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THE GABBROS AND ASSOCIATED ROCKS IN DELAWARE

BY

FREDERICK D. CHESTER

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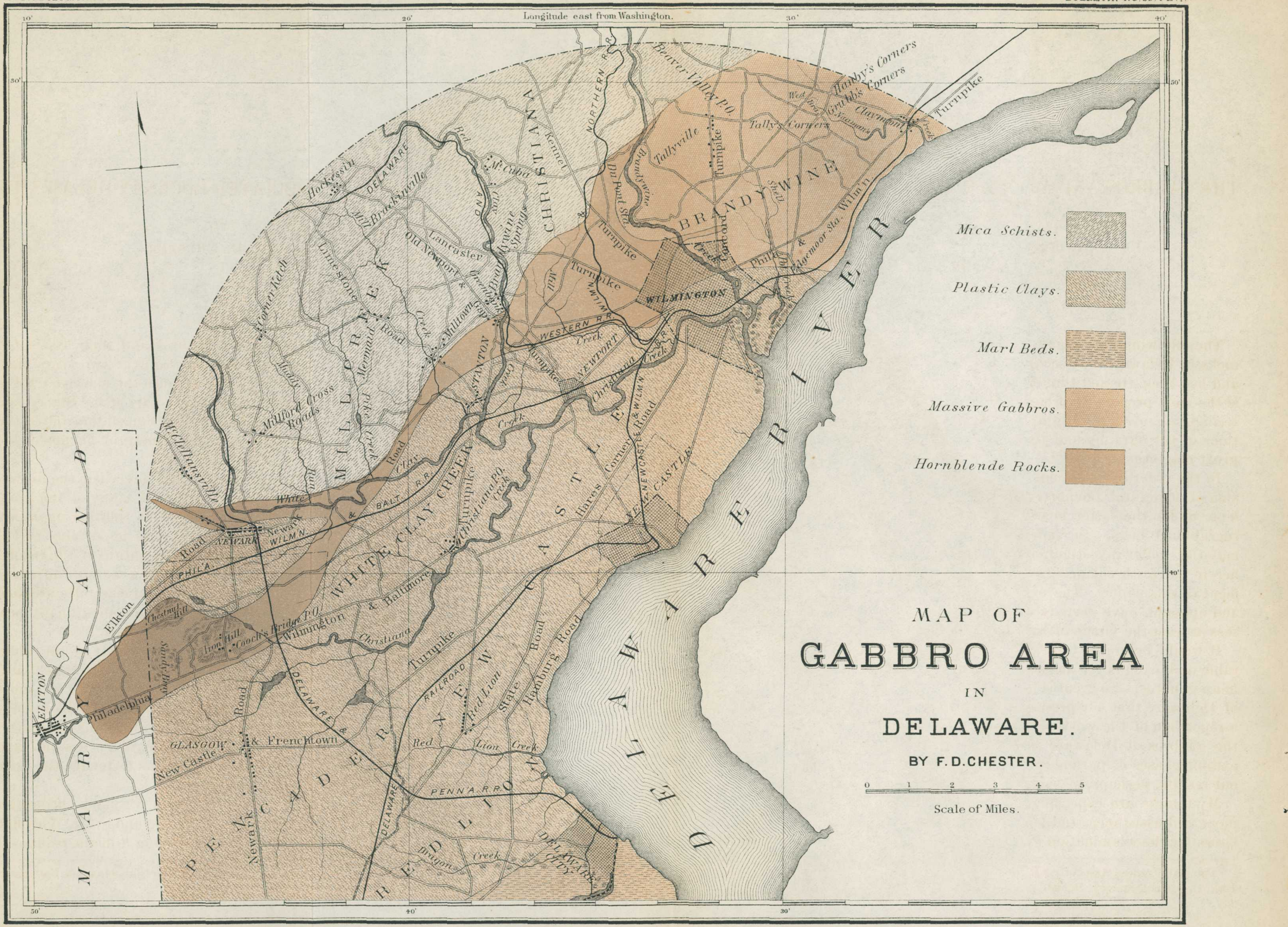
Longitude east from Washington.
MAP OF
GABBRO AREA
IN
DELAWARE.
BY F. D. CHESTER.
0 1 2 3 4 5
Scale of Miles.
Mica Schists.
Plastic Clays.
Marl Beds.
Massive Gabbros.
Hornblende Rocks.
DELAWARE RIVER
WILMINGTON
NEWPORT
STANTON
NEWARK
NEW CASTLE
ELKTON
GLASGOW
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Corner Ketch
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McClellansville
Mt. Cuba
Wyoming Springs
Milltown
Tallyville
Talley's Corners
Grubbs Corners
Hanby's Corners
Claymont
Beaver Valley P.O.
Christiana P.O.
Cooch's Bridge P.O.
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Hares Corner
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Turnpike

THE GABBROS AND ASSOCIATED ROCKS IN DELAWARE.

By Frederick D. Chester.

INTRODUCTION.

The following investigation upon the gabbros and their associated rocks in Delaware has occupied my attention for over two years past, and has been treated thus in detail, first, because the massive gabbro is the most prominent formation in the northern part of the State; and second, because a thorough study of it embraces some interesting questions in petrography and their bearing upon structural phenomena of great magnitude.

In the order of treatment the petrography has preceded the discussion of structural phenomena, for the reason that many of the problems under the latter head must depend for their solution upon petrographical facts. In view of the magnitude and importance of the material under investigation, reflection upon the nature of the results herein set forth compels the confession of a certain timidity of statement in this paper. The evidence at hand has been carefully weighed and opinions have been recast, until the results embodied finally possess at least the virtue of having been patiently evolved.

It would be unjust to prior authorship not to take note of the admirable and exhaustive memoir of Dr. G. H. Williams[1] upon the Baltimore gabbros. So great is the similarity between these rocks and those of Delaware that our present descriptions must in some cases involve a repetition of the work of Dr. Williams. In another sense, however, the gabbros of Delaware merge into types so entirely distinct and exhibit phases of paramorphic change so novel, as to render the present results, perhaps, of some additional interest.

My thanks are especially due to Dr. Williams for much encouragement and assistance, and also to Prof. R. D. Irving and to Mr. Whitman Cross for the examination of thin sections involving difficult points.

[1] The Gabbros and Associated Hornblende Rocks in the Neighborhood of Baltimore. Bull. U. S. Geol. Survey, No. 28. 1886.

GENERAL PETROGRAPHICAL CONSIDERATIONS.

The petrography of the Delaware traps is based upon an examination of numerous thin sections from all parts of a relatively small area, the form and extent of which are seen from the accompanying map. These sections show the different variations in our Delaware rocks, together with the various stages of paramorphic change from pyroxene to amphibole, so fully as to render additional material of no essential moment in establishing the conclusions adduced.

The Delaware traps, exclusive of the younger orthoclastic granites, may be designated by two terms, *gabbros* and *gabbro-diorites*.[1] These terms, however, have only the most general application, while a closer study reveals a variety of petrographical forms, not so much distinct in themselves as expressions of a wide variation from some arbitrary form which we call primary. This primary form is more clearly the common hypersthene-gabbro, or the so-called blue granite of the Delaware quarries. It is normally a finely granular mixture of basic plagioclase, hypersthene and diallage in nearly equal proportions, with accessory quartz, magnetite, apatite, hornblende, and biotite.

Reference to the following analytical table will make clear the lines of variation proceeding from this primary hypersthene-gabbro:

(A.) HYPERSTHENE-GABBRO. Plagioclase, hypersthene diallage, with accessory quartz, apatite, pyrite, magnetite, brown hornblende, biotite.	By addition of (original?) brown hornblende	(B.) GABBRO-DIORITE and HORNBLENDE GNEISS.
	By addition of biotite as an important constituent; quartz in large amount.	(C.) GABBRO-GRANITE.
	Highly feldspathic and quartzose, with a little hypersthene and much magnetite.	(D.) NORITE.
	By paramorphism of pyroxene to green hornblende (uralitic).	(E.) GABBRO-DIORITE. (Iron Hill.)
	By addition of compact green hornblende, either paramorphic or original.	(F.) GABBRO-DIORITE and HORNBLENDE GNEISS.
		feldspar to epidote.
		(G.) EPIDOTIC DIORITE.

In considering the Delaware gabbros as a whole we might say that their chief distinguishing feature is their highly acidic character, due to the large admixture of quartz. This is at once evident to the most casual observer, who not only sees quartz as a prominent constituent

[1] This very convenient term has been used by Törnebohm and G. H. Williams to indicate transitional types of rocks between gabbro and diorite, and to all uralitic diorites of like origin.

in every hand specimen, but who observes in the faces of the rock in situ great seams and segregated masses of the same. It has been noticed that the rock which in a general sense we would regard as a normal hypersthene-gabbro is a most unstable form, running on the one hand into a rock possessing strongly the character of a granite, and on the other into those distinctly dioritic. Quartz, which is found in such large amounts in the fine-grained gabbros northeast of Wilmington, is absent or in but a small amount in the normal gabbro of which a number of types have been found. This more basic standard, however, is not long maintained; on the other hand, the Delaware gabbros tend by indistinct gradations to become more and more acidic from a gradual gain of quartz.

This last variation of gain in quartz is also characterized by an equally gradual gain of biotite, until, as in many of the Bellevue and Claymont rocks, we have a type which is more properly a granite, with pyroxene as only an accessory constituent.

The presence of a brown dichroic hornblende as a very variable constituent of the hypersthene-gabbro is a fact of the greatest interest, since by the gradual increase of this mineral from a mere trace to an amount sufficient to subordinate the pyroxene elements we are led to see an equally gradual transformation to a black, highly schistose, hornblende rock, which, structurally and macroscopically, seems at first sight to have no genetic relationship with the gray, compact gabbro with which it is associated. Regarding this brown hornblende as original, as I believe we must from present data, we can attribute this change from a gabbro to a diorite only to the result of an original variation in the character of the eruptive material.

In the change, on the other hand, from gabbros to green hornblende rocks we have, to a large degree at least, the results of a paramorphic change affecting the pyroxene of the mother rock; the final product in all cases being a perfectly compact, green hornblende, whether this results directly from the alteration of diallage, or, as when hypersthene is the primary substance, from the intermediate fibrous amphibole, as described by Lehmann and by Williams.

Thus we may affirm that the whole result of a deliberate study of an extensive series of thin sections has been to teach most emphatically the principle that apparently diverse types can in reality possess an intimate genetic relationship. It is also believed that the sooner this is fully realized the sooner geologists will be defended from many errors of generalization based upon structural data alone. Nearly every section in our series is a transition stage from one type to the other, and so few are the clearly defined forms, that no sharp lines can be drawn or strong designations made. Those set forth in the accompanying table, it must be understood, are largely arbitrary, serving simply to indicate certain dominant tendencies in the line of variation.

It can not be otherwise than evident to the most casual observer that many of our former theories respecting the metamorphic rocks are undergoing radical alteration since the microscope has taken such a prominent place in geological investigation. This is particularly true as regards that great class of schistose, amphibole rocks which, until quite recently, have been generally regarded as altered sediments.

But since the investigations of Lossen in the Harz, J. H. Kloos in the Black Forest in Baden, F. Becke at Langenlois, Lower Austria, Törnebohm in Sweden, Lehmann in Saxony, Teall and Phillips in England, Wadsworth, Irving, and Williams in this country, an entirely new field has been opened, and geologists are in a fair way to discriminate between crystallized sediments and metamorphosed igneous rocks. That highly foliated schists in many cases may have had an eruptive origin has already been demonstrated by a respectable body of workers, while what is more encouraging than all is the indication of future developments in this fertile field of research. The element of pressure which plays such an important role in the development of slaty cleavage in the sedimentary rocks and their derivatives must in the future be recognized in accounting for the secondary products of the massive traps, by producing great structural alterations, and possibly by inducing molecular rearrangements and consequent paramorphic changes.

HYPERSTHENE-GABBRO.[1]

This is taken as the primary and typical form of the trappean series. In color, it varies from a dark bluish gray to a black; in texture, from one distinctly crystalline to one quite aphanitic. Macroscopically the rock appears to be a finely granular mixture of striated feldspar, bluish quartz, rounded grains of black highly metallic hypersthene and a small amount of foliated greenish diallage. Under the microscope the several mineral constituents present characters which render their determination satisfactory.

The hypersthene occurs in irregular grains, never in crystals, which vary in size from 1^{mm} to 7^{mm}, the majority approaching 4^{mm} to 5^{mm}, while others again are spreading branching individuals, which fill up the spaces between the plagioclase and inclose numerous rounded grains of the latter. The cleavage is well developed parallel to the prismatic face (∞ P) and to the brachypinacoid (∞ P $\breve{\infty}$).

The pleochroism of all sections is strong, offering a ready means of distinguishing this mineral from its associated diallage. Sections in which the double prismatic cleavage is well developed, and which, with concentrated polarized light, show a biaxial interference cross, show also strong yellow and reddish pleochroism. Other sections with powerful greenish and yellow pleochroism were found, with which

[1] I have adopted the term *hypersthene-gabbro* in view of its use by Dr. G. H. Williams, yet it remains a question whether, in consideration of the acidic character of many of our true hypersthene-gabbros, the term *norite* might not better express the position which our rocks bear to those in Europe.

equally clear interference crosses could be obtained. It is evident from this that in these two cases we have sections respectively parallel to the basal pinacoid (0P) and to the macropinacoid ($\infty P \bar{\infty}$), and thus the rhombic character of the mineral as well as the arrangement of the pleochroic colors is well established.

The trichroism is as follows: $\mathfrak{a}$ copper-red; $\mathfrak{b}$ yellow; $\mathfrak{c}$ green.

All prismatic sections extinguish parallel to the cleavage. A number of cleavage leaflets detached by a penknife from the prismatic face of a coarser fragment gave the same parallel extinction, and the color of the $\mathfrak{c}$ ray, with a combination of the $\mathfrak{a}$ and $\mathfrak{b}$ rays for light vibrating at right angles to the cleavage.

The specific gravity of a number of these fragments, which, after examination with the microscope, were found to be pure, was determined by means of the Klein solution and found to be 3.38. This high specific gravity excludes the possibility that this mineral is bronzite.

The hypersthene seems to be entirely free of the brownish, leafy inclusions, so characteristic of many hypersthenes, and also of the hypersthene in the Iron Hill rocks, but beautiful symmetical needles or rods arranged parallel to the cleavage lines are common, associated with coarser, lenticular, black inclusions either of magnetite or of titanic iron ore.

The diallage can sometimes be found in the coarser hand specimens as a grass-green mineral with an eminent parting parallel to the orthopinacoid and to the prismatic face. Under the microscope thin sections have a pale green color, and show no apparent pleochroism, while thicker cleavage fragments show only the slightest change of color on revolving the stage over the polarizer.

Most prismatic sections give high angles of extinction approaching 45°. Cleavage leaflets parallel to the orthopinacoid extinguish parallel to the prismatic cleavage lines as would be expected, and give with concentrated polarized light the characteristic single optic axis. The specific gravity of a number of microscopically pure fragments of this mineral was determined by means of the Klein solution. While the diallage pieces remained freely suspended in the solution a fragment of green hornblende was dropped in, which easily rose to the surface and floated. The specific gravity of the solution, and therefore of the diallage, was 3.24. The diallage contains the same inclusions as the hypersthene, i. e., opaque needles and grains of magnetite, with frequently included fragments of hornblende and grains of plagioclase.

The feldspar occurs as granular particles, which vary in size from .1^{mm} to .5^{mm} in diameter. They show a fine polysynthetic twinning, and quite commonly two systems of striation approximately at right angles to each other, according to the well-known albite and periline laws. The feldspars show those irregularities of twinning characteristic of many gabbros, i. e., lack of parallelism of the twinning lamellæ, irregularity in the length of the same, and their frequent wedge-shaped character, showing under crossed nicols a beautiful interlocking of individual lamellæ. The angles of extinction are invariably high, indicating a basic feldspar. The examination of cleavage fragments of the feldspar isolated from a typical gabbro gave angles of extinction answering to a more basic labradorite. The specific gravity of the same isolated feldspar was 2.689, confirming the optical determination.

The feldspar from a typical Brandywine gabbro was separated by means of the Thoulet solution by Mr. J. S. Diller in the petrographical laboratory of the U. S. Geological Survey, and analyzed by Mr. R. B. Riggs, with the following result:

SiO_2 = silica	51.44
Al_2O_3 = alumina	30.05
Fe_2O_3 = ferric oxide (FeO not det.)	.96
CaO = lime	13.19
MgO = magnesia	trace.
Na_2O = soda	4.07
K_2O = potash	.21
Loss on ignition	.35
	100.27

Dried at 105° C.

This answers to the most basic member of the labradorite group and to a feldspar having the theoretical composition $Ab_1\ An_2$.

An examination of a number of cleavage fragments extracted from the feldspars of many of the coarser gabbros will show these feldspars to vary somewhat, which we could scarcely expect to be otherwise, in view of the great variation in the character of the iron-bearing silicates and in the proportion of quartz. This is illustrated most forcibly in the case of the more acid biotite-bearing gabbros, rocks similar to those which elsewhere have been styled *norites*. A typical sample of this rock was also treated by Mr. Diller, and the feldspar separated in the usual way from the ferruginous silicates. An analysis of the feldspar gave the result shown below, in column I:

	I.	II.
SiO_2 = silica	70.37	64.12
Al_2O_3 = alumina	18.36	24.76
Fe_2O_3 = ferric oxide (FeO not det.)	.58	.....
MnO = manganese oxide	trace.	.....
CaO = lime	5.08	5.44
MgO = magnesia	.04	.....
Na_2O = soda	4.32	5.68
K_2O = potash	.63	.....
H_2O = water	.45	.....
	99.83	100

Dried at 105° C.

Column II gives theoretical composition of a feldspar having the formula $Ab_3\ An_1$, answering to oligoclase.

If in column I the .63 per cent. of potash be assumed as replacing some of the soda, the ratio between soda and lime becomes more accordant in I and II.

In Column I the excess of silica above that required to form the feldspar molecule is represented by quartz which this specimen is known to contain, but which could not easily be separated from the feldspar owing to the little difference in the specific gravity of the two minerals. The small amount of iron present is undoubtedly represented by inclusions of magnetite dust, which all the feldspars contain. On the supposition that the small amount of water in the analysis represents some kaolin, the amount of alumina in the analysis is thus slightly abnormal, but this will be fully counteracted by the opposite tendency of foreign matter to lower the alumina percentage.

Neglecting these small amounts, and adding proportionately the excess of silica to the alumina, lime and soda in column I, we get a result nearly in accord with column II.

An optical examination of a number of cleavage leaflets detached by a penknife showed in all cases for sections parallel to 0 P, an extinction so nearly parallel to the twinning bands as to make the less basic character of the feldspar plain. Sections parallel to ∞ P $\breve{\infty}$ gave with reference to the cleavage an extinction angle of $+5^{\circ}$. The specific gravity of these fragments was 2.635.

Thus we are led to believe that the more acid biotite-bearing gabbros contain at least as an accessory constituent the species oligoclase. Upon the whole the facts seem to strengthen forcibly the presumption that as our gabbros become more acid the feldspars also assume the more acid types. We shall furthermore see as we proceed that the hornblendic gabbro-diorites have a tendency in the opposite direction, the feldspar in the Iron Hill rocks being clearly anorthite.

Notwithstanding these variations, a notable fact is the uniformity of micro-structure observed in all the feldspars from one end of the belt to the other. They are quite similar to those found so characteristically in other gabbro-feldspars.

These consist largely of black opaque needles of clear definition and of remarkable straightness, which, as they become wider, show generally an oblique termination at each end.

These run into elongated prisms or columns of a brownish color, similarly truncated, the longer axis of which, however, seems to bear no constant ratio to the shorter; the longer ones passing into those with nearly rhombic section. With these we find again similarly shaped prisms and rhombic sections of a black color and highly metallic character. The dust-like particles which everywhere occur as cloudy patches near the center of the feldspar individuals or arranged in bands coincident with the twinning lamellæ are made up of the shorter needles which merge into mere specks, or again of extremely minute crystals or irregular particles of a black, metallic character.

All the inclusions show a definite arrangement in parallel systems, of which there are commonly four, though sometimes only three. Of these, two show an arrangement parallel to the edge 0P ; ∞ P $\breve{\infty}$ and to the vertical axis. A section of triclinic feldspar, apparently parallel to the plane $\infty P \breve{\infty}$, showed distinct basal cleavage, approximately parallel to which was a definite arrangement of needles; but the system containing the greatest number of inclusions was that forming an angle of 110° with the cleavage, i. e., nearly parallel to the vertical axis. Sections more or less parallel to 0P show an arrangement nearly parallel to the twinning traces, with another at right angles to the same. These two systems are again crossed by two other sets, perpendicular to each other, and forming with the first two sets angles from 20° to 25°. The character and arrangement of these inclusions are best shown in Fig. 1.

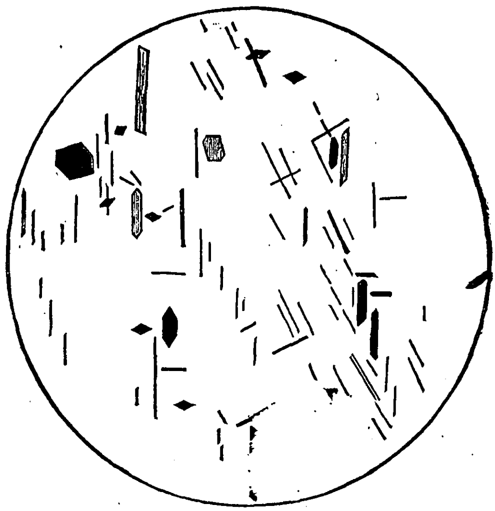

FIG. 1.—Inclusions within feldspar of hypersthene-gabbro.

Besides these, the feldspars are everywhere full of inclosures of foreign minerals, including rectangular crystals and dust-like particles of magnetite, well formed crystals of brown hornblende, and traces of biotite and pyroxene. In a few cases they contain very minute elliptical or elongated inclusions, with darkly defined borders, arranged linearly, without bubbles, and similar to gas pores. These are scarcely more than .001^{mm} in diameter; associated with them are elliptical or greatly elongated tapering glass inclusions of a light brown, sometimes greenish color.

Magnetite is a very constant constituent of all the Delaware rocks, occurring frequently in such large amounts as to nearly or quite equal the pyroxene. It occurs as grains and dust-like particles from .02 to .4^{mm} in diameter. With reflected light it is found associated in many cases with pyrite. It shows no decomposition into leucoxene, while a careful test gave only a slight reaction for titanium; hence it is probably a true magnetite.

Apatite occurs as prismatic and cross-sections, more generally as inclusions within the feldspars, also frequently within the hornblende and the pyroxene. It contains in many cases an abundance of inclusions. These consist (a) of long transparent needles or prisms, frequently etched or corroded, at other times intact, centrally arranged parallel to the longest development of the inclosing substance; (b) black, opaque granules in elongated or irregular forms, such as so commonly occur within the feldspars, possibly ilmenite—these occur fully within the apatite, at other times partly or nearly penetrating one end or side of the same. In a few cases the apatite crystals are corroded, owing apparently to the caustic action of the feldspathic liquid. In one case at hand the apatite prism has been cut entirely across in the center by a fissure, and the space has been filled with feldspathic matter; a little below this is another fissure which has so far eaten into the crystal as nearly to bisect it.

Quartz occurs as an important element of all our rocks. In the thinnest sections it gives clear colors and feeble polarization, and is easily recognized by its want of cleavage and by the appearance with converging polarized light of a uniaxial interference figure. It generally contains groups and lines of extremely minute, darkly defined inclusions, entirely free from bubbles, possibly gas pores. Less frequently are found inclusions with quiescent or feebly moving bubbles, which do not disappear on heating the stage to nearly 100° C.

Brown hornblende and *biotite* occur as accessories, by the increase of which the hypersthene-gabbro (A) merges indistinctly on the one hand into the gabbro-diorite (B) and on the other into the gabbro-granite (C). See table, p. 8.

Garnet is found as an accessory in rare instances.

The true gabbros occur most abundantly along the Brandywine and upon all the roads leading out from Wilmington. In these localities admirable exposures are found in numerous quarries, and upon the particularly rocky picturesque slopes of the Brandywine Valley. Northwest of the city, however, the rocks become distinctly hornblendic and exhibit the various varieties of gabbro-diorite; northeast in Brandywine Hundred the rocks are associated with those acid forms which we have here for convenience termed gabbro-granites, although the two are never separated by any closely drawn structural lines.

GABBRO-DIORITE.

This name is given to those rocks which represent an extreme stage in the variation of the normal gabbro. Brown hornblende is known to occur as an accessory constituent of true gabbro, but some phases of the Delaware rocks show a peculiarly large admixture of this mineral, which becomes even of such importance as to more than equal the pyroxenic matter.

In extreme cases, again, the rock consists mainly of a mixture of brown hornblende and plagioclase, with pyroxene in but a trace. In short, we find every stage between the massive gabbro and a rock which is apparently a hornblende gneiss, making, as a consequence, a proper designation of the rocks difficult. Many types described under this head might strictly be placed with gabbros, others might be placed with hornblende gneisses or amphibolites, the rock possessing upon the whole a union of gabbro and diorite characters, for which reason the term gabbro-diorite is adopted only as a convenient one in the present instance, without attempting to add to the already burdened rock nomenclature. In hardly a single case, so far discovered, has the progress to more and more highly dioritic forms resulted in an entire absence of pyroxene; on the other hand, most of the forms presenting in the field all the characters of a hornblende gneiss or an amphibolite, contain pyroxene in such an amount as to make the rocks from microscopic examination no more strictly amphibolites than gabbros, but rather standing intermediate between the two, and thus the term in many cases is a natural one.

The extreme type of the gabbro-diorite is a black rock with a satiny lustre, showing generally a high degree of foliation; other transitional types show an obscure foliation, which serves to connect structurally the foregoing rocks with the massive gabbros. The hypersthene and the diallage of this rock are identical with the preceding. The feldspar gives somewhat higher angles of extinction, in the more extreme forms of this rock, approaching anorthite. It contains, however, the same characteristic inclusions and is apparently identical.

The hornblende occurs in large irregular grains. They have a greenish brown color in ordinary light and show powerful dichroic properties. Sections transverse to the vertical axis with the prismatic cleavage well developed give for the $\mathfrak{a}$ ray a deep yellow, and for the $\mathfrak{b}$ ray a deep brown with powerful absorption. Many longitudinal sections show no perceptible change of color or absorption upon revolving the stage over the polarizer; these are presumably sections approximately or quite parallel to the orthopinacoid ($\infty P \bar{\infty}$), and give the color and absorption of the $\mathfrak{b}$ and $\mathfrak{c}$ rays. The mineral is therefore *dichroic* and of the variety known as *basaltic*.

The absorption formula is, as usual, $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$.

The mineral offers no notable characters except that it is unusually filled in many cases with inclusions of magnetite, which commonly in prismatic sections show an arrangement parallel to the cleavage. With these are found crystals of apatite, dust-like particles and symmetrical or irregularly shaped needles placed parallel to the vertical axis. A cleavage section of the brown hornblende parallel to the prismatic face gave an extinction angle c to $\mathfrak{c}$ of 19°. Magnetite, pyrite, apatite, quartz and biotite occur as accessories of the gabbro-diorite (B, p. 8).

The relation which the hornblende bears to the pyroxene makes it probable that both consolidated out of a more or less molten magma; while it seems that in many cases the pyroxene consolidated first, it is equally true that pyroxene individuals in many cases must have formed around hornblende particles, since grains of both hypersthene and green pyroxene, giving uniform optical orientation, are seen to inclose large and small grains of brown hornblende. If we can accept the well known theory that hornblende and pyroxene are only two different crystalline forms of the same substance, determined by different physical conditions at the moment of consolidation, such as temperature and possibly rate of cooling, we might venture in this connection to suggest that the association of brown hornblende and pyroxene in these rocks might be accounted for by supposing these conditions to have been intermediate or oscillatory between those extremes, which in one case would produce a true gabbro and in another a true diorite. We have already intimated that the gradual increase of brown hornblende proceeding from a massive rock was also accompanied by the gradual assumption of a more schistose structure. That this structural change has been induced by pressure is quite probable, hence there would seem to be some relationship between pressure and the relative proportion of hornblende to pyroxene. Could we have abundant proof of the alteration of pyroxene to compact brown hornblende, which is possible in view of the late studies of Dr. G. H. Williams on the rocks of the Cortlandt series[1] and of Prof. R. D. Irving on the rocks of the northwest,[2] we would have a most natural explanation, especially since these rocks present similar structural changes from massive to schistose forms.

In an article by the late Dr. G. W. Hawes[3] we find a record of a rather doubtful instance of the alteration of pyroxene to compact brown hornblende in the occurrence of obscurely outlined inclosures of brown hornblende within pyroxene, the author remarking in support of his opinion that paramorphic alterations of this character might originate inwardly as well as outwardly. Thus in a like way do we find in the class of gabbro-diorites under consideration inclusions of hornblende with indistinct borders; but cases of this character unaccompanied by other evidences of paramorphism can hardly be considered as at all conclusive, consequently until further facts come to our notice we must regard this brown hornblende as original.

The distribution of the rocks of this class is by no means a definite one. Many of the exposures along the Brandywine show in places the imperfect development of a foliated character, these rocks in turn becoming more or less hornblendic. The northern and northwestern limits of the city of Wilmington are covered by eminently or obscurely foliated rocks containing both pyroxene and brown hornblende, and the same is true of all the exposures along the Concord and Lancaster turnpikes leading out from the city. Roughly speaking, a line drawn from Kiemensie station, on the Wilmington and Western Railroad, through

[1] Am. Jour. Sci., 3d series, vol. 28, 1884, pp. 259-268.
[2] Fifth Ann. Rep., U. S. Geol. Survey, 1885, pp. 175-242.
[3] Am. Jour. Sci., 3d series, vol. 12, 1876, p. 136.

the northern limits of the city of Wilmington to the Brandywine will serve as a boundary north of which the outcrops are of black foliated rocks of this class. However distinct this area may at first sight seem to be, it is discovered that in all these rocks the genetic connection with the massive gray gabbros is steadily maintained, and into these the rocks of this area indistinctly merge. Since the most interesting feature of the brown hornblende gabbro-diorites is the position which they hold as connecting links between massive gabbros and highly schistose hornblende gneisses, it will be profitable to describe in order a series of slides which reveal most clearly these transformations.

SERIES ILLUSTRATING TRANSFORMATIONS.

Brandywine Creek, Wilmington.—A dark gray rock of uniform structure, massive, and possessing in the field the characters of a true gabbro. Consists mainly of hypersthene and plagioclase nearly equally developed, with a small amount of brown hornblende. Diallage in but a trace. The hypersthene as irregular branching individuals .5^{mm} to .6^{mm}, which fill up the spaces between the feldspar and which inclose minute grains of plagioclase. Garnets in rectangular, isotropic crystals of a pinkish color. Quartz in a few small grains. Magnetite, apatite. The feldspars partly clouded by dust inclusions, and numerous minute crystals of brown hornblende.

Wilmington City Reservoir.—Rock black, as massive bowlders with obscure foliation, consists mostly of plagioclase with a small amount of hypersthene and a few particles of diallage; brown hornblende somewhat subordinate. Magnetite; apatite rare. The feldspars much clouded by dust inclusions. Quartz in small amount.

Henry Clay P. O. (Dupont's).—Rock black, with obscure foliation. Plagioclase the principal constituent, brown hornblende and hypersthene nearly equally represented. Diallage apparently absent. Quartz in several large grains. Magnetite; apatite.

Toll Gate, Kennot Turnpike.—Rock black, partly foliated, consists mostly of plagioclase with much quartz. The next element is brown hornblende with a little biotite; hypersthene in greatly subordinate amount. Diallage absent. Magnetite, pyrite, apatite.

Back of Old Alms House, Wilmington.—Rock black, thinly bedded, schistose, offering in the field all the characters of an amphibolite. The bisilicates somewhat in excess of the feldspar. Brown hornblende the chief bisilicate constituent, with less pyroxene represented about equally by hypersthene and diallage. Magnetite and apatite. This rock has the schistose character more strongly developed than the preceding, which is due to the relatively large proportion of bisilicate.

Kiemensie Station, Wilmington and Western Railroad.—A thinly bedded, highly foliated rock. Bisilicates considerably in excess of the feldspar, consisting of nearly equal parts of hypersthene and brown hornblende, and a small amount of characteristic diallage. Quartz in small amount. Magnetite scarce. The discovery of this rock is of particular interest, inasmuch as it forms a lenticular mass of highly foliated, thinly bedded hornblende rock between mica schists, along the north border of the main gabbro belt. A little farther north, and just below Brandywine Springs, is another outlying bed of gneiss, which is associated with a similar rock next to be described. Such facts as these enable us to assume with some probability that the outlying, lenticular masses of amphibolite within the mica schists are not to be separated in nature or in origin from the hornblende rocks of the larger area to the south.

Just Below Brandywine Springs Station.—A black, aphanitic rock. Under crossed nicols the ground mass is seen to be made of minute quartz and plagioclase grains, 1^{mm} to 2^{mm} in diameter, in which are porphyritically developed large and small hypersthene individuals, and numerous crystals of garnet, several millimeters across. The hypersthene was of a yellowish color, visibly but not eminently pleochroic, yellow and copper red with distinct prismatic cleavage, many of these sections showing with concentrated polarized light a biaxial cross. The garnet occurs as rectangular pieces of a pinkish color, entirely isotropic and full of characteristic inclusions enclosed by individuals of hypersthene. Brown hornblende in small amount. Magnetite rare. The feldspar highly basic, approaching anorthite.

Three miles north of Newport.—A black, semi-foliated rock, consisting of a nearly equal mixture of plagioclase and hornblende with but a trace of pyroxene, yet that little in well characterized fragments. The rock, therefore, represents the extreme stage of variation, and is properly a hornblende gneiss. The hornblende offers peculiarities; it is visibly trichroic, but not so strongly so as is characteristic of the green. The color of the $\mathfrak{c}$ ray is a dark green; that of the $\mathfrak{b}$ varies from a brown, quite like that of the basaltic variety to a greenish brown; and that of the $\mathfrak{a}$ ray is a fine yellow. Absorption $c > b > a$. Sections approaching parallelism to the clinopinacoid gave extinction angles of about 15°. The hornblende, therefore, stands intermediate between the green and the brown, and is possibly indicative of an alteration of brown hornblende into the green variety. Magnetite in one large piece several millimeters across, full of beautiful included grains of plagioclase, also in smaller granules. The feldspars give high angles of extinction, and are probably either bytownite or anorthite.

Lancaster Pike and Wilmington and Northern Railroad.—Black, fine-grained rocks in association with coarser varieties; thinly bedded and schistose, although less strongly so than the intimately related coarser rocks, showing the feeble effects of pressure in developing a schistose structure in such aphanitic rocks, notwithstanding the large amount of hornblende. The principal constituent of the rocks is brown hornblende with somewhat less plagioclase. Hypersthene and green pyroxene in but small amount. Magnetite, pyrite, apatite.

GABBRO-GRANITE.

Another accessory constituent of the normal gabbro (A) is biotite, which gradually increases in amount so as nearly or quite to equal the pyroxene. This particular phase of the Delaware rocks, as already intimated, is furthermore accompanied by much quartz, so that the rocks become of an abnormal type, possessing in a strange degree a mixture of granitic and gabbro characters. So peculiar is this feature of Delaware petrography that it seems best, for want of a better term, to designate these extreme types as *gabbro-granites*. We find all stages of transition from the typical form of this rock to those with but a trace of biotite, and in the other direction to those which are nearly true granites.

The biotite occurs generally as oblong blades, showing the usual basal cleavage and extinction of light parallel to the longest development; also as scales parallel to 0P. All prismatic sections show strong pleochroism, i. e., a light yellow color and weak absorption for rays vibrating perpendicular to the cleavage or parallel to $\mathfrak{a}$, and a deep brown with powerful absorption for rays parallel to the direction of cleavage. Sections parallel to 0P give, as usual, but little variation of color or absorption.

The biotite frequently contains as inclusions apatite crystals and grains of magnetite; otherwise poor. Magnetite also generally in intimate association or contact with biotite, but never in borders around the latter. The biotite commonly shows those mechanical deformations so characteristic, i. e., a bending and twisting of the lamellæ. The relation of the biotite to the other minerals shows that it must have consolidated before the other magnesian silicates, but subsequent to the consolidation of the feldspar.

The plagioclase from several measurements on sections parallel to 0P corresponds probably to labradorite, with it, and possibly replacing it in some cases. The less basic oligoclase can be proven to exist, as shown by examination of a number of cleavage fragments extracted from the coarser hand specimens. The feldspars in all cases contain the same characteristic inclusions already described. The highly micaceous rocks of Bellevue, which offer notably distinct characters, contain a greasy gray, coarsely crystallized feldspar. A cleavage leaflet of this mineral parallel to M (∞ P $\breve{\infty}$), as judged from the absence of twinning, gave with reference to the cleavage an extinction angle of —15°, and with concentrated polarized light the side appearance of an optic axis on the margin of the field. This would indicate a more acid labradorite in accord with the very acid character of these rocks. Quartz occurs in large amount in all the rocks of this class, several forms being largely a mixture of plagioclase and quartz, with little pyroxene or biotite; it is rich in liquid inclusions, with quiescent or feebly moving bubbles, which remain permanent at a temperature above 100° C. Most of the highly quartzose rocks of this class show the results of mechanical movements in a partial or an entire crushing of the more brittle quartz granules, protruding angles being commonly broken off, or again an entire side reduced to a mass of granules from the pressure exerted by surrounding larger individuals. Again, smaller fragile granules of feldspar wedged between large, tough, quartz masses have been partly or completely crushed. The rocks of this class cover all that region east of the Brandywine, and are found in such intimate association with the true gabbros as to render all attempts to accurately define their distribution quite ineffectual. As a rule, the gabbro-granites are massive, but assume a semi-foliated character whenever the biotite becomes an important constituent. In order to trace out the gradual passage from normal gabbro to those rocks of a highly granitic type it will be well to describe a few slides best illustrative of this point.

SERIES ILLUSTRATING TRANSFORMATIONS.

Characteristic Rock of the Brandywine Quarries.—Rock bluish black to gray, entirely massive. It consists primarily of a mixture of quartz and plagioclase, the former in large grains several millimeters in diameter, the latter in smaller particles. Bisilicates consist of hypersthene and diallage nearly equally represented, with biotite in small amount. Magnetite; apatite; the feldspar rich in inclusions.

Walnut Hill, Brandywine Hundred.—Rock bluish black, massive, much like the preceding, but contains a larger portion of bisilicates, which is mostly hypersthene with but a trace of diallage; biotite in small amount. Quartz rich in liquid inclusions; magnetite, apatite.

Concord Turnpike, two and one-fourth miles from Wilmington.—Rock dark-gray, massive, of a peculiar acid type, consisting essentially of a mixture of plagioclase and quartz, with scarcely more than a trace of biotite and pyroxene. Magnetite and apatite in small amounts.

Episcopal Church, Concord Turnpike, North of Talleyville.—Rock black, semi-foliated to massive, consists mostly of plagioclase with much quartz; hypersthene and diallage with a little biotite; magnetite.

Silver Brook Station, Wilmington and Northern Railroad.—Rock may be taken as an average type of this class, presenting an equal combination of granitic and gabbro characters. Plagioclase is the principal constituent, with which is a smaller amount of hypersthene; diallage and biotite about equally represented. Quartz in a number of large grains; brown hornblende in small amount; magnetite, apatite.

Talleyville, Concord Turnpike.—Rock much like preceding, except that it contains a little less pyroxenic matter than biotite. Quartz rich in inclusions of apatite and liquid cavities.

Bellevue, Del.—A black, thinly bedded, schistose rock, presenting a strong contrast to the massive gabbro-granites with which it is associated; it contains a much larger proportion of biotite and pyroxene to feldspar than any of the other rocks of this type. Upon a superficial examination in the field it might be mistaken for an amphibolite, but under the microscope it is not to be separated from the highly massive gabbro-granites already described, except in the relative proportion between plagioclase and the other constituents. The rock is of special interest in showing the effects of pressure in causing a schistose structure in highly basic rocks, and its notably lesser effect upon the highly acidic rocks with which it is associated. It consists primarily of a mixture of hypersthene and biotite, and a somewhat less amount of plagioclase. Magnetite abundant; apatite, the feldspars unusually rich in characteristic inclusions.

In this locality, as in many others, the rocky faces of a light, coarse-grained trap appear streaked and beclouded by lenticular and most irregularly shaped segregations of a much darker fine-grained rock. These are found to be due to local variations in the relative proportion between feldspar and the iron-bearing silicates. This section, which is a type, is practically identical with the latter, but while the preceding rock covers a large area, the present type occurs as included masses whose dimensions are measured in inches; the cases, however, are parallel and show the great tendency of this rock to variation within very limited areas. The rock consists mainly of a mixture of hypersthene and biotite, with a somewhat less amount of plagioclase; diallage in very small amount; magnetite. Long, characteristic needles of zoisite richly developed in the feldspars; apatite in stout prisms; acicular inclusions abundant.

Characteristic Rock of the Bellevue Quarries.—A coarsely crystalline rock of a bluish to greasy gray color, which in hand specimens appears to be a granite, consisting of a mixture of greasy, gray labradorite, bluish quartz and biotite. It is usually quite massive, but shows in places in the large quarry walls an imperfect foliation. Under the microscope plagioclase and quartz predominate; biotite in subordinate amount; hypersthene, scarcely more than a trace. Magnetite and apatite rare. The quartz is rich in inclusions; these consist of darkly bordered cavities without bubbles, arranged linearly and in groups, with many reddish brown inclusions, probably of glass, elliptical or elongated with tapering ends, acicular or imperfectly hexagonal. The quartz also contains numerous black hair-like needles, possibly rutile.

NORITE.

Nothing is more variable than the exact shade of color which the massive rocks assume, dependent upon the relative proportion between feldspar and the bisilicates; thus the light gray norites are found in all stages of graduation into the bluish black gabbros, with which they are associated. As a rule the rock is highly quartzose, containing veins and lens-shaped masses of this substance developed within the body of the rock. In the field these are readily recognized by their light gray or dirty white colors, which, in extreme cases, stand in strong contrast to the dark gray or bluish black colors of their associated rocks.

A typical section under examination is composed mainly of a very fine-grained mixture of quartz and plagioclase, which, in hand specimens, appears quite homogeneous; in this ground-mass are porphyritically developed larger grains of hypersthene and magnetite, with generally a few shreds of biotite.

The rocks are invariably massive, although in one prominent case along the Brandywine, a true norite lies adjacent to a highly schistose hornblende gneiss, while the passage from one to the other through darker gabbros is so gradual as to be indistinguishable. That these norites have been subjected to great pressure at one time or another, is evidenced by the nearly complete crushing of the quartz granules and the associated plagioclase, no rocks exhibiting stronger evidence of mechanical action than these.

The norites are found in such intimate association with the darker gabbros that it is quite impossible to restrict their distribution. Along the Brandywine are frequent alternations of lighter and darker trap, while over the whole of Brandywine Hundred one meets with outcropping bowlders truly characteristic of the rocks of this class.

THE IRON HILL GABBROS AND GABBRO DIORITES.

In macroscopical and structural characters the hypersthene rocks and diorites of Iron, Chestnut and Red hills seem to be quite distinct from those already described. That this difference, however, is more apparent than real, is shown by microscopic studies, which lead us to regard those under consideration as but modified forms of the finer grained, more acid gabbros of Wilmington. The Iron Hill rocks are essentially coarse-grained mixtures of triclinic feldspar and hypersthene, with a greenish diallage in variable amounts. They seem to be nearly or entirely free from quartz, and, so far as studies have been carried, of the basaltic variety of hornblende, but they contain a large amount of a green, paramorphic hornblende which, by entirely replacing the pyroxene, causes the rock to run into true diorites, with which it is found in the most intimate association. In the field, the rock generally possesses a very characteristic purplish gray color, and is sometimes so coarse as to yield large paramorphic crystals of a grayish, fibrous mineral, several inches in length, which have the physical properties of fibrous hornblende, but the cleavage angle of hypersthene. Microscopic examination proves these secondary crystals to contain cores of hypersthene, with fibrous hornblende as borders around them. The process of alteration of hypersthene to green hornblende is by no means a uniform one, but the most common method is as follows: A single individual of hypersthene becomes surrounded by a fringe of colorless fibres, probably tremolitic, which, on the outer border becomes bluish green to green. These last highly colored needles sometimes show but slight pleochroism, again, distinct bluish to yellowish colors. Under crossed nicols the whole fringe shows the most brilliant aggregate polarization, revealing fibres sometimes placed in radiating tufts, at other times perpendicular to the periphery of the hypersthene nucleus; while again, the white fibres of tremolite form a most confused arrangement. Later stages in the process show the gradual encroachment of this fibrous tremolite upon the hypersthene until finally it takes entire possession of the latter; thus we have in many sections cores consisting of a mass of tremolitic fibres surrounded by borders more or less deep of green hornblende needles.

Another stage in the paramorphism consists in the gradual deepening of the border of green hornblende aggregates until, finally, it takes entire possession of the secondary tremolite. Furthermore, there is a marked tendency of the fringes or cores of hornblende aggregates to assume a more compact nature, either upon the outer border or by the appearance of irregular nuclei within the body of the fibrous hornblende individuals. Thus we find in the last stage, individuals of perfectly compact green hornblende with only the remains of small nuclei of green hornblende aggregates within the latter. So abundant and complete are the various stages of paramorphism in the relatively few thin sections which have been prepared that no link in the chain needs to be supplied by the imagination, and everything points to the gradual transformation of one mineral into another. Fig. 2 shows an early

FIG. 2.—Section illustrating the alteration of hypersthene into tremolite and fibrous green hornblende.

stage in this process of paramorphism. In the large piece a core of copper red, highly pleochroic hypersthene lies buried in a white substance which, under crossed nicols, is shown to consist of a dense mass of tremolitic fibres, yielding brilliant polarization colors. The shaded portion surrounding the white tremolite is composed of dark green hornblende fibres, giving aggregate polarization and rather feeble pleochroism. The large amount of magnetite, shown in the figure by the black granules, is a common associate of the secondary hornblende, being undoubtedly a separation product from the highly ferruginous hypersthene. In the paramorphic process just described the alteration has been entirely an outward one, the original hypersthene retaining its fresh appearance within the envelope of secondary matter; in many cases again, the hypersthene assumes a peculiarly fibrous character, while still retaining the characteristic pleochroism and parallel extinction of ordinary hypersthene. Between crossed nicols it is seen that this appearance is due to the development along the cleavage fissures of brightly polarizing fibres, which stand out prominently in brilliant colors when the cleavage lines of the hypersthene coincide with the plane of vibration of the light, in which position the hypersthene is dark. The nature of these inwardly developing fibres is not so evident in the early stages as when the original hypersthene becomes nearly or entirely replaced by aggregates of parallel white fibres, which, by polarizing identically with those in the loosely aggregated fringes, are probably tremolitic. Furthermore, this change rarely stands alone, but is accompanied by the usual outward fringing, the confusedly placed fibres of the latter often penetrating the original hypersthene. Sometimes the cores of white tremolite, instead of being made up of aggregates of fine threads, become more compact, and are composed of coarser fibres or columns placed parallel, which give angles of extinction from nearly 0° up to 15°, and in converging polarized light show the appearance of one optic axis which lies parallel to the cleavage line.[1] Furthermore, it must be mentioned that the fringes of green hornblende aggregates which surround the tremolite and hypersthene cores do not always consist of confusedly placed needles, but very commonly the green hornblende possesses a finely fibrous character similar to uralite. This finely fibrous hornblende possesses rather distinct pleochroism, i. e., bluish green and yellow, and gives between crossed nicols rather brilliant aggregate polarization. Unfortunately, the term *uralite* has generally been used in a rather ambiguous sense to indicate a substance which possesses the external form of augite but the cleavage and the optical properties of green hornblende, yet showing in addition a few special characters that, in the particular cases from which the current descriptions have been framed, are clear and unmistakable; in others, not so. Thus it is difficult to use the term *uralite* with that confidence with which others have used it. Suffice it to say, however, that the green hornblende aggregates which stand

[1] Rosenbusch; Mikroskopische Physiographie. Second edition. Vol. 1, 1885, p. 465.

between the original hypersthene and the final compact hornblende possess all the optical characters of green hornblende, and that the process is quite similar to that which is generally called *uralitization.*

The paramorphic process next to be described is one of particular interest, inasmuch as, in many respects, it is a novel one. In this case the hypersthene, instead of being changed into fine, loosely placed aggregates, passes into a more compact, green hornblende. The properties of this hornblende are generally distinct—its pleochroism is strong, with the usual blue, yellow and green colors characteristic of ordinary green hornblende. The customary cleavage is well developed, but there is an entire absence of that finely fibrous habit characteristic of uralite. The optical orientation is uniform, and altogether the mineral appears perfectly compact. It forms borders around the hypersthene *with the usual intervention of a layer of white tremolite.* These borders, which, with ordinary light, appear to continuously surround the pyroxene cores, are, between crossed nicols, sometimes found to be made up of differently orienting areas of a compact nature, or again, very commonly a uniform extinction of light takes place throughout the whole border.

Notwithstanding some misgivings as to the secondary nature of these hornblende borders, as opposed to the idea of parallel growths of two original substances, the evidence still remains strong, and is based upon the following considerations: First, the process is identical with the ordinary alteration into uralite even to the intervention of tremolite, these two processes showing intermediate stages where the same individual is in one portion partly surrounded by a compact border and in another altered into loosely placed aggregates. Second, there are found all stages in the transformation, from large individuals of hypersthene with narrow fringes, to those with but traces of cores within individuals of apparently compact green hornblende. Bearing further upon this alteration of hypersthene to apparently compact green hornblende, it is necessary to consider the alteration of a monoclinic pyroxene, which proceeds in a like manner. The mineral which has been identified as a monoclinic pyroxene occurs in irregular grains of a greenish gray color, with an eminent cleavage, and frequently possessing the finely striated appearance characteristic of diallage. It is entirely unpleochroic, and gives high angles of extinction approaching 45°. These individuals of diallage are generally surrounded by borders of compact green hornblende, whose relations to the pyroxene cores are such as to be quite convincing regarding their secondary nature.

The contact between the diallage and the green hornblende borders is generally quite irregular, tongues and shreds of green hornblende continuous from the latter commonly penetrating far into the original pyroxene, and in one case under observation passing entirely through the core to the other side. The line of contact between the original and the secondary minerals is in some cases quite clearly defined and sharp, in others a line of separation can scarcely be discovered with the highest powers. Accompanying this outward change there is observed the development within the pyroxene of numerous elongated inclusions of green hornblende, arranged generally parallel to the cleavage lines, and so covering the faces of the diallage sections as to give to the latter a peculiarly streaked appearance, often to the nearly complete replacement of the pyroxene. The outlines of these inclusions are indistinguishable with low powers (×75), in most cases, and their forms are very irregular, which, together with their number, renders an accurate delineation difficult. We have already mentioned an extension of the outer green border in the form of narrow tongues into the pyroxene substance; in a similar way we often observe tongues or necks of green hornblende connecting the outer border with some of the more irregular of these inclusions which spread and branch throughout the central nucleus. In Fig. 3 we have a typical case of this alteration of pyroxene.

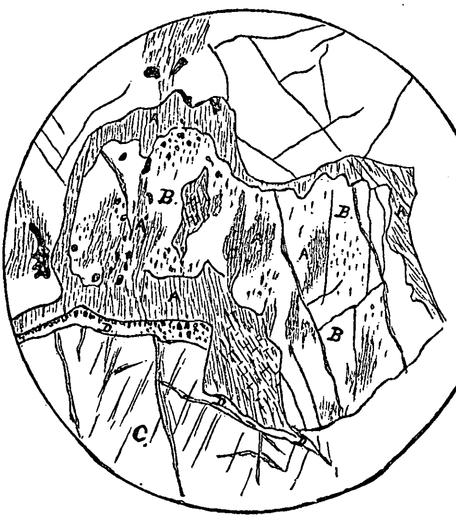

FIG. 3.—Section illustrating the alteration of diallage into compact green hornblende.

The central core of pyroxene (BBB) is of a greenish gray color with eminent cleavage, as shown in the figure. It is entirely devoid of pleochroism, and gives an extinction of 33°. The border of green hornblende which surrounds it is entirely compact, its pleochroism is strong, with bluish and yellow colors. Between crossed nicols the portion marked AAA extinguished light uniformly at the same instant, while the portion DD deviated from the first position of extinction but a few degrees. With the very sensitive quartz plate the whole border showed uniform polarization colors, and was in the strictest sense compact. Within the body of the pyroxene cores are seen the characteristic inclusions of green hornblende, which is undistinguishable from that on the outer margin; two of these are continuous with the border by clearly defined necks. The outlines of these inclusions are somewhat indistinct and not so clearly defined as the drawing must show; they shade gradually into the lighter pyroxene substance and on their borders fail to extinguish the light, but in their centers extinguish uniformly with the border, strongly testifying to the crystallographic identity of the two. The case of the alteration of diallage to compact green hornblende, which has just been described and figured, may be taken as a type of many others as observed in a study of the Iron Hill gabbros and gabbro diorites. Exactly similar cases in the Baltimore area have been described by Dr. G. H. Williams,[1] who regards these hornblende fringes and intergrowths as secondary; and in the Black Forest, by J. H. Kloos,[2] who regards them as original. In the example before us a great mass of evidence, as I believe, goes to favor the derivative nature of this compact hornblende, not alone because of the favoring facts which a single typical case can furnish, but partly because the study of a long series of thin sections reveals all stages in the passage from diallage to green hornblende, and this, therefore, weakens to a large degree the assumption that all these cases can be explained by any theory which implies an original crystallization of both minerals.

A change like this, involving the diallage, being, as I believe, the result of a molecular rearrangement more favorable to the lower temperature, may take place within the body of a diallage particle as well as upon its surface, and hence we observe in the rocks under consideration these two processes going hand in hand to the complete replacement of the original substance. What has already been written regarding the alteration of diallage to compact green hornblende can be brought as a further evidence regarding the secondary nature of those hornblende borders which surround the hypersthene, as the two kinds of hornblende occur together and are identical. It must be observed, however, that the process of paramorphism in the two cases is distinct. There has as yet been found no substantial proof of the direct alteration of hypersthene to compact green hornblende without the intervention of a colorless tremolite zone, and there is furthermore, as was observed by Dr. G. H. Williams, an entire absence in the body of the hypersthene of those obscurely defined green hornblende inclusions which so characterize the diallage; on the other hand, the change is an outward one in all cases, and as the same writer has admirably demonstrated, the hornblende appears to be due to a reaction between the hypersthene and the accompanying feldspar, the basic plagioclase furnishing the lime necessary to this change.

Regarding the paramorphism of diallage, it must be mentioned that while the method just described seems to be the most general one, there is also an alteration into true uralite similar to that affecting the hypersthene in so many instances. This consists in the gradual replacement of diallage particles by aggregates of light fibres, either

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[1] Bull. U. S. Geol. Survey, No. 28, 1886, p. 41.

[2] Neues Jahrbuch für Mineral., III Beilage-Band, pp. 24–34, 1885.

tremolite or actinolite, which in turn changes outwardly into a light green finely fibrous hornblende.

The feldspars of the Iron Hill gabbro-diorites are apparently somewhat more basic than those found in the more acid gabbros near Wilmington.

The feldspar in a typical sample of the rock was separated by Mr. Diller as follows: The iron magnesian silicates were first separated by means of the Thoulet solution having a specific gravity of 2.877. The separated feldspar was then put into a solution of 2.592 specific gravity, in which an orthoclase indicator was slowly raised to the surface. The feldspar, thus cleaned of any suspected orthoclase, proved from microscopic examination to contain much included matter; to remove this a solution of 2.749 specific gravity was used. It barely lifted the feldspar, allowing portions containing the inclusions to remain behind. The feldspar thus obtained has a specific gravity between 2.749 and 2.592, with most of it as heavy as 2.749.

An analysis of the feldspar, by Mr. Riggs, is given below.

	I.	II.
SiO_2 = silica	44.09	44.87
Al_2O_3 = alumina	35.41	35.66
Fe_2O_3 = ferric oxide (FeO not det.)	.51	.....
MnO = manganese oxide	trace.	.....
CaO = lime	18.47	—18.61
MgO = magnesia	none.	.....
Na_2O = soda	.99	.86
K_2O = potash	.19	.....
Loss on ignition	.35	.....
	100.01	100.00

Column No. II gives the theoretical composition of a feldspar with the formula $Ab_1 An_{12}$. The mineral is therefore an intermediate member of the anorthite series, and is considerably more basic than the analyses of the feldspars separated from the acid gabbros indicate. A cleavage section of an Iron Hill gabbro-diorite feldspar was detached; it gave an extinction angle with the cleavage of $-35°$ and had a specific gravity of 2.745, both answering again to anorthite. The development of inclusions within the feldspars is a notable feature of these rocks; these dust particles often so cover the twinning lamellæ as to make them appear like a series of parallel black bands, separated by lines of light coincident with the twinning traces; again, short opaque needles occur in abundance, but there seems to be an absence of those brownish prisms so characteristic of other feldspars.

The hypersthene and the diallage show the same micro-structure already described, and frequently the former mineral contains a number of light brown inclusions arranged parallel to the vertical axis, similar to those which in other hypersthenes are regarded as brookite.

DIORITE.

To draw a distinct line between this type and the foregoing upon petrographical considerations is quite impossible; the distinction is more properly a structural one, standing as it does quite apart in macroscopical characters. The main mass of a series of elevations, of which Iron Hill is the most prominent, consists of a fine-grained, greenish-black rock, from which all traces of pyroxene have disappeared, the one bisilicate consisting of amphibole, either the colorless tremolite or the fibrous green hornblende. As we should expect, the rock is an extreme form of the one already described, in which the hypersthene has nearly or entirely disappeared, and has been replaced by secondary tremolite and green hornblende. The less advanced stages of the rock show cores of tremolite fibres, giving between crossed nicols brilliant aggregate polarization, with these cores in turn surrounded by borders of greater or less thickness of green hornblende aggregates; other sections are entirely green, showing cores of green hornblende needles passing into the compact form. Fig. 4 represents an individual of

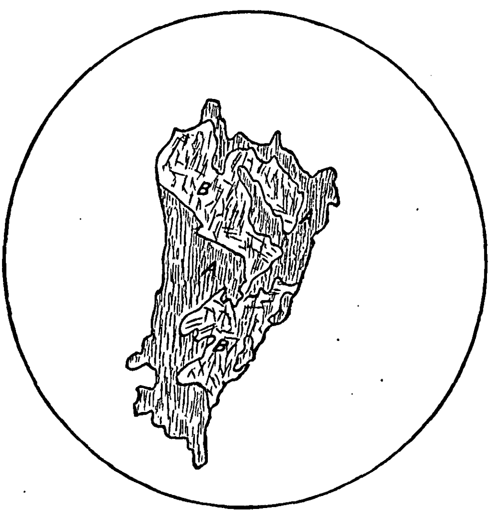

FIG. 4.—Section illustrating the alteration of fibrous into compact green hornblende.

hornblende which, with ordinary light, appears to be quite homogeneous; with the use of the polarizer alone the whole is distinctly pleochroic, but more uniformly so over the portions marked AA. Between crossed nicols this last portion AA, including all the areas in the figure correspondingly shaded, extinguishes uniformly, and appears to be perfectly compact; the portions marked BB show brilliant aggregate polarization and appear to be composed of irregularly placed needles of green hornblende, which, from their marked pleochroism, are probably the latter and not actinolite. The irregularity and indistinctness of this compact border, which a drawing can not well portray, leaves no doubt whatever of its secondary nature, and furnishes a typical instance of that final transformation which is everywhere observed. The feldspars of the typical diorites of this order are particularly notable for the number of colorless inclusions which they contain. These show an arrangement commonly parallel to the twinning traces, and again in patches which greatly obscure the feldspar; they have a definite crystalline form, and polarize strongly and distinctly from the feldspar which encloses them; in size they average $.01^{mm}$ by $.0075^{mm}$, many, however, measured near $.005^{mm}$ by $.0025^{mm}$. The forms of these can be seen in Fig. 5. On account of their minuteness the extinction

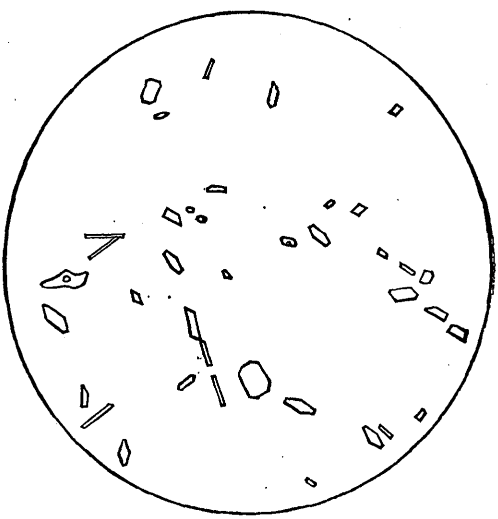

FIG. 5.—Inclusions within feldspar of Iron Hill gabbro.

could not be definitely determined, except that it was oblique to the prismatic edges. With these commonly occur numerous light green needles which, from their faint pleochroism, are probably actinolite. The feldspars of the highly paramorphosed diorites also show a notable alteration to epidote; the process, however, has seldom been carried beyond the formation of narrow fringes around ragged cores of plagioclase. In order, as before, to make still clearer the paramorphic tendencies already pointed out we will describe a series of sections.

SERIES ILLUSTRATING TRANSFORMATIONS.

Red Hill.—A coarse-grained purplish gray rock, consisting of a mixture of basic plagioclase, hypersthene, and diallage, showing an early stage in the transition to diorite. The hypersthene individuals, which are mostly large, and full of dark, acicular inclusions, are surrounded in the usual way by borders of tremolite and hornblende aggregates. In other cases individuals of hypersthene become surrounded by borders of perfectly compact green hornblende, with the usual intervention of a layer of white tremolite fibres. A light green diallage occurs in considerable amount, surrounded by the usual borders of compact hornblende, and full of obscurely defined green hornblende inclusions. Magnetite in large amount as a secondary product associated with the amphibole.

Road between Iron Hill and Sandy Bray.—Much unaltered hypersthene, and a light green pyroxene, with less plagioclase rich in inclusions. Both hypersthene and green pyroxene surrounded by borders of compact green hornblende with the usual characteristics. There is, however an entire absence of anything like uralite. The hypersthene rich in inclusions; magnetite as usual.

J. W. Dyett's.—Somewhat further paramorphosed than the latter. All the hypersthene in this section is much altered. The hypersthene individuals show all stages of passage into aggregates of whitish parallel fibers, yielding the brilliant aggregate polarization characteristic of tremolite. This change seems to take place along the cleavage fissures, as well as outwardly. Individuals of hypersthene in this section are found in all stages of passage into these tremolitic aggregates; these cores in turn altering outwardly into green hornblende needles, or into a finely fibrous green hornblende, the feldspars rich in dust-like inclusions; magnetite in small amount much altered to oxide of iron.

West end of Chestnut Hill.—This section shows ragged remnants of hypersthene imbedded in aggregates of tremolite fibers which are outwardly green. Green pyroxene individuals surrounded by borders of compact green hornblende, and much streaked by inclusions of the latter; magnetite in large amount as dust particles within the bisilicates; the feldspars much clouded by inclusions and partly decomposed.

Iron Hill.—Shows a somewhat more advanced stage than the latter, with only traces of hypersthene embedded in the tremolitic fibers which outwardly become green. Inclusions in the feldspars abundant; magnetite.

Just below Iron Hill Station.—This rock shows no trace of hypersthene, but several pieces of a quite fresh light green diallage, which is found in all stages of replacement by aggregates of parallel fibers of light color, surrounded by borders of a finely fibrous, green hornblende, or by aggregates of green hornblende needles. The feldspars are notable for the dense clouds of colorless inclusions which obscure the twinning. The feldspars have their edges greatly corroded and fringed with epidote; magnetite with pyrite in small amount.

Iron Hill, road to Whitaker's.—A still further stage in the process. The pyroxene has entirely disappeared, and been replaced by aggregates of white tremolite fibert which outwardly are green. The feldspar much clouded.

GABBRO-DIORITE AND HORNBLENDE GNEISS.

The normal gabbro is again found to merge by the addition of a green hornblende into the common hornblende rock of this region. The rock shows always a more or less perfect foliation, and has a black or greenish black color. Macroscopically it appears to consist entirely of hornblende, but thin sections show the presence of a considerable amount of basic plagioclase, also of either or both pyroxene elements; we have, therefore, adopted the term gabbro-diorite in this case, as in the others; where, however, the pyroxene becomes entirely replaced by green hornblende, the gabbro-diorites will merge into true hornblende gneisses. From massive gabbro to gneiss the same indistinct gradations are found, although in this case the structural change seems to more abrupt.

The hypersthene is identical with that in the normal gabbro; with it is associated a light green, nearly colorless, pyroxene, with the cleavage and other characters of diallage, occurring in large individuals several millimeters in diameter, of the same form as the green hornblende with which it is most intimately associated. It is the one pyroxene element in this variety of gabbro-diorite, hypersthene being found in but small amount, rarely in more than a trace. The green hornblende which is such an important constituent of these rocks occurs in irregular grains and elongated individuals, showing the usual prismatic cleavage; its pleochroism is strong but distinct from that observed in the basaltic variety. Cross sections, in which the cleavage fissures intersect at about 124° and 56°, give for the $\mathfrak{a}$ ray a light yellow, and for the $\mathfrak{b}$ ray a green.

Sections which show an extinction parallel to the cleavage lines, and therefore sections parallel to the zone 0 P : ∞ P $\bar{\infty}$; give the color of the $\mathfrak{c}$ ray, which is a bluish green; and with concentrated polarized light the appearance of one optic axis. A cleavage leaflet detached with a pen-knife and parallel to a prismatic face (∞ P) gave, with reference to the other prismatic cleavage fissures, an extinction between 14° and 15°. The green hornblende shows no notable characters; it commonly is quite full of included grains of magnetite arranged parallel to the cleavage lines, and of black, opaque, acicular inclusions similar to those found in the basaltic variety. The feldspars of these rocks give somewhat higher angles of extinction than the true gabbros, and probably upon the whole indicate a more basic form. Numerous measurements were made where alternate sets of twinning bands extinguish at equal angles on each side of the twinning traces, and the angles were all high, indicating a highly basic feldspar.

Cleavage fragments parallel to (0 P) were obtained from a typical Harmony Mill rock, and gave extinctions of –34° and –35°; the specific gravity of the fragments was 2.745. Similar cleavage fragments from a typical gabbro-diorite below Jessup and Moore's, on the Brandywine, gave extinction angles from –34° to –39° and a specific gravity of 2.737. Thus, in common with the Iron Hill gabbro-diorite, those of this class seem to contain, at least in the more extreme types, the basic anorthite. It will be well to repeat here that the more basic character of the feldspars is in accord with the fact that the rocks of this type always contain in addition to hornblende the lime-bearing pyroxene (diallage), almost to the exclusion of the magnesian silicate (hypersthene), and with the further fact that these rocks are poor in quartz. Magnetite and apatite occur in these rocks, but never in large amount; they are also less quartzose, although quartz is frequently found in small amount. The intimate association of diallage and green hornblende at once suggests the question whether the latter should be considered a secondary or an original substance. The evidence of the direct passage of diallage into compact green hornblende, which was so near at hand in the Iron Hill gabbros, is not so clear in this type of rocks. The study of particular thin sections might lead one to explain the intimate association of pyroxene and green hornblende on the supposition of parallel growth, while others would incline the observer to the view that the hornblende might be a secondary product from diallage; hence a most thorough comparison of many sections is the only safe ground for any conclusion. I am not therefore ready as yet to take any positive ground until further material shall have been collected and studied. It will be well, however, to weigh the evidence at hand and endeavor to explain the question in the light of all the facts.

In an examination of these rocks, after a study of the green hornblende gabbros, one is struck with the entire absence of continuous borders of green hornblende around the pyroxene. Inclusions of green hornblende within pyroxene, similar to those in the Iron Hill gabbro-diorites, are, however, common. These are, as a rule, very irregular in shape and so obscurely defined that even to high powers no well defined limit can be discovered. Their pleochroism is distinct, whereby they are placed in strong contrast to the inclosing unpleochroic diallage. At other times these included hornblende particles have such clearly-cut boundaries as to leave little doubt of their primary origin.

Similar instances of the intergrowth of hornblende with diallage have been described at various times by Kloos, Streng, Macpherson, and Rohrbach, who have differently regarded these intergrowths either as original or as secondary. The analytical results of Rohrbach[1] testify to a marked difference in composition after separation between the pyroxene and the hornblende, and he is led to believe in the original character of both substances. The studies of Williams[2] give somewhat different results, and render possible the existence of hornblende practically identical in composition with diallage.

It was my intention to make a similar chemical study upon some very promising material, but the press of work in the laboratory of the U. S. Geological Survey at Washington has hindered the forthcoming results. The true nature of the green hornblende intergrowths as seen so commonly in this variety of gabbro-diorite can only at best be conjectured. Those of a more obscure outline are linked in the closest manner, as seen by a comparative study of sections, with those so common to the Iron Hill rocks, and appear to form such an indissoluble part of the diallage substance as to scarcely be regarded as original crystallizations.

I have spoken of the absence of continuous borders around individuals of pyroxene; an outward alteration is, however, none the less apparent. In some cases a clearly defined isolated individual of diallage has one end replaced by compact, green hornblende. I was at first inclined to pass over these instances superficially, but as attention was more closely drawn to them the conviction became stronger that these were cases of alteration of pyroxene to hornblende. In a notable case in view an individual about 1^{mm} by 5^{mm} is shown as a clearly de-

[1] Ueber die Eruptivgesteine im Gebiete der Schlesisch-mährischen Kriedeformation: Tschermak's Mineralogische und Petrographische Mittheilungen, n. s., vol. 7, 1886, p. 24.

[2] Bull. U. S. Geol. Survey, No. 28, 1886, p. 44.

fined grain, which, crystallographically, can not be regarded as other than a unit. One end of this particle gives the color, pleochroism, etc., of the ordinary green hornblende, this hornblende substance extending also as a narrow, obscure border partly around the grain; the other end is of a lighter green color, totally unpleochroic, gives with reference to the cleavage a high angle of extinction, and is identical with the common green pyroxene of the section.

With a low power the two optically different portions shade indistinctly into each other; with the highest power no line of separation can be discovered. Between crossed nicols the green hornblende half gives uniform extinction where the color is deepest; where the two parts shade into each other and over the slightly pleochroic border of the diallage, no extinction occurs in any position; but at a point where the direction of vibration of the light makes a large angle about 38° with the cleavage, the inner portion of the diallage half of the individual extinguishes the ray and reveals two irregular nuclei of unaltered pyroxene, which surround a light green, faintly pleochroic substance.

Sometimes individuals which with ordinary light have the appearance of the common diallage show with the polarizer a faint pleochroism on the outer border. Between crossed nicols the compact center extinguishes uniformly, but the outer faintly pleochroic portion fails in any position to extinguish the light. Thus it seems that the pyroxene outwardly changes first into an optically obscure substance, which, consisting of a mixture of hornblende and diallage matter, gives no definite optical orientation. Furthermore, when the diallage appears outwardly to be replaced by compact green hornblende, it is generally separated from the uniformly orienting diallage by an intermediate zone of this last substance.

The perfectly fresh, compact nature of all the green hornblende is the strongest proof in favor of its original nature; the boundary lines of the individual grains are clear and well defined, and have not that ragged form so characteristic of secondary minerals. This, however, is in conformity with the facts favoring a theory of paramorphism. In all those cases where individuals of diallage show the hornblende pleochroism at one end or upon the border, the original boundaries of the diallage remain intact. This may be true of all paramorphic changes, which, as we understand, are merely molecular rearrangements, and imply none of those disintegrating influences which characterize pseudomorphic alterations, as in the case of the alteration of the hypersthene to green hornblende, where such a change requires a reaction between the original pyroxene and its adjacent lime-bearing feldspar.

Epidote.—A most important accessory of this variety of gabbro-diorite is the mineral epidote, which in certain instances occurs in such an amount as nearly to replace the feldspar. It occurs as colorless individuals, generally elongated columnnar, also granular, which have a high index of refraction, as shown by their darkly marked relief. As would be expected from the absence of color in the thin section, the mineral is entirely unpleochroic. The elongated prisms, as is usual with epidote, extinguish the ray parallel to the longest development. The cleavage is most eminent in the direction of the base (0 P), also parallel to the orthodiagonal ($\infty P \bar{\infty}$). One section showed two directions of cleavage, crossing each other at an angle of 115°, over which the light is extinguished for rays vibrating nearly parallel to the vertical cleavage, and at an angle of 25° with reference to the basal cleavage lines. Such a section as this can only be one of epidote nearly parallel to the clinopinacoid ($\infty P \grave{\infty}$).

As in the case of the Baltimore rocks the epidote is secondary from feldspar, the microscopic peculiarities being the same as figured and described by Dr. G. H. Williams. Granular individuals of epidote occur, in which cores of striated feldspar are found, whose outlines are so irregular and ragged as to leave little doubt as to their relations to the surrounding epidote. The secondary nature of the epidote is still further evidenced by the continuity of the cleavage lines of the feldspar across the epidote borders both above and below, and the extension of many of the twinning lamellæ with their marked interference colors for a certain distance beyond the limit of the feldspar cores, as determined with ordinary light. As shown by Williams, this alteration of feldspar to epidote is most frequent along the contact between a feldspar and a hornblende individual, the result of which is the corroding of both substances. A few slides show scarcely a grain of hornblende in its originally fresh condition, all the borders being highly etched and corroded into ragged forms, adjacent to which is invariably found the secondary epidote. This at once suggests the idea already advanced by Williams, that the epidote is due to a reaction between the feldspar and the hornblende, in which the hornblende took a far subordinate part, but a sufficient part to cause a considerable etching at points adjacent to the feldspar.

The gabbro-diorites and hornblende gneisses (F, p. 8) occupy a narrow belt which can be only roughly defined. Over the narrow tongue of rock which crosses the Brandywine at Jessup and Moore's, colored dark on the map, we have black schistose rocks, which to the eye appear to consist entirely of green hornblende, but under the microscope show a large amount of both hypersthene and diallage. Some hand specimens have a ground mass of hornblende and plagioclase, in which are porphyritically developed large bronze-colored crystals of hypersthene, and a light green foliated pyroxene. Farther to the west the same rocks outcrop back of the old almshouse in Wilmington. A section of this rock is typical of the class, i. e., thinly bedded schistose, with a slightly less amount of diallage than of green hornblende, and but a trace of hypersthene. Thence, in a direction due west, the rock occurs abundantly in the Wilmington and Northern Railroad cuttings. Again, on both the eastern and the western sides of Harmony Mills a diallage-green hornblende rock is abundantly exposed; this rock contains a variable amount of epidote which give the same a characteristic greenish color. Farther west again, at White Clay Creek church, exposures of this same rock occur, but with less pyroxene in proportion to hornblende. From here to Newark and beyond the continuity of the rock is apparent, although the pyroxene seems to be entirely replaced by green hornblende, and the gabbro-diorite becomes a true hornblende gneiss. Between Harmony Mills and Iron Hill the outcrops are all of a greenish massive rock, in which there is much secondary epidote.

STRUCTURAL RELATIONS.

THE GABBRO BELT.

As will be seen from the map (Pl. I) the great rock mass which forms the subject of the present study is club-shaped in general outline, widest in its northeastern part and gradually tapering to the southwest. It forms an orographic part of the "syenitic areas" of southeastern Pennsylvania, already described as regards their structural habits by Mr. C. E. Hall.[1] It also continues with more or less breaks into Maryland, and is largely similar to the gabbro in the neighborhood of Baltimore, described by Dr. G. H. Williams. It will be seen that to the west of Newark the gabbro belt tapers quite rapidly and loses itself between the mica-schists; this, however, is the only point where the micaceous rocks are found upon both the north and the south sides of the gabbro mass. On the other hand, for the main distance, the plastic clays, of possible Jurassic age, rest upon the southern flank of the gabbro, with the mica-schists either overlying or dipping below these rocks on the north. The topographical position of the rocks of this belt, especially westwardly, is such as in many cases to obscure their natural boundaries. Skirting the slope of the upland region of the State, which lies north of the horizontal Mesozoic clays, is a terrace of Quaternary gravel, already described by me,[2] which rises two hundred feet or more above tide, and from which the gravel spreads southward as a uniform sheet twenty-five feet in depth. This gravel deposit, covering as it does all older formations, offers at points but a limited opportunity for the exposure of the rocks of this belt, consequently in a few places the line can not be accurately drawn. The northern limit of this area from its western point to Newark can be clearly traced, the gravels passing below these rocks. From Newark the line is traced close to White Clay Creek, by frequent outcrops, to Roseville and Harmony Mills, on the Philadelphia and Baltimore Railroad, where a fine exposure of an epidotic diorite occurs

[1] Second Geol. Survey Pa., reports C 4 on Chester County, 1883, and C 5 on Delaware County, 1885.

[2] Am. Jour. Sci., 3d series, vol. 27, 1884, p. 189; vol. 29, p. 36.

in the railroad cut. From this point the gravels so cover the older formations that for a mile or more no outcrops occur until Milltown is reached, below which there is found a hornblende rock of this formation. From Milltown occasional outcrops of a greenish gabbro occur along the upper Wilmington road until at Green Bank and Kilmensie stations frequent exposures of gabbro-diorite are found as minor interstratifications between mica-schists. Green and brown hornblende rocks, all containing both of the pyroxene elements, are found again a short distance from the last place, with an abrupt turn of the line to the north, upon the Lancaster pike, near the "Oak Hill" school-house. Then again the contact between schists and gabbro is well exposed just below Greenville station, on the Wilmington and Northern Railroad; thence the line turns abruptly north, the contact again occurring at Dupont station, on the same road; from here the line keeps close to the road from Dupont's to Rockland; then it passes abruptly northeastwardly, crossing the Concord pike near William T. Talley's place, above the Episcopal chapel, running into Pennsylvania, joining the gabbros of Delaware County, as delineated by Mr. C. E. Hall in his map of Delaware County. The southern boundary of the gabbro belt is made still more indefinite by the covering of gravel. From the western end to Harmony Mills the outcrops are confined to a narrow belt scarcely more than a quarter of a mile wide. From Harmony Mills a neck of gabbro, outlined by the outcrop of occasional bowlders of a green massive diallage-hornblende rock, runs nearly due southwest, connecting this last place with the Iron Hill mass. The northern boundary of this rather obscure neck cuts the main road from Newark to the hill near J. W. Evans's place, whence it runs west by northwest along Christiana Creek to the Philadelphia, Wilmington and Baltimore Railroad; thence it curves slightly to the southwest, keeping close to the railroad, crossing the railroad below Iron Hill station. Here it bends again to the south, or close to the railroad, to a point just north of Elkton, where it curves around Red Hill, returning again about one-half mile south of the old Philadelphia, Wilmington and Baltimore turnpike, gradually approaching nearer this road along the south slope of Iron Hill and Sandy Bray, to Cooche's Bridge, where the line again becomes the indefinite south line of the neck referred to. From Harmony Mills to beyond the Red Clay Creek the southern limit of the belt is mainly outlined by tracing out the northern boundary of the Mesozoic clays, which appear in the railroad cut back of Stanton and again at Newport. Between Newport and the Wilmington and Northern Railroad gabbro-diorites appear north of the turnpike and beyond the railroad to the south of the turnpike, where they run into Wilmington, crossing the center of the city, appearing most conspicuously at the Brandywine Bridge. From this point the line curves rapidly to the southeast, cutting the Delaware River near Edgemoor station. The thick mantles of Mesozoic and Quaternary deposits probably deeply bury a portion of this gabbro mass, offering no opportunity to study its structural relationship on the south with other rocks possibly contemporaneous. That the gabbro is bounded on the south by the same mica-schists which occur to the north can only be inferred from analogy. We know that to the west of Newark the schists do occur both north and south of the gabbro belt, this exposure being due to the fact that beyond Newark the northern limit of the Mesozoic bends abruptly to the south, bringing the micaceous rocks nearer the surface. Furthermore it must be noticed that a number of lenticular bodies of gabbro-diorite have been found along the northern border of the main belt as included masses, rather than independent formations, and thus there is reason to believe that the main gabbro body bears a similar relationship to the great formation of micaceous rocks.

STRATIGRAPHY.

We have learned from a study of the various rock species and varieties that they may be divided into two classes from a structural point of view—the massive gabbros and the more or less schistose gabbro-diorites and hornblende gneisses. The portion more deeply colored upon the map is covered by a rock generally highly schistose, and containing a large amount of hornblende with a subordinate quantity of pyroxene, while the lighter portion is covered by the various varieties of massive gabbros, norites, and gabbro-granites. The boundary line between the two is of necessity general and somewhat arbitrary, since these two areas shade into each other quite indistinctly.

In this connection it must be understood that when one portion is spoken of as covered by schistose and the other as covered by massive rocks, reference is had only to their dominant features; in truth, we often find over the former area rocks perfectly massive including true gabbros, and in the latter area the local development of more or less schistose hornblende rocks. To demonstrate that the rocks of these structurally distinct regions are genetically one has been the aim of former petrographical work, while, at the same time, these results are confirmed in the field by a study of the contact between the rocks of the two areas at the excellent Brandywine exposures, where there is revealed a most gradual passage of massive gabbro into black schistose gabbro-diorite, instead of a stratigraphical break as might be looked for. So true is this, that it is impossible to define where one begins and the other ends. Therefore, as has been repeatedly urged, we can not regard the foliated hornblende rocks as metamorphosed sediments and the massive gabbro as a body of intruded "trap" of later origin, but that the whole formation belongs to an important class of altered eruptive rocks, so prominently brought to our notice of late, is far more probable.

In the region covered by the hornblende rocks both strike and dip can be made out with considerable accuracy. The latter, from the extreme western point of the belt to one near Milltown, is to the southeast at high angles. From Milltown onward the dip has been reversed to the northwest, the mica-schists in this case overlying the hornblende rocks and massive gabbros. The strike varies, but is generally within the limits of N. 40° to N. 60° E. In Delaware there is apparent conformity between the hornblende rocks and the mica-schists to the north. At Newark the hornblende gneiss dips with regular bedding to the south, the mica-schists pitching conformably beneath them; the strike for both is N. 55° to 60° E., dip 50° S. To the west of Newark the tongue of gneiss bears around slightly to the northwest, in conformity to which the inclosing mica schists have an average strike of N. 50° W. On both sides of the tongue the mica schists dip to the south, conformably inclosing the hornblende rocks. At Roseville the contact between the hornblende rock and the mica schist is not a distinct one as at Newark, but is marked by the occurrence of minor interstratifications of gneiss with schist. The same evident fusion of these two formations into each other occurs, as already pointed out, at Kiemensie station and at Brandywine Springs. Along the Wilmington and Northern Railroad, between Dupont and Adams stations, near Henry Dupont's place, the mica-schists strike N. 50° E., dip 55° N., and are deeply exposed in the cut. A short distance farther south is another fine exposure of the black hornblende rocks, which strike N. 62° E., dip 40° N. Considering the great variability in the position of these rocks within very narrow limits, equally noticeable at this point, it is not at all probable that here any unconformity can be said to exist, notwithstanding that the actual contact of the two formations is not visible. Farther north, at Jessup & Moore's paper-mill, no evidence of unconformity can be discovered; on the other hand, the positions of the rocks of both formations are the same.

I have looked carefully for any other evidence of bedding except that coincident with the cleavage, but have found none. The so-called "bottoms"[1] in Delaware County, Pa., described by Mr. C. E. Hall, could not distinctly be made out in Delaware. Planes which might be taken for these were irregular and not continuous, and correspond more to joints than to planes of bedding. The unconformity discovered by Mr. Hall in Delaware County between the "trappean" rocks and the mica schists has not the same chronological bearing, should we regard the gabbros and their associated hornblende rocks as intruded masses. Possibly, again, these so-called "bottoms," as Mr. Hall has suggested,[2] may exist, but so obscurely defined as to be unrecognizable, in which event all that we have said regarding an apparent conformity must be changed, and our gabbros and gabbro-diorites must bear the same structural relation to the mica-schists that Mr. Hall claims they have in Pennsyl-

[1] These "bottoms" are bedding planes, which cut across the cleavage of the mica-schists, and consequently have a much lower angle of dip than that indicated by the cleavage.

[2] Second Geological Survey, Pa., report 1885, Chap. 5, Part I, p. 3.

vania, even to the borders of Delaware. But, however this may be, the real nature of the gabbros and their associated rocks, irrespective of chronological position, is not affected, and as no attempt is here made to determine the last point, the facts bearing upon it have no special relation to the aim of our investigation.

It must be noted, however, that if we consider the true planes of bedding of the mica schists to lie nearly horizontal, then the thin outlying lenticular masses of gabbro-diorite at Kiemensie and at Brandywine Springs, which are apparently interbedded with micaceous rock, must be regarded more strongly than ever as intruded bodies, cutting across the stratification. That these rocks are of this character the author is strongly inclined to believe.

The gabbros are devoid of all stratigraphical form, and it is only the development of local masses of hornblende gabbro, or the appearance of an obscure foliation in occasional cases that enables us to discern anything substantial. Everything learned from a study of the extensive quarries of bluestone along the Brandywine points to the conclusion that the rock before us is as truly eruptive as any ancient trap whose origin is indisputable. Huge jointage planes cut the rock into massive columns with rhombic cross-section. These continue downward at high angles indefinitely with persistent regularity, except when broken off by irregular cracks which, independent of the regular direction of the jointage planes, cut up the rock into massive pieces of various sizes and shapes. The jointage planes include two parallel sets—those running normal to the direction of pressure and nearly parallel to the axis of the mass, and those whose north ends bear a little to the left of lines perpendicular to the first set.

THE ORIGIN AND GENETIC RELATIONSHIP OF THE GABBROS AND THEIR ASSOCIATED HORNBLENDE ROCKS.

Regarding the origin of the Delaware gabbros, two theories might be advanced—that which would regard them as highly metamorphosed sediments, and that which would consider them as metamorphosed eruptive rocks.

In considering the former view but little need be said. The opinion which has been advanced that the gabbros, variously called "syenites" and "diorites," were but the so-called metamorphoic hornblende gneisses more highly metamorphosed, is, I believe, entirely irrelevant. Such a change as this would involve the alteration of hornblende into pyroxene, an idea which probably never would have been advanced had the real nature of these massive rocks been understood. Pyroxene we are taught to regard as a product of direct igneous fusion, the hornblende arrangement of the molecules being more in accord with the conditions of ordinary metamorphic action; hence it is questionable whether, in any case, the more advanced stages of ordinary metamorphic action could ever result in the transformation of hornblende into pyroxene, or of a hornblende rock into a gabbro. On the other hand, we have had of late abundant and reliable instances where the alteration of pyroxene has occurred. The recent results from a large body of workers on both sides of the Atlantic, all go to explain the occurrence of schistose hornblende rocks in these instances to paramorphic or pseudomorphic changes affecting an original gabbro. Over the Delaware area the intimate association of pyroxene and hornblende rocks meets with an easy explanation from the facts set forth in previous pages, and the genetic unity of the two has been thoroughly revealed.

In the brown hornblende gabbro-diorites, which structurally possess all the characters of hornblende gneisses, we see this genetic unity admirably displayed in the gradual passage from massive to highly schistose forms, even a field study, without the use of a thin section, enabling us to trace forms which show all grades of semi-foliation, and which to the unaided eye show much hornblende in addition to pyroxene. In the Iron Hill gabbros we have seen the clear passage into dioritic forms through a two-fold alteration of hypersthene into uralite, and of monoclinic pyroxene into hornblende of the compact variety. In the Wilmington and the Harmony Mill green hornblende rocks an absolute proof of the origin of the hornblende from the green pyroxene is, as we have seen, impossible at this date; their genetic unity with the gabbros, however, is none the less evident from an equally gradual transformation from massive to schistose forms.

While it would be unwarrantable to make any detailed statement as to the exact origin of the Delaware gabbros, it is at least evident that they were at one time in a more or less molten state. This is particularly evinced by the occurrence within the quartz and the feldspar of what appear to be gas pores and glassy particles, and from the caustic action which a few of the earliest-formed minerals have suffered under the influence of none other than a molten liquid.[1] Thus we believe ourselves warranted in the assumption that all the rocks included in the scope of this paper were at one time molten; whether we regard this original magma as one truly gabbro in its nature or strongly dioritic through the presence of original hornblende. Supposing, then, the matter entering into these schistose-hornblende rocks to have been at one time molten, i. e., a true dioritic magma, the structural habit which they show we must regard as the result of some external secondary influence. This influence many geologists in like cases of late have attributed to pressure. That a powerful pressure affected the whole gabbro body is shown in many instances. In thin sections of the schistose gabbro-diorites and hornblende gneisses, which lie transverse to the plane of foliation, the effect of pressure is seen in a flattening and an elongation of both pyroxene and hornblende individuals, producing a structure similar to the so-called "flasser structure" of the German

[1] See observations on apatite crystal, op. cit., p. 13.

petrographers. Thin sections cut in these directions show a definite arrangement of the bisilicates, which appear as elongated particles whose greater axes are commonly six times the length of the shorter, these greater axes lying parallel to the planes of foliation, and at right angles to the directions of pressure. Not only have these individuals been pressed into flattened and elongated forms, but in some cases they appear bent, as shown by the curved positions of the cleavage lines and disturbances in the optical symmetry of the substance.

Quartz, wherever it occurs, commonly shows fracture—a marginal crushing—and sometimes an entire destruction, while the smaller grains of feldspar wedged in between the rigid quartz granules show also the results of mechanical action in crushing phenomena. That the pressure which, as I believe, has resulted in the structural change above mentioned, must have affected the whole gabbro mass, is shown by the occurrence within perfectly massive rocks of those highly schistose. The schistose forms of our gabbro derivatives may be grouped under two heads: First, including those varieties of gabbro-granite which contain a considerable amount of mica; and second, nearly all those rocks which contain a notable amount of hornblende, original or secondary, the degree of foliation bearing a direct ratio to the amount of hornblende.

It is a familiar fact that many truly eruptive granites merge into granitoid gneisses and into true gneisses by an increase of mica, the result of a normal variation. Exactly the same thing is observed in the study of the gabbro-granites, these rocks showing all degrees of semi-foliation. At Bellevue the prevailing rock is a coarse gabbro-granite containing about an equal mixture of hypersthene and mica. This rock is upon the whole quite massive, but shows in the quarry walls a continual tendency towards semi-foliation through increase of biotite with probably accompanying pressure. With it is associated a jet-black rock thinly bedded and highly schistose, which to general appearance seems to have no relationship with the former. A thin section, however, shows that this rock owes its black color to a large development of hypersthene and biotite, and its schistose structure to the relatively larger amount of biotite as contrasted with the highly quartzose and feldspathic rocks which surround them. That these massive rocks have been subjected to great pressure is shown by mechanical deformations in a crushing of the quartz and in an occasional bending of the mica laminæ. We must recognize, then, that the reason why the more highly micaceous rocks are more strongly foliated is not alone one of difference of composition, but because a given pressure was more capable of producing a structural change in rocks of this character than in the more quartzose and feldspathic forms associated with them.

The intimate association of schistose hornblende rock with massive gabbro is admirably revealed in the Brandywine section at Jessup &

Moore's paper-mill. A reference to the map will show a tapering of the area of schistose hornblende rocks running out into a tongue as it crosses the Brandywine. In the railroad cut below the paper-mill is an exposure of highly schistose thinly bedded green hornblende gabbro-diorite (F, p. 8), which upon either side gradually shades into a grayish perfectly massive gabbro without the least sign of any distinct line of separation between the two structurally different rocks. That these two structurally distinct rocks are genetically one is conclusively shown by an examination of a number of thin sections of each. How, then, are we to account for a schistose mass wedged between perfectly massive rocks? Not from an effective pressure in one case and its absence in another, but rather, as we can well see, because of the different effects which a given pressure will have upon rocks of different mineralogical characters. It is not that pressure has not affected our highly feldspathic and quartzose norites, but that pressure in these cases has been ineffective in producing a structural change—such rocks as these showing a crushing rather than a flattening of the mineral constituents. It would be difficult to prove conclusively whether the pressure which has resulted in the foliation of these rocks acted previous or subsequent to the consolidation. Writing of the Lizard gabbros of Pen Voose, near Landewednack,[1] J. J. H. Teall finds that in those places where the foliation is most eminently developed he sees exhibitions of profound earth movements; and such seems to be the view of Lossen and Lehmann, who consider these changes the result of great orographic or mountain-making influences, such as have affected consolidated rocks of all formations. The reverse dip in the eastern and in the western parts of the gabbro area, together with the twisted and contorted condition of the more highly foliated rocks in places, is proof that they have suffered the effects of orographic forces since consolidation.

The relation between pressure or foliation and paramorphic changes is not what would be looked for. Those hornblende rocks which show the foliation habit eminently developed, i. e., those which cover the darkly shaded area on the map, exclusive of the Iron Hill body, are the very ones in which we find an original brown hornblende or a green hornblende whose secondary nature can not be definitely established. The Iron Hill gabbro-diorites, in which the derivative nature of the hornblende is alone clear, show invariably a massive character. Many thin sections before the writer are taken from rocks strongly foliated, but with the hypersthene and diallage which they contain perfectly fresh and the brown hornblende apparently original. Such facts as these indicate that pressure is not in all cases sufficient to produce paramorphic changes, even though this pressure be great enough to cause structural alteration; and again that paramorphism may be eminently revealed where we have no evidence of the action of these mountain-building forces.

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[1] The metamorphosis of the Lizard Gabbros, J. J. H. Teall, Geol. Mag., decade 3, vol. 3, London, 1886, p. 488.

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