strongly pleochroic, as is represented in Plate II, Fig. 1. Gradually the interior crystals also appear to turn green like the others, and the rock passes into a typical gabbro-diorite, the feldspar, which has not united with the hypersthene substance, having suffered no material change. (Plate II, Fig. 2.)

The compact brown hornblende, which exceptionally occurs as a constituent of the Baltimore gabbro, appears finally to succumb to the same changes which the pyroxene undergoes,¹ although it resists the change much longer than this. It is frequently observed quite intact when the other bisilicates are completely altered, but has itself been seen in all stages of transition to the fibrous form. One specimen from Green Spring avenue (No. 116) shows this distinctly.

In some cases this compact brown hornblende may have given rise to the corresponding green form, filled with black inclusions, which has been mentioned on page 29.

§ 4. GENERAL CONCLUSIONS.

From the evidence presented in sections 1 and 2 of this chapter the hypersthene-gabbro and the gabbro-diorite of the Baltimore region must be regarded as geologically and chemically identical. They undoubtedly represent two modifications of one continuous rock mass, which differ only in the crystalline form of the bisilicate constituent.

If, as its relations to the surrounding rocks seem strongly to indicate, this mass be considered of igneous origin, there are but two reasonable suppositions which can account for its present differentiation: either the magma originally crystallized in two modifications, or it was at first mineralogically as well as chemically homogeneous, but subsequently underwent certain molecular changes, which were caused by the new and different conditions to which it was exposed.

The latter of these hypotheses is rendered *a priori* the more probable by a consideration of the peculiar relations existing between the minerals pyroxene and hornblende.

These two substances have long been known to be dimorphous, i. e., identical compounds, which, like sulphur, assume different crystalline forms under different conditions. Of these forms, the one characteristic of pyroxene is more stable at high temperatures, while the hornblende form is better in accordance with ordinary temperatures. If a

¹ F. Becke describes and figures a like change of compact hornblende in the kersantites of Lower Austria (Mineralogische und petrographische Mittheilungen, V., p. 187, 1883, Pl. I., Figs. 5 and 6).

crystal of hornblende be fused it will assume, on again solidifying, the augitic form. The reverse of this process may often be observed in nature, in the gradual passage of pyroxene crystals to those aggregates of hornblende needles to which, over fifty years ago, Gustav Rose gave the name "Uralit."

In certain cases, even under the same physical conditions, slight differences in chemical composition may determine whether the pyroxenic or the hornblendic form is assumed on crystallization, as Dr. G. W. Hawes has attempted to prove by a comparison of careful analyses of both forms.¹ Dr. Bernhard Harrington has maintained, after a study of the uralitized pyroxene of Canada, that this process is always accompanied by such chemical changes and that it is to be regarded as an example of pseudomorphism, rather than paramorphism.²

In spite of these differences, however, it would seem that, other things being equal—i. e., where the composition of both minerals is identical—temperature alone is sufficient to determine which crystalline form is assumed.³ It would therefore be difficult to imagine a continuous and homogeneous magma, crystallizing under precisely the same conditions in one spot, as a typical gabbro, wholly free from hornblende, and in another as a typical diorite, entirely destitute of pyroxene.

Of much more immediate bearing on the question of the origin and relations of the two rocks of the Baltimore gabbro area is the evidence furnished by the microscopical study of the forms intermediate between them (Chap. IV, § 3, pp. 40–45). Here we have ocular demonstration of the gradual passage of the pyroxene of the gabbro into the hornblende of the diorite convincing enough, in the opinion of the writer, to warrant the assertion that all the diorite, even when it contains no trace of pyroxene, has resulted by paramorphism from the former rock. The very form in which the hornblende of the diorite occurs strongly supports this view. It is never in the compact brown crystals characteristic of volcanic rocks and similar to that which is frequently associated with the pyroxene of the unaltered gabbro, but, on the contrary, always in that green modification which is most characteristic of the crystalline schists. This is, moreover, just that form which is known to result from the alteration of pyroxene, and even when it is not so finely fibrous as to merit the name of uralite its individuals are grouped together in such confused aggregates as invariably to give to a freshly fractured surface of the diorite the peculiar satiny appearance mentioned on page 27.

Such specimens, therefore, as by themselves would pass for typical diorites, composed of plagioclase and a comparatively compact green hornblende, the writer must regard, in the light of their association, as

¹ Mineralogy and Lithology of New Hampshire, 1878, p. 65.

² Geological Survey of Canada, Report of Progress for 1878-'79, Appendix G, p. 23.

³ G. H. Williams: On the Paramorphism of Pyroxene to Hornblende in Rocks, American Journal of Science, October, 1884.

alteration forms of the hypersthene-gabbro, and hence to be designated by the name "gabbro-diorite".¹

Regions more or less similar to the one near Baltimore in the character of their rocks, and quite analogous to it in the nature of the changes which these rocks have undergone, have been studied and described by Phillips in Cornwall,² by Reusch in Norway,³ by Törnebohm in Sweden,⁴ by Dathe⁵ and Lehmann⁶ in Saxony, by Becke in Lower Austria,⁷ and by Kloos in Baden.⁸

Streng,⁹ Wadsworth,¹⁰ and Irving¹¹ have described similar changes of pyroxene to hornblende as taking place on a large scale in the ancient crystalline rocks of the Lake Superior region, while Dr. G. W. Hawes¹² and F. D. Chester¹³ have discovered them in the eastern part of the United States.

In none of these cases does there seem to be any doubt entertained as to the fact or nature of the alteration. Everywhere the hornblende

¹ Another possible supposition, viz, that the diorite was the original rock and a member of the crystalline schists like the gneisses, does not seem worthy of serious attention. It might be imagined that such hornblendic schists were locally subjected to a degree of heat sufficient to have thereby lost their schistose structure, or even in places to have been so perfectly fused that they crystallized again in the form of gabbro. Such a theory is, however, quite at variance with the facts observed in the field, and even more so with those disclosed by the microscope. Whenever there is any change directly visible we have the fibrous hornblende fringing the compact core of pyroxene. All observations unite to prove that, if either mineral has resulted from the alteration of the other, the pyroxene must have been the original form.

² Quarterly Journal of the Geological Society, XXXII, 1876, p. 155, and XXXIV, 1878, p. 471.

³ Die fossilienführenden krystallinen Schiefer von Bergen in Norwegen. German translation by R. Baldauf, 1883, p. 35.

⁴ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, p. 391. 1877.

⁵ Erläuterungen zur geologischen Specialkarte des Königreichs Sachsen. Section Waldheim (No. 62), 1879, p. 35.

⁶ Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, p. 190. Bonn, 1884.

⁷ Mineralogische und petrographische Mittheilungen, IV., p. 357. 1882. Becke has also described fine-grained hypersthene-gabbros, more or less altered to hornblendic rocks, as occurring in the peninsula of Chalcidice. *Ib.*, I., p. 244. 1878.

⁸ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, pp. 24-34. 1884.

An extremely interesting account of the small gabbro area near Rådnansö, north of Stockholm in Sweden, has very recently been published by Prof. E. Svedmark. In many respects it more closely resembles the Baltimore area than any other which has yet been described. (*Geologiska Föreningens i Stockholm Förhandlingar*. VII. Band, 1885, pp. 789-846, Plates 19-24, and VIII. Band, 1886, pp. 221-248.)

⁹ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, pp. 133 and 240. 1877.

¹⁰ Bulletin Museum Comparative Zoölogy of Harvard College, Cambridge, VII, p. 46.

¹¹ American Journal of Science (3), XXVII, February, 1884, p. 134.

¹² *Ib.* (3), XII, p. 136.

¹³ Proceedings of the Academy of Natural Sciences, Philadelphia, October 14, 1884, p. 244.

is readily seen to be secondary to the pyroxene, either with or without chemical change.

In reference to the immediate cause producing this alteration of pyroxene to hornblende in rocks not much has been said; indeed, there seems no reason for supposing that it is in every case the same.

Both Hawes and Harrington, as has already been noted, have called attention to prevailing chemical differences between the two forms, which are undoubtedly influential in determining the original crystallization.

It has, however, been repeatedly shown by experiment that precisely the same compound will crystallize as augite at high and as hornblende at low temperatures. Augite, therefore, which is a mineral especially characteristic of lavas, in which it was formed at a high temperature, may at ordinary temperatures be regarded as a less stable form than the hornblende of a corresponding composition, although the molecular cohesion consequent upon the solid state may not be overcome by the tendency of the molecules to suit their arrangement to the altered conditions.

Such a tendency we see plainly manifested in the case of many dimorphous minerals whose crystal form depends upon the temperature at which they originated. In boracite it is shown by an intense optical disturbance without alteration of the external form; in leucite the tension is relieved by a slight distortion of the crystal angles and the production of twinning lamellæ parallel to the "slipping-planes" (Gleitflächen), which are here those of the dodecahedron, $\infty 0$ (110).¹ In the case of monoclinic sulphur the whole internal structure is torn down and the original form replaced by an aggregate of needles having the orthorhombic symmetry which is more in accordance with ordinary temperatures.

The phenomena exhibited by boracite and leucite have not been observed in the case of pyroxene and amphibole, nor, indeed, on account of the relations existing between the morphological and the optical properties of these minerals, could they be expected. Crystals having the form of augite, however, but composed of needles of hornblende, often with more or less of the original substance remaining as a core in the center, were long ago described by Rose and are familiar to all mineralogists. The microscope has revealed the widespread occurrence of this change in many of the older crystalline rocks.

The *tendency* on the part of the augite molecules to change their arrangement at ordinary temperatures is therefore apparent, and this tendency may be assisted by the action of any influence which can increase the facility of their motion without raising the temperature to that degree at which the pyroxene arrangement becomes the most stable.

¹C. Klein: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, p. 576. 1885. H. Rosenbusch: *Ib.*, II., p. 59. 1885.

Professor J. Lehmann,¹ as well as the present writer,² has been inclined to ascribe the uralitization of some rocks to the action of great pressure such as might be exerted by the upheaval of mountains. It seems as though such a pressure, when extended over a very long interval, might bring about a gradual slipping and rearrangement of the molecules without any great increase of temperature.

Very recently Mr. Frederick H. Hatch, of London, has reached similar conclusions from his studies of the gabbros and derivative schistose-hornblende rocks occurring at Wildschönau in the Tyrol.³

As already stated⁴ (p. 32), only such rocks within the Baltimore gabbro area exhibit a schistose structure as have their pyroxene *entirely* replaced by green, fibrous hornblende. By no means all of the plagioclase-hornblende rocks, however, are schistose. The larger proportion of these are as massive as the gabbros.

Pressure may and doubtless does in many instances assist in the paramorphism of pyroxene in rocks, but it cannot in all cases be regarded as even a necessary adjunct.

The rocks of the Baltimore gabbro area, for instance, do not exhibit in their individual mineral constituents the effects of having been subjected to an enormous strain. The bending and breaking of crystals and the disturbance of their optical constants, which is so often observed in the rocks of some much contorted regions, are here rarely noticed. Moreover, in those particular specimens (Nos. 99 and 147) in which these phenomena are most prominent, uralitization of the pyroxene has hardly more than commenced. The very fact that the pressure has not been as great as in certain other more disturbed areas may perhaps itself be sufficient to account for the abundant masses of the unchanged pyroxene rock occurring in the midst of its hornblendic derivative.

In point of fact we know at present almost nothing of what determines the crystalline form of the bisilicate in a molten magma, and still less do we understand the ultimate cause of the subsequent alteration of one form into the other—a change which is to be regarded as in no way allied to weathering or the degeneration of a rock, but rather as a transition from one crystalline state to another no less crystalline, dependent on some change in physical conditions.

All that can now be affirmed with certainty is that the evidence that such a change has taken place is abundant wherever crystalline rocks have been studied; moreover, there are few localities which could furnish more satisfactory and instructive material for tracing this change through all its stages than the gabbro area near Baltimore.

¹ Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine. Bonn, 1884.

² American Journal of Science (3), XXVIII, p. 266. October, 1884.

³ Mineralogische und petrographische Mittheilungen, VII., p. 83. 1885.

⁴ American Journal of Science, October, 1884, p. 267.

CHAPTER V.

THE OLIVINE-BRONZITE-GABBRO, PERIDOTITES, AND ASSOCIATED SERPENTINES AND AMPHIBOLE ROCKS OF THE BALTIMORE REGION.

Olivine rocks and serpentines are more or less extensively associated with most of the larger gabbro areas which have hitherto been carefully studied and described (e. g., Harz Mountains, Saxony, Lower Austria, Scandinavia, &c.), and the Baltimore region proves to be no exception to this rule.

In many places olivine rocks are found so well preserved that their original character is beyond doubt, while from these every stage of transition may be clearly traced to those extensive deposits of serpentine and of massive actinolite or talcose rocks which are so widely distributed in and around the gabbro area proper.

The true olivine rocks occurring near Baltimore always contain bronzite and diallage, although the latter mineral is sometimes present in unimportant quantities. Feldspar is also a frequent constituent. This is rarely abundant, but as a rule it plays such an accessory rôle that the rocks in which it is present must be regarded as occupying an intermediate position between olivine-gabbros and true peridotites in which no trace of feldspar can be found.

All the rocks of this class occurring near Baltimore have a strong resemblance to each other. All are dark-brown or greenish-brown in color and have a peculiar rough appearance on the weathered surface, by which they may be recognized at a considerable distance. This is produced by the decay of the olivine, which leaves the crystals of the more stable bronzite standing out like knobs upon the surface.

These rocks are to be found at very many localities within the gabbro area (see map, Plate IV). Some of the most typical are as follows: near the tenth mile-post on the Western Maryland Railroad, between Pikesville and Howardville (Nos. 52 and 54); on the road a short distance east of Howardville Station (No. 61); on the northern edge of the gabbro area, just south of Smith avenue, about half a mile west of the Mount Washington copper mine (here very abundant) (No. 114); on the old Liberty turnpike, half a mile west of Druid Hill Park; near the junction of the old Liberty turnpike and Forest avenue; in the bed of Gwynn's Falls, at and above the Windsor road bridge (Nos. 133 and 170) (here rich in feldspar); on Green Spring avenue, north of Druid Hill Park (No. 41), (here much altered). Many other localities quite as good

as those here given might be mentioned in the neighborhood of Howardville, Wetheredville, and Woodberry, along the upper part of Gwynn's Falls, and in the western portion of the area, near the Patapsco River. The rock sometimes occurs in comparatively narrow, well characterized dikes; sometimes in small oval or lenticular patches. In the latter case it is nearly always associated with serpentine, which has originated from its alteration.

A macroscopical examination of these rocks always discloses a compact greenish-black groundmass, in which are imbedded large crystals of a glistening yellow bronzite. In some cases no other constituent can be recognized with the unaided eye, but generally much smaller crystals of black diallage can be detected. Feldspar is frequently thinly sprinkled in small white grains throughout the rock, and in one specimen it was even so abundant as to make up one-third of the entire mass (No. 133).

The bronzite varies considerably in both the size and the number of its individuals. These range even in the same hand specimen from 1 to 8 millimeters in diameter. In some cases this mineral alone seems to compose nearly the entire mass of the rock, while in others it is so sparingly present as to appear quite accessory.

Cleavage plates of this bronzite are readily obtained parallel to $\infty P \propto (010)$ and $\infty P (110)$. These always show, when examined under the microscope in parallel polarized light, an extinction parallel to the vertical (ϕ) axis. In thin sections of the rock this mineral is nearly colorless, and can hence exhibit no pleochroism. In thick plates, however, this phenomenon is plainly visible, viz: $\ddot{a} = \alpha =$ reddish-brown; $\ddot{b} = \flat =$ reddish-yellow; $\acute{c} = \tau =$ green; absorption $\tau > \alpha > \flat$. In converged polarized light, sections parallel to $\infty P \propto (010)$ show no axial interference figure. Sections parallel to $\infty P (110)$ show a bisectrix indistinctly and in an oblique position. In thin sections the bronzite appears as large yellow or colorless plates. It has often a fibrous structure parallel to the vertical axis. Characteristic inclusions like those found in the hypersthene do not occur, but brightly polarizing spots with a highly inclined extinction angle are very prominent between crossed nicols when the bronzite itself is dark, although in ordinary light they are quite invisible. They seem to be due to an intergrowth of small portions of diallage substance. As alteration of the bronzite commences fine bands of serpentine are seen to be developed along cracks which traverse it. Minute fibers resembling bastite are also of common occurrence.

The diallage of the olivine rocks yields in isolated splinters cleavage plates parallel to $\infty P \propto (100)$ and $\infty P (110)$. The former show in polarized light an extinction parallel to the cleavage lines, i. e., to the vertical axis, while in converged polarized light the same sections show an interference figure consisting of a single axis, which remains nearly stationary in the field when the stage of the microscope is revolved.

Sections parallel to ∞P (110) show an extinction angle of from 10° to 13° when measured against the vertical axis. In thin rock sections an extinction angle as high as 35° was observed in this mineral.

The diallage shows no pleochroism. Thin sections of it are nearly colorless, while such as are quite thick, but thin enough to transmit light, remain green in all positions, with no perceptible change in the intensity of the color when the transmitted ray is made to vibrate in different directions through the crystal.

The diallage has a much more perfect cleavage than the bronzite; it likewise presents a marked contrast to this mineral in the frequency with which twinning lamellæ occur in it. These seem to be of secondary origin, produced probably by pressure, as was also observed in the case of the diallage of the hypersthene-gabbro (see p. 22). Such secondary lamellæ are often present in great numbers and are especially distinct when the diallage crystal has been broken or bent.¹

The feldspar is shown by all its physical properties to be bytownite. Its specific gravity, determined by the Thoulet solution and a Mohr's balance at $15^\circ C.$, is 2.722. The average of a large number of stauroscopic measurements on cleavage fragments gave extinction angles on OP (001) of 19° , and on $\infty P \propto$ (010) of 32° , values which agree well with the specific gravity. This feldspar is soluble with difficulty in concentrated hydrochloric acid and fuses readily in the flame of a Bunsen burner. This mineral shows a marked freedom from inclusions, differing in this respect from the feldspar of the hypersthene-gabbro. Wherever it comes in contact with the olivine, the peculiar reactionary rims of amphibole described by Törnebohm (see above, p. 43) are finely developed. The interior zone of these rims next to the olivine is narrow, granular, and almost colorless. Outside of this is a darker-greenish portion, having a feathery appearance; this exterior zone projects in rounded tufts into the feldspar substance, at the expense of which it has apparently been formed.

The main mass of the feldspar is not always fresh. The change which it has undergone is the interesting and unusual one to a zeolite mineral (probably scolecite), instead of the more common one to saussurite or calcite. While the larger portion of a feldspar crystal remains quite unchanged, radiating tufts or continuous bands of stout colorless needles may frequently be seen, having the appearance represented in Fig. 2. These needles show the most brilliant interference colors in polarized light, even when the section is exceedingly thin, an effect well known to be characteristic of the zeolites. The axes of elasticity, so far as could be determined under the microscope, appear to be parallel to the crystallographic axes. When treated in a section with hydrochloric acid these needles readily gelatinize before the feldspar substance is affected. Such of the feldspar as contains these needles in the greatest abun-

¹ See Van Werveke: Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, II., p. 197. 1883.

dance gives off water when heated, a fact which is further indicative of the presence of a zeolite. In all particulars these needles seem to agree very closely with those which J. H. Kloos has recently described as occurring in the feldspar of the Ehrberg gabbro from the Black For-



FIG. 2.—Olivine-gabbro. (No. 54.)

est, Baden.¹ These he found by careful analysis to be a zeolite closely allied to scolecite. Similar alterations of feldspar in rocks have been mentioned by Höfer, who found the andesine of a melaphyre from Niederen Tatra changed to heulandite,² and by H. Rosenbusch, who describes the feldspar in the picrite from Schwarzenstein as changing to radiating fibers of some zeolitic mineral.³

The olivine (the most characteristic constituent of this class of rocks) exhibits no very striking peculiarities. It is present in small rounded grains, forming the dark, compact groundmass in which crystals of the other minerals are porphyritically imbedded. The structure of these rocks is therefore quite an exceptional one for the family of peridotites: first, on account of the porphyritic character, which is rare in members of this class, and, second, because of the unusual position of the olivine in the groundmass, indicating that it is here the youngest, instead of the oldest constituent, as is generally the case. The grains of olivine are always more or less completely changed to serpentine, although in many specimens cores of the original mineral remain intact. The serpentine is of a bright-yellow color when seen in a thin section under the microscope and shows in an admirable manner the well known process of its formation out of the olivine substance. The fine serpentine fibers are developed along cracks and fissures in the olivine, working their

¹ Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. III. Beilage-Band, pp. 38-48. 1884.

² *Ib.*, p. 145. 1871.

³ Mikroskopische Physiographie. Vol. II. Die massigen Gesteine, p. 529. 1877.

way from these inward, until finally none of the olivine remains. A considerable quantity of magnetite in fine shreds and lines is always disseminated through the serpentine, having been separated from the olivine during the process of its alteration.

No other constituents were observed in the olivine rocks of the Baltimore region, except in rare cases small quantities of a compact, brown, strongly pleochroic hornblende, which is filled with minute dust-like inclusions. This mineral is most intimately associated with the diallage, the two being completely intergrown in the same crystal. (Specimen No. 61, from the road near Howardville Station, and No. 79, from Gwynn's Falls near Milford; in the latter the brown hornblende is abundant.)

Three types may be distinguished among the olivine rocks of Baltimore County according to the amount of feldspar which they contain. They are, however, in reality, very closely related, the one type passing by insensible gradations into the others.

(1) *Olivine-bronzite-gabbro*.—This rock contains from 25 per cent. to 35 per cent. of feldspar. It is not of common occurrence, having been observed only in Gwynn's Falls near the Windsor road bridge (Nos. 133 and 170).

(2) *Feldspathic peridotite*.—This rock differs from the above only in the accessory rôle which the feldspar plays in it. This mineral does not compose over 5 per cent. of the rock, through which it is scattered in the form of small white particles. This is by far the commonest type of the class, and occurs at a majority of the localities mentioned on pages 50, 51.

An analysis of a fresh and typical specimen of this rock, taken from the dike on the Western Maryland Railroad, north of Howardville (No. 54), was made by Dr. Leroy McCay, of Princeton, with the following result:

	Per cent.
SiO ₂	41.00
Al ₂ O ₃	7.58
Fe ₂ O ₃	5.99
FeO	4.63
MnO	Trace
CaO	10.08
MgO	23.59
Na ₂ O .....	.52
CO ₂	3.62
H ₂ O	4.73
	<hr/>
	101.74
Specific gravity.....	2.989

(3) *Lherzolite*.—At some localities the feldspathic constituent is altogether absent, making of the rock a true peridotite. Aggregates of olivine, bronzite, and diallage have been designated by petrographers as "Lherzolite," a name which may be properly employed in spite of the many striking differences between the rocks here described and the

original types of this class. No. 120, from an exposure recently made in opening the new highway known as Belvidere avenue, south of Mount Washington, is an example of this type in which the bronzite is much subordinated to the diallage. No. 80, from the farm of Mr. Baker on Gwynn's Falls, is a beautiful example of the same rock, though differing much in external appearance from the specimen last mentioned. It contains some diallage and many large oval crystals of bronzite, nearly 5 millimeters in diameter, which are so numerous as to render quite subordinate the dark-green, olivine groundmass in which they are inclosed. No. 174, from the Johnnycake road, is quite similar.

Another class of massive rocks is well represented in Baltimore County, which, though closely allied to the preceding, differs from it in the entire absence of both feldspar and olivine. Like the olivine rocks they give rise to serpentinous and talcose alteration products, but are themselves composed wholly of bronzite or hypersthene, sometimes with, sometimes without diallage.

In several localities very coarse-grained aggregates of long blade-like crystals of bronzite and titanite iron are encountered. As an example of this rock may be mentioned specimen No. 62, collected near the tenth mile post on the Western Maryland Railroad. In it the bronzite crystals are from twenty to thirty millimeters in length.

Comparatively fine-grained aggregates of both monoclinic and orthorhombic pyroxene, generally free from all other minerals, are also not uncommon. One in particular (No. 176), found on the Johnnycake road, deserves especial mention on account of its freshness and beauty when seen under the microscope. It is composed of a non-pleochroic, green diallage and a very strongly pleochroic, deep-red hypersthene, both in rounded grains of nearly equal size ($\frac{1}{2}$ millimeter in diameter) and both almost wholly free from inclusions. It would be difficult to conceive of the occurrence of these two interesting minerals in a purer state than in this rock.

A very similar rock to the one just described was found by the roadside near the Pikesville station (No. 100). It had evidently been brought there for road ballast, and hence its source could not with certainty be determined. In place of the pleochroic hypersthene of No. 176 this specimen contained a much paler orthorhombic pyroxene, which possesses the properties of bronzite. In other respects the two rocks are not to be distinguished from each other.

Pyroxene rocks like the above, free from both olivine and feldspar, have been described by R. Drasche as giving rise by their alteration to certain serpentines of the Tyrol and Ireland;¹ Berwerth has attributed a similar origin to some of the serpentines occurring near Rosignano and Castellina Marittima, south of Pisa, in Italy;² and Rosenbusch re-

¹ Tschermak's *Mineralogische Mittheilungen*, I., p. 10. 1871.

² *Ib.*, IV., p. 238. 1876.

gards the serpentines of Todtmoss, in Baden, as derived from allied rocks.¹

Many serpentines of Pennsylvania have long been known to be the alteration product of a rock composed almost wholly of enstatite.

The olivine-bearing rocks of the Baltimore region exhibit a most interesting and instructive series of alterations, the study of which has satisfactorily established the fact that masses of a similar character were the original form of a varied group of magnesian rocks common throughout the district.

Not merely in the neighborhood of Baltimore, but throughout the entire Archean belt of the Eastern United States, masses of serpentine and of asbestiform and talcose rocks are of such common occurrence that the tracing by means of the microscope of a few such types through transitional stages back to an original aggregate of pyroxene and olivine must possess more than a local interest.

Generally speaking, the olivine of these rocks changes to serpentine and magnetite; the pyroxene, whether bronzite or diallage, alters at first to a light-green or colorless hornblende, having the composition of actinolite or of tremolite. This hornblende in turn is frequently transformed into talc, accompanied by the separation of the calcium in the form of the carbonate. A series of changes nearly identical with these has recently been described in some detail by F. Becke, who has traced them in the serpentines and associated rocks of Lower Austria.²

All of these changes may often be very perfectly and satisfactorily traced out in a single rock-mass of small dimensions. Moreover, wherever any of the original minerals remain, they seem to be, for rocks of this class, in all cases the same. No other process of alteration could be discovered in the peridotites within the area examined; and hence it would appear quite justifiable to assume a similar origin for all such serpentines and talcose masses as are identical with undeniable alteration products of olivine rocks, even though they may not themselves contain any remnants of their original constituents.

The mineralogical composition of the final product depends, of course, upon that of the mother rock; but by a careful study of the changes to which each component is subject, both alone and in association with other minerals, it becomes quite possible to conclude what the original condition of the derived rock must have been.

The alteration of olivine to serpentine, thanks to the careful figures and descriptions of Tschermak³ and others, is now too well known to need further mention.

¹ Mikroskopische Physiographie. Vol. II. Die massigen Gesteine, p. 538. 1877.

² Die Gneissformation des niederösterreichischen Waldviertels. C. Olivingesteine und deren Begleiter. Mineralogische und petrographische Mittheilungen, IV., pp. 322-352. 1882.

³ Sitzungsberichte der k. Akademie der Wissenschaften. LVI. Beilage-Band. Wien, Juli 1867.

Whether the less common alteration of this mineral to hornblende, as described by F. Becke,¹ also takes place in our rocks is not certain. Most of the serpentines contain considerable amphibole, but no instance has yet been observed where it could not be traced with more probability to the pyroxene than to the olivine.

In case the olivine is the only constituent which has undergone much alteration, a bronzite or diallage serpentine results, in which crystals of the pyroxene are porphyritically scattered through the serpentine groundmass. Such are specimens No. 41, from Green Spring avenue, and No. 122, from the Western Maryland Railroad near Highland Park station.

The alteration of the pyroxene of the olivine rocks seems to be at first always to some form of hornblende. Sections of many comparatively little altered specimens show under the microscope a tendency to develop colorless hornblende needles and fibers in the bronzite and diallage crystals. (See No. 120, from Belvidere avenue.) This change may be continued until no vestige of the pyroxene remains. In connection with the alteration of the olivine, it gives rise to hornblendic (tremolite) serpentines, which are by far the most abundant of the magnesian rocks of Baltimore County. To them belong the serpentines of the Bare Hills, some seven miles north of the city, which are well known for the abundance of chromite and other minerals which they contain. In sections of these serpentines unmistakable traces of diallage may sometimes be discovered, although, as a rule, colorless hornblende needles and serpentine are the only silicate minerals which are present. Rocks identical in all respects with the Bare Hills serpentines have a widespread distribution in and around the gabbro area. They are especially abundant about its edge. On the Falls turnpike, which follows the eastern bank of Jones Falls northward from the city, a considerable area of them is encountered nearly opposite Melvale. The rock has here been quarried for road ballast. Smaller masses of a similar character are very abundant along all the roads in and near the valley of Jones Falls from Lake Roland to the city. In many of these exposures the gradual transition to the little-altered olivine rock may be traced, both macroscopically and microscopically, with great clearness.

Similar conditions prevail toward the western side of the area as we approach the valley of the Patapsco River. At the western edge of the bridge at Hollifields, an interesting magnesian rock occurs, in which the original constituents, olivine and pyroxene, were arranged in parallel bands. This structure is still perfectly preserved in the alternating layers of nearly black serpentine and silvery white hornblende.

¹ Mineralogische und petrographische Mittheilungen, IV., pp. 355, 450. 1882. Ib., V., p. 163. 1883.

In this specimen (No. 197) the microscope discloses numerous unaltered remains of the original minerals.

The large area of serpentine farther to the northeast, known as Soldiers' Delight, appears to be of the same nature as that at the Bare Hills. Similar rocks also occur along the southern limit of the gabbro area in the valley of the Patapsco near Ilchester.

In many specimens of these magnesian rocks a peculiar glistening mineral is largely developed which imparts a light silvery-green luster to a freshly-fractured surface. Small scales of this substance are easily separated parallel to its one perfect cleavage. They are exceedingly soft, and show in converged polarized light a biaxial interference figure. The bisectrix is perpendicular to the cleavage surface and the optical angle is very small. Before the blow-pipe this mineral is infusible, which, together with the above-mentioned characters, clearly indicates that it is *talc*.

This alteration of hornblende to talc in olivine rocks was first described by Tschermak, who regarded the presence of olivine as a necessary condition of the change.¹ Becke has discovered the same alteration in the hornblende serpentines of Lower Austria.² Tremolite passes into talc, accompanied by a change of the calcium silicate to calcium carbonate.

The secondary origin of talc in hornblende may be distinctly seen in specimens No. 115*a*, collected on the new road from Mount Washington to Green Spring avenue, and No. 140, from the Baltimore and Ohio Railroad, opposite Thistle Mills, in the Patapsco Valley.

The pure pyroxene rock mentioned on page 55 as composed wholly of diallage and bronzite would be naturally expected to yield somewhat different alteration products from those derived from the olivine rocks. Finely fibrous masses of an apple-green color are not uncommon within the gabbro area. (Nos. 59, collected north of Howardville; 82, from the Liberty turnpike; 90, 109, 110, 111, and 191, from the Mount Hope railroad cutting; 118 and 119, from Green Spring avenue, and 146, from the Dogwood road.) These rocks are composed of minute hornblende needles, which are sometimes colorless, sometimes of a light-green tint when seen under the microscope. They seem to be that form of secondary amphibole known as smaragdite, and may be seen to have originated from the diallage, remnants of which still remain in several sections.

Where such smaragdite rocks contain no serpentine they have doubtless resulted from the alteration of diallage or diallage-bronzite aggregates. Such a specimen (No. 146), smaragdite rock from the Dogwood road, near the Patapsco River), was found by Mr. W. S. Bayley to contain 49.16 per cent. SiO_2 ; 5.63 per cent. Al_2O_3 , and 10.62 per cent. iron (estimated as Fe_2O_3 , although probably present wholly as FeO). The

¹ Tschermak's Mineralogische Mittheilungen, IV., p. 65. 1876.

² Mineralogische und petrographische Mittheilungen, IV., pp. 339, 349. 1882.

close agreement of these percentages with those of the compounds in the diallage of the gabbro specimen No. 148 (p. 44) is noticeable.

Smaragdite, agreeing closely in character with that of these Baltimore rocks, is well known to be the commonest alteration product of the diallage in many European gabbros.

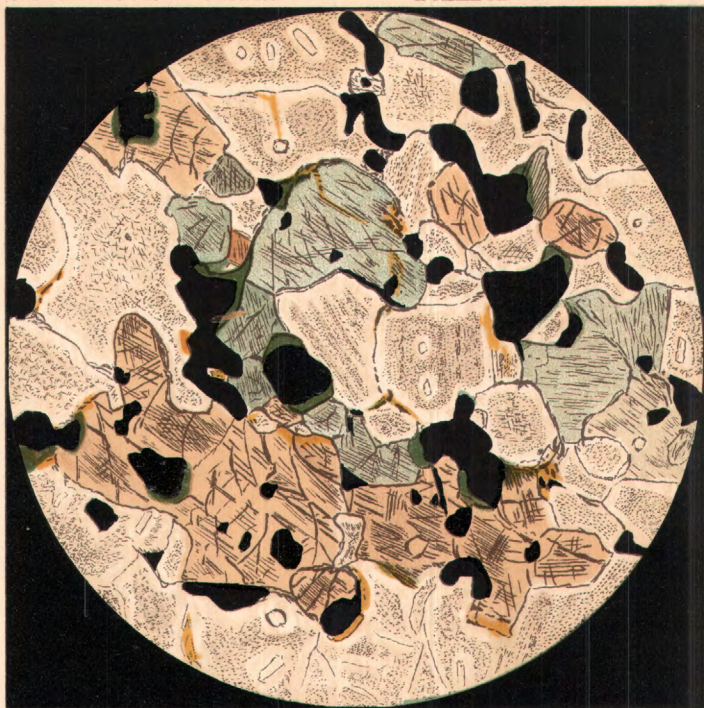
It seems possible that the asbestos deposits of Baltimore County (e. g., like the one near Elysville) may likewise be the results of the alteration of original pyroxene masses.

(669)

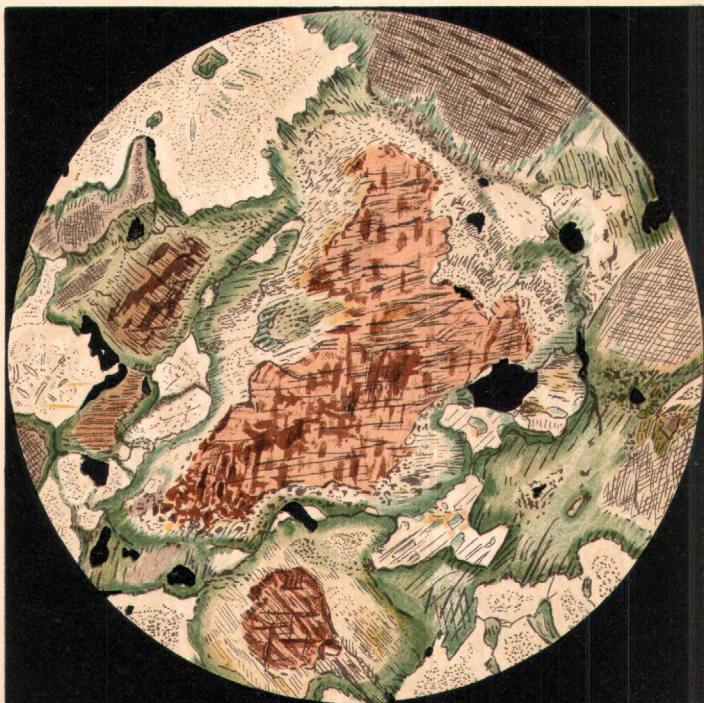
PLATE I.

FIG. 1, section of the typical hypersthene-gabbro from Mount Hope, Baltimore County, as seen under the microscope, magnified 30 diameters. The white mineral, with inclusions, is bytownite; the reddish one, hypersthene; the green one, diallage; and the black one, magnetite (section No. 91).

FIG. 2, section from the transitional zone, occurring between the hypersthene-gabbro and gabbro-diorite. Specimen (No. 65) collected near Pikesville; section magnified 30 diameters. The border of fibrous hornblende, surrounded by a rim of darker, more compact hornblende, is seen around both hypersthene and diallage. The characteristic differences between the secondary rims about the two minerals, described on page 42, are here well shown.



HYPERSTHENE - GABBRO.



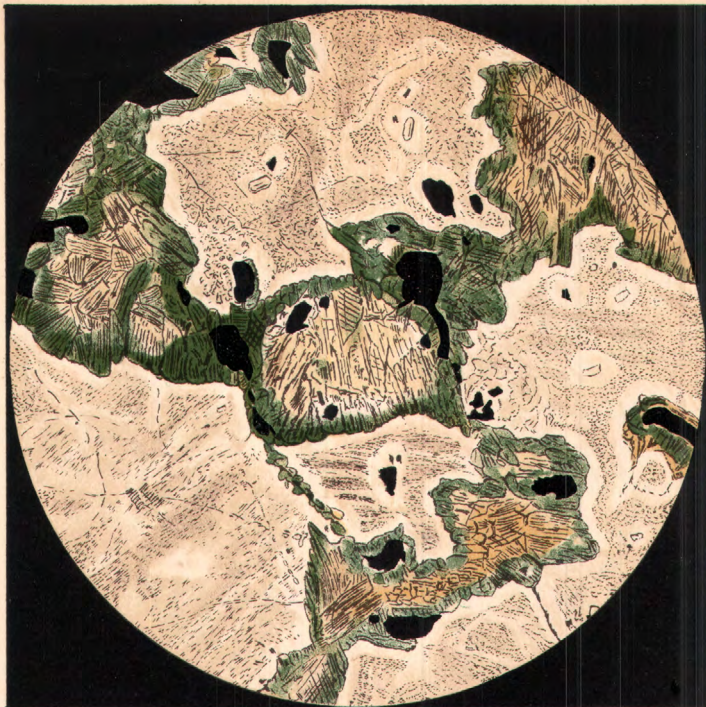
G. H. W. del.

JULIUS BIEN & CO. LITH.

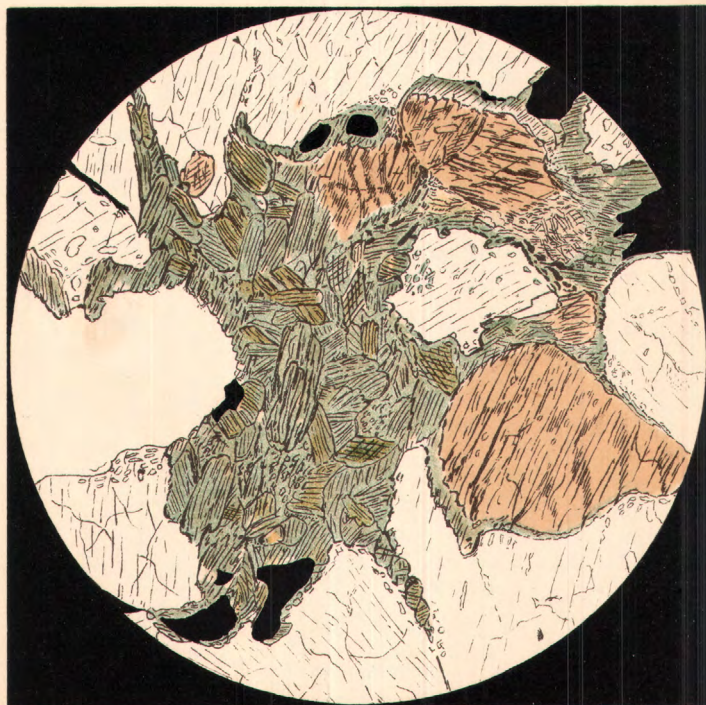
URALITIZED HYPERSTHENE - GABBRO.

PLATE II

- FIG. 1**, section (No. 103a) from Mount Hope, represents the appearance of the gabbro-diorite after the total disappearance of the hypersthene. The place of this mineral is taken by aggregates of hornblende crystals, the interior ones being white and the exterior ones green, as in the case of the fringe which surrounds the hypersthene before its complete alteration. Magnified 30 diameters.
- FIG. 2**, section (No. 84) from the old Liberty turnpike, showing the final stage of alteration and the character of the green hornblende which is most common in the gabbro-diorite. Remains of both the hypersthene and diallage are here also seen. Section magnified 80 diameters.



GABBRO - DIORITE.



G. H. W. del.

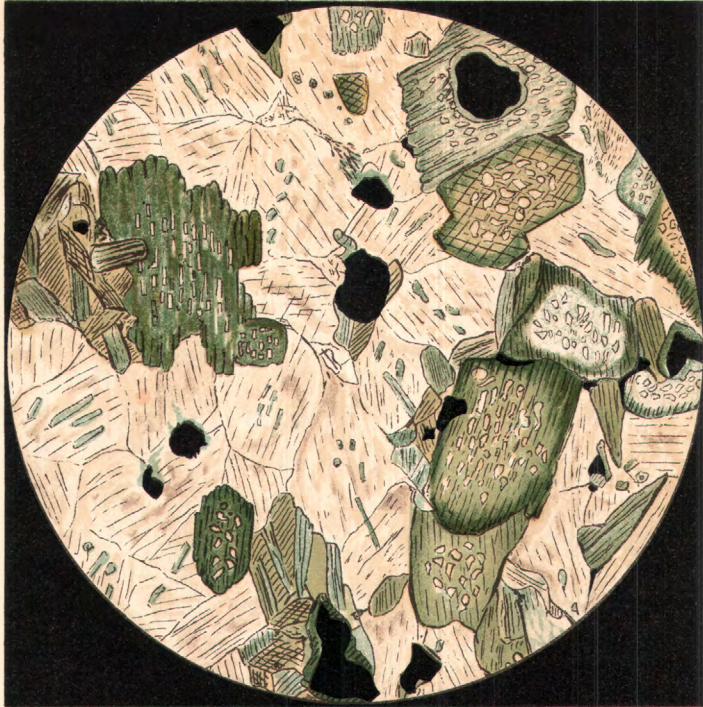
JULIUS BIEN & CO. LITH.

GABBRO - DIORITE.

PLATE III.

FIG. 1, section (No. 92) from Mount Hope. The peculiar structure of some of the secondary hornblende of the gabbro-diorite is here represented, which is described on page 28. The exterior portion is quite compact, while the interior is made up of a fine aggregate of hornblende needles and quartz grains. Magnified 30 diameters.

FIG. 2, section (No. 95) showing the border of epidote needles surrounding the feldspar at its contact with the hornblende in the gabbro-diorite. Specimen collected at Mount Hope. Section magnified 30 diameters.



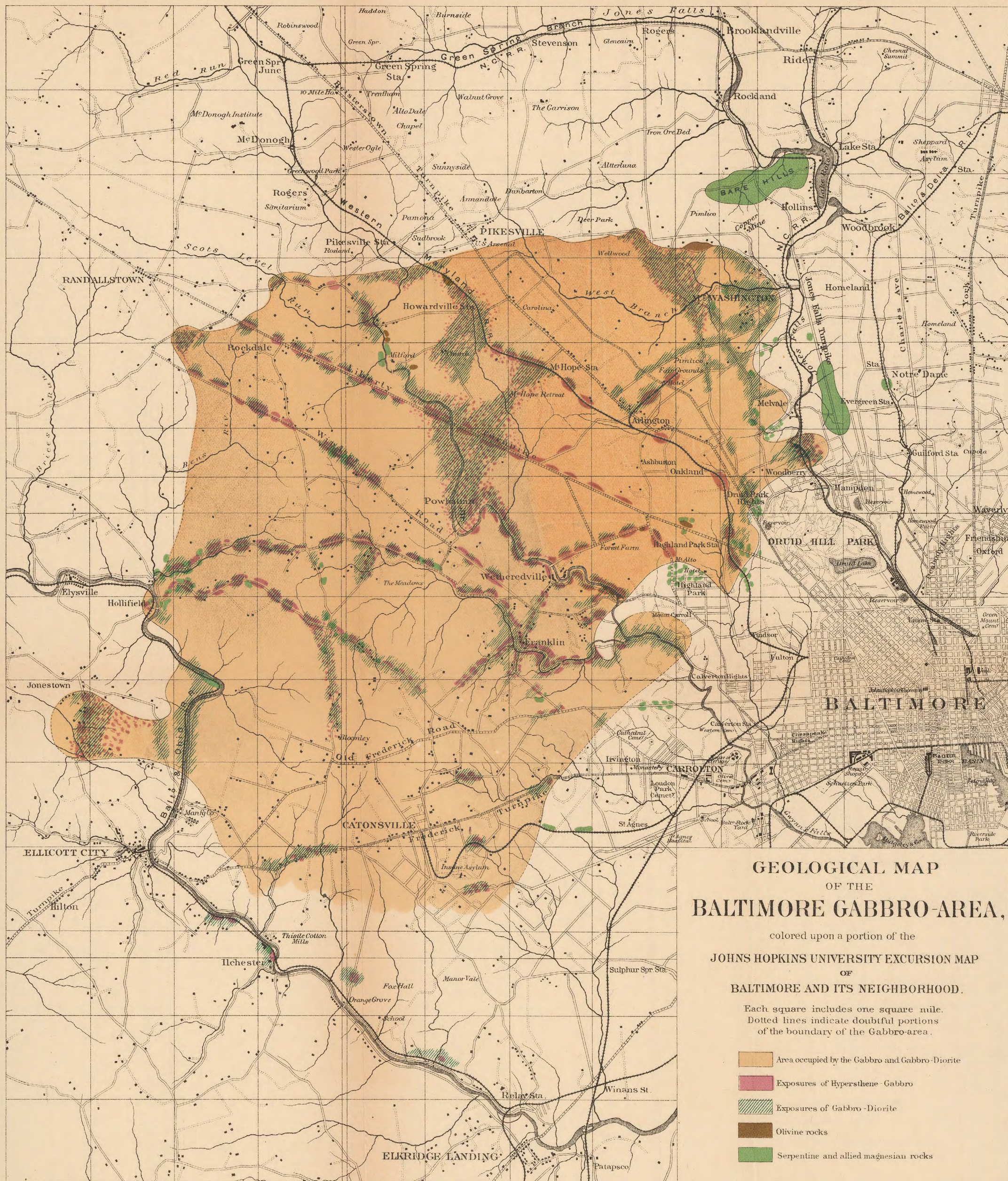
GABBRO - DIORITE.



EPIDOTE IN GABBRO - DIORITE.

PLATE IV. *

Geological map (as a basis for which the excursion map of Baltimore and its neighborhood, recently published by the trustees of the Johns Hopkins University, has been used) giving the area occupied by the gabbro and its derivative diorite. The dotted parts of the boundary line indicate portions that could not be accurately located. Toward the south the overlying Cretaceous deposits render it impossible to fix the limits of gabbro even approximately. The most important exposures of the olivine rocks and their associated serpentines and other magnesian masses are likewise indicated upon this map.



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