ART. XXXVIII.—*The Gabbros and Diorites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y.;*
by GEORGE H. WILLIAMS.

IN two former papers* I have described two types—peridotites and norites—which form members of that complex group of massive rocks occurring in the northwestern corner of Westchester County, N. Y., and designated by Prof. J. D. Dana as the "Cortlandt Series." The area occupied by these rocks—about twenty-five square miles in extent and nearly coincident

* This Journal, III, xxxi, Jan. 1886, p. 26; ib., xxxiii, Feb. and March, 1887, p. 135 and p. 191.

with Cortlandt township—is mainly composed of norite, the many varieties of which were described in my last paper. In the southeastern and southwestern corners of the township, as well as on Stony Point on the opposite side of the Hudson River, olivine-norites and peridotites are found, while at other localities, mostly in the southwestern portion of the area, still different but closely allied types of massive rocks occur. These, which form the subject of the present communication, are:—

Class III, Gabbro,
Class IV, Diorite,
Class V, Mica-Diorite.

These rocks are everywhere connected so closely by intermediate forms that they may, to a certain extent, be regarded as facies of the norite. Indeed, even in the types most widely removed from the prevailing rock hypersthene is very liable to recur. There are enough general resemblances and connecting links to join all the rocks of this series into a geological unit; and at the same time there are differences sufficient to show that many types were successively produced from the same igneous focus.

CLASS III. GABBRO (*von Buch.*)

1. *Gabbro proper.*—This rock is to be found at only a few isolated localities, of which the most representative is “Munger’s Corners,” a short distance west of Montrose Station on the N. Y. C. & H. R. R. Prof. Dana has designated this place as “g” on his map, and describes the occurrence as “a grayish white augitic rock.”* It is represented by several slides in both Prof. Dana’s and the Johns Hopkins University collection. (No. 42 and K, Mt. 13 (D)).

Under the microscope this rock appears as an aggregate of allotriomorphic plagioclase and augite grains. The latter mineral is of a reddish or grayish color, both often appearing in the same crystal individual. It is without pleochroism and frequently shows a pronounced orthopinacoidal parting. The substance of the augite or diallage is for the most part unaltered, although a little green uralite is occasionally developed. Accessory constituents in this rock are biotite, apatite, ilmenite and sphene. The last named mineral is quite abundantly represented in all sections and appears to have resulted from the alteration of the titanite iron.

The gabbro shows evidence of great dynamic action. The twinning lamellæ of the plagioclase are much curved and both

* This Journal, III, xx, p. 195, and p. 211, Sept. 1880.

the feldspar and the augite are often peripherally granulated by crushing and rubbing.

Another rock (No. 44) occurring at Centerville on the south side of Prof. Dana's limestone 4,* is in all respects identical with the gabbro at Munger's Corners.

The eruptive dykes which occur in such intimate association with the limestone at the southern end of Verplanck Point, are in part gabbros; in part mica- or hornblende diorites. No. 111, from one of the narrowest of these dikes, is quite like the gabbros last described, except that it is finer grained. Its augite also is more extensively changed to uralite. The thin section of this specimen includes some of the limestone in contact with the eruptive rock. This is altered by the metamorphic action into a granular aggregate of pale green pyroxene together with some pale hornblende and pleonaste.

2. *Mica-Gabbro*.—The presence of accessory biotite in the gabbros has been mentioned above; in some cases this mineral becomes so largely developed as to equal or even exceed the amount of augite present. Thus No. 109 and VK 5, of Prof. Dana's collection, both from dikes at Verplanck Point, differ only from the normal gabbro of this locality in the increased amount of biotite present. No. 45 also is only a biotite modification of the Centerville gabbro above mentioned.

The most interesting point in regard to the gabbros of the Cortlandt Area is that they always (so far as observations yet extend), *occur immediately beside limestone*. They seem to represent a local modification of the norite produced by an increase of lime, for this, as is well known, would change the orthorhombic magnesian hypersthene to a monoclinic pyroxene.

CLASS IV. DIORITE. (*Havy*.)

The hornblende, which imparts the essential character to this class of rocks, is compact and homogeneous in structure, possessing every appearance of a primary constituent. It occurs in allotriomorphic individuals which vary in size according to the coarseness of the rock grain. In the main this hornblende is identical with that already described at length from the hornblende-peridotite of Stony Point.† In some instances this hornblende contains the same delicate inclusions, while in others these are totally wanting. Its pleochroism is always strong, and its color either a deep chestnut brown or a bright green. More rarely it shows by transmitted light a color intermediate between these two.

* Vid. the map in Prof. Dana's article. This Journal, III, xx, p. 195, Sept., 1880.

† This Journal, III, xxxi, p. 31, Jan. 1886.

The two types of diorite produced by the presence of brown or of green hornblende are quite distinct both in their occurrence and relationships. The former is always associated with pyroxene rocks and tends to pass gradually into norite, gabbro, or pyroxenite; by a total loss of feldspar these diorites may also develop into massive hornblendites. The diorites composed of green hornblende, on the other hand, show their closest relationship to the mica-bearing rocks.

The grain of these diorites varies extremely, from aphanitic varieties to such as have hornblende individuals over six inches in length.

1. *Brown-hornblende-Diorite*.—This type is best developed in the wonderfully complicated net-work of massive rocks exposed on the river bank along the northern portion of Montrose Point. The brown diorite is most intimately associated with norite, and grades, on the one hand into this, and on the other into a massive brown hornblendite. The other constituents are triclinic feldspar (presumably the same *andesine* as occurs in the norites),* apatite and magnetite. Accessory hypersthene is common by which the diorite shows its tendency to grade into the norite.

The brown diorites extend, with exactly the same associations, eastward from Montrose Point nearly as far as Montrose Station, as is shown by a large number of sections in both the University and in Prof. Dana's collection. They were, however, not encountered in other parts of the Cortlandt Area.

2. *Hornblendite*.—Both coarse- and fine-grained aggregates of compact brown hornblende occur abundantly along the northern portion of Montrose Point. These rocks have a glistening black color and are most intimately associated with the norites, hyperites, diorites, and pyroxenites which also occur there. No more complicated interpenetration of eruptive rock-types could possibly be imagined than is displayed at this locality—every rock includes and forms dykes in every other; and at the same time every type passes by gradual changes in its mineralogical composition into every other one!

The striking examples of the passage by paramorphism of pyroxene into compact brown hornblende described some time since by the writer,† occur in rocks from Montrose Point intermediate between pyroxenite and hornblendite. The origin of the brown hornblende from both the diallage and the hypersthene is so apparent as to suggest the derivation of all the hornblendites by paramorphism from preëxistent pyroxenites.

* This Journal, III, xxxiii, p. 140, Feb., 1886.

† This Journal, III, xxviii, p. 261, et seq., Oct., 1884.

Specimen Mt. 7 of Prof. Dana's collection is interesting as illustrating the alterations which one of the coarser hornblendites from Montrose Point has undergone. The change of the brown hornblende is to serpentine and talc.

Hornblendite composed entirely of green hornblende is rare within the Cortlandt Area. It does, however, occur among the dykes intersecting the limestone at Verplanck Point, as shown in section VK.1. of Prof. Dana's collection.

3. *Green-hornblende-Diorite*.—Typical diorites of this class are not common in the Cortlandt Area. Those observed occur in narrow dykes on Montrose or Verplanck Points. These diorites which are wholly free from biotite always contain a hornblende, which, though it may properly be called green, has nevertheless a decidedly brownish tinge. On the whole the relationship of these rocks with the brown hornblende diorites is much closer than it is to those of the following class.

By far the most typical development of the green-hornblende diorites belonging to the "Cortlandt Series," occurs along the edge of the steep rock wall which extends westward from Cruger's Station, toward Montrose Point. This abrupt ascent marks the contact between the massive rocks and the softer, though much metamorphosed schists. These diorites, however, always carry a large amount of biotite and therefore are more properly classed as

4. *Mica-hornblende-Diorites*.—The association between this type and the pure mica-diorite (class V) is extremely intimate and there is everywhere observable a tendency toward the development of the latter rock by the total replacement of the hornblende by the biotite.

The most prominent microscopical peculiarity of these green diorites is their sudden and extreme alterations of grain; very coarse and fine varieties occurring side by side in the same exposure, in a manner unequalled in any other part of the entire Cortlandt Area. The best locality to observe this structure is just above the brick-sheds near Cruger's Station, at a point marked "*p*" on Professor Dana's map.*

The constant mineral constituents of these diorites are a finely striated plagioclase, green compact hornblende, biotite, magnetite, epidote and apatite. Less abundant are an unstriated feldspar (orthoclase) and quartz. Garnet is a frequent endo-metamorphic product near the contact of the diorite with the schists. The hornblende differs only in its color from the compact brown hornblende already described in other members of the "Cortlandt Series." It occurs in irregular individuals which are filled with magnetite inclusions. The color is a deep green, often inclining to bluish-green, and the pleochroism is very intense.

* Loc. cit.

All the other constituents of the coarse hornblende-mica-diorites of Cruger's Point are identical with those of the typical and more abundant mica-diorite. They may therefore best be described in connection with this rock (class V), of which indeed the type now under consideration is only a particular facies.

A very fine-grained variety of the hornblende-mica-diorite is quite common as a dike rock on both Montrose and Stony Points. In many respects this presents a resemblance to Rosenbusch's group of *dioritic lamprophyres* or *kersantites*, and yet its extreme freshness and freedom from calcite, the frequently granular form of the feldspar, and the association in nearly equal proportions of biotite and green hornblende while augite is wholly wanting, separate this rock from any of the many varieties of kersantite described in Rosenbusch's recent work. The fine-grained, dark-gray dikes of this rock may be most advantageously seen in the cuttings on the West Shore Railroad through and near Stony Point. Here they intersect the much contorted schists, the peridotite and the mica-diorite and afford the evidence upon which Professor Dana admitted the truly eruptive nature of at least the more basic members of the "Cortlandt Series." * These dikes are, however, shown by the microscope to belong to the more acid rather than to the more basic of the massive rocks.

CLASS V. MICA-DIORITE.

This rock is more uniform in its character than any other of the important members of the Cortlandt Series. It is in all cases essentially a rather coarse-grained aggregate of plagioclase and biotite, with accessory epidote, apatite and magnetite; often a little orthoclase and quartz; and sometimes garnet. The latter mineral is an endo-metamorphic product, and is to be found only near the contact with the schists.

The mica-diorite occurs only in the south-western part of the Cortlandt area; on the east side of the Hudson River west of Cruger's station, and on the west side at Stony Point (see map in my paper on the Cortlandt Peridotite, this Journal, Jan., 1886, p. 29).

No such pure type of mica-diorite† has ever, to my knowledge, been described from any locality.

* This Journal, III, xxviii, p. 384, Nov., 1884.

† Professor J. D. Dana called this rock *soda-granite*, (this Journal, III, xx, p. 198), and later *hemi-diorite*, (ib., xxv, p. 478). The first name was proposed by Haughton in 1856 to designate, as it still does, a true granite in which the soda is in excess of the potash, (cf. A. Gerhard, Neues Jahrb. für Min., etc., 1887, II,

I have as yet been unable to secure a complete analysis of this rock, but an average of four determinations of its silica gives 53.94 per cent. This is sufficient of itself to establish the dioritic nature of the rock.

The feldspathic constituent varies considerably in composition as may be seen from the different extinction-angles occurring even in the same individual; nevertheless a number of specific gravity determinations, lying between 2.67 and 2.648, show that the mineral belongs to the oligoclase-andesine series. Some of this plagioclase is notable for being almost free from twinning striation. This is especially true for section No. 87, from Stony Point, whose feldspar was particularly studied. In other cases the striation is finely displayed, not infrequently according to both the albite and pericline laws. A zonal structure is common, and the delicate inclusions described in detail in the feldspars of the norites,* are sometimes abundant and sometimes absent.

The mica, which constitutes the only other essential constituent of these rocks, is a biotite very rich in iron. Its absorption is intense and basal sections are only translucent when very thin. Their color is then a greenish-brown. The optical angle is so small that it is impossible to determine whether the mineral is anomite or meroxene. The mica contains no other inclusions than magnetite grains and apatite needles. None of the pleochroic aureoles so common in the granites were observed.

The presence of orthoclase was not positively substantiated in these rocks. An unstriated plagioclase might easily be mistaken for orthoclase.

Quartz occurs sparingly in grains, which, from their allotriomorphic character, were evidently the last product of crystallization. These are frequently penetrated in every direction by the minute and indeterminate black needles mentioned by Hawes, Rosenbusch and others.

Magnetite is universally distributed. Apatite occurs in rare abundance, size and perfection. Sphene and zircon are often present, and epidote of somewhat exceptional character is very common, especially in the mica-diorite from Stony Point. This mineral is of a pale green color, without pleochroism and its

p. 267). Prof. Dana objects to the term mica-diorite, because (1) the original diorite was a hornblende rock and (2) because hornblende and mica are widely different minerals. It must, however, be remembered that, although these two minerals are so different, they play a very similar rôle in rock-composition. The name mica-diorite is here retained because, in spite of all objections to it, it has the very great advantage of being readily intelligible to students of petrography the world over,—something that cannot be said of any other term which might be proposed in its place.

* This Journal, III, xxxiii, p. 141. Feb., 1887.

source cannot be traced in the alteration of any older constituent. It is generally without terminations but is most remarkable for the peculiar eaten or corroded aspect presented by the crystals, (see fig.) These are often divided into the most complicated fret-work of interlocking tongues. The cleavage is parallel to the long direction of the crystal, and the extinction is parallel to the cleavage lines. The mineral is shown to be epidote and not a pale pyroxene, by the fact that the plane of the optic axes is perpendicular to the cleavage lines. Twin crystals of this epidote occur as shown in the figure.

Epidote in Mica-Diorite (No. 28.)

The bright red garnet crystals which are so often found in this rock are most frequent near the edge of its mass and are doubtless an endo-metamorphic product.

The structure of the mica-diorite is hypidiomorphous in the sense of Rosenbusch. It is most closely connected with the diorite proper, into which it grades through the mica-hornblende-diorites as explained above. On the other hand, it passes into the norites through the group of the mica-norites.* Some of these rocks contain much more biotite than hypersthene, closely resembling the hypersthene-bearing mica-diorite from Campo Major in Portugal described by Merian† and the norite facies of the Klausen diorite mass described by Teller and von John.‡ In the latter rock the feldspar has also been shown to belong to the andesine series.

Quartz-Mica-Diorite.—A quite exceptional member of the massive rocks of the "Cortlandt Series" occurs a short distance eastward of Montrose Station. This has a very light color with only comparatively rare and small flakes of biotite scattered through it. It forms a bed of moderate thickness within the dark massive norite against which it is sharply defined, i. e., there is here nothing like a gradual transition from the one rock to the other.

Professor Dana has described this rock as a granitoid mica-

* This Journal, III. xxxiii. p. 191, March, 1887.

† Neues Jahrbuch für Min., etc., Beil. Bd. III, p. 292, 1885.

‡ Jahrb. k. k. geol. Reichsanst., xxxii, p. 589, 1882.

ceous quartzite,* but a careful petrographical study of it shows that it is a massive rock, best to be designated as a *porphyritic quartz-mica-diorite*.

Under the microscope well-formed crystals of feldspar are seen imbedded in a rather coarse-grained groundmass composed mostly of quartz and feldspar. The porphyritic crystals possess a beautiful zonal structure and sometimes, though not commonly, polysynthetic twinning striation. No porphyritic quartz occurs.

The groundmass is a mosaic of interlocking grains unlike the structure of a quartzite. It contains biotite and epidote exactly like that characteristic of the mica-diorite proper, except that their amount is here much less. The feldspar of the groundmass is sometimes striated, sometimes not. Specific gravity determinations made with the Thoulet solution show all the feldspar of this rock to be plagioclase, varying between 2.63 and 2.67. This renders its separation from the quartz and the quantitative determination of the latter impossible.

This rock differs from the mica-diorite proper only in its greater amount of quartz and the proportionately smaller amount of biotite and epidote. It may be regarded as a variety of the former rock and as the most acid type of the whole "Series," which is throughout essentially a plagioclastic one.

We have now, within the limits of this and of my two former papers traced out the following types of basic and ultra-basic rock which form members of the group called by Professor Dana the "Cortlandt Series."

Class I. Peridotite.

1. Hornblende - Peridotite
(Cortlandtite).
2. Augite-Peridotite (Pikrite).

Class II. Norite.

1. Norite proper.
2. Hornblende-Norite.
3. Mica-Norite.
4. Augite-Norite (Hyperite).
5. Pyroxenite.

Class III. Gabbro.

1. Gabbro proper.
2. Mica-Gabbro.

Class IV. Diorite.

1. Brown-hornblende-Diorite.
2. Hornblendite.
3. Green-hornblende-Diorite.
4. Mica-Hornblende-Diorite.

Class V. Mica-Diorite. ("Soda-granite," "Hemidioryte," Dana.)

1. Mica-Diorite proper.
2. Hornblendic Mica-Diorite.
3. Hypersthenic Mica-Diorite.
4. Quartz-Mica-Diorite.

In spite of the extent to which the subdivision of the various types has been carried in the descriptions, the actual variety of intermediate or transitional forms has not been adequately represented. In order to show more completely the

* This Journal, III, xx, p. 218, Sept., 1880.

number and relationships of these intermediate members and to connect all the various types together in one geological unit or "Series," the following diagram has been constructed. All

varieties represented in the circles correspond to actual specimens collected within the Cortlandt Area and many others might have justified a still more minute differentiation. The lines connecting the circles indicate the directions in which the best marked transitions take place.

These rocks present an admirable example of what are called *facies* of a geological unit mass. In spite of their great petrographical variety, they are everywhere connected by transitional forms into the closest relationship. And yet we need not regard all the rocks as having been formed simultane-

ously. The region was probably for a long time the scene of eruptive activity. At different periods different types may have been produced which broke through these already solidified. The quartz-mica-diorite near Montrose Station seems to be a later intrusion into the older and more basic norite.

This will conclude what the writer has to say on the massive rocks of the "Cortlandt Series." These are however so extremely varied that their study can hardly be said to be more than begun. It is earnestly hoped that some one may in future work out all their manifold variations and relationships more completely than the writer, at such a distance from the field, has been able to do.

Enough perhaps has already been said regarding the nature and mode of occurrence of these rocks to place their truly eruptive nature beyond all question; nevertheless all the evidence bearing on this point may be more advantageously summarized at the conclusion of the next and final paper, which will deal with the phenomena of contact metamorphism produced by the massive rocks in the adjoining schists.

Petrographical Laboratory, Johns Hopkins University,
Baltimore, Jan. 27, 1888.