ART. XXVI.—*The Contact-Metamorphism produced in the adjoining Mica schists and Limestones by the Massive Rocks of the "Cortlandt Series," near Peekskill, N. Y.;* by GEORGE H. WILLIAMS. With Plate VI.

IN three former papers I have described the principal types and some of the intermediate varieties forming the complicated group of massive rocks known as the "Cortlandt Series."* Aside from their own intrinsic interest, these rocks are hardly less worthy of attention on account of the unusual contact-metamorphism which they have occasioned in the adjoining schists.

The area occupied by the Cortlandt massive rocks—about twenty-five square miles in extent—is bordered on the south mainly by mica schists and on the west mainly by limestones. Both of these rocks have been altered by the masses which have broken through them, although the metamorphosing influence has not extended far from the contact. The gneisses, on the other hand, which border the Cortlandt area on the north, do not appear to have been materially affected.

The two localities where these phases of metamorphism were best observed—both already known through Professor Dana's descriptions of them—are here selected as typical. A further search would doubtless reveal other localities as interesting, while the emery and iron (pleonaste) deposits already described by the writer as occurring in the southern part of the Cortlandt area,† may with certainty be referred to the same category.

The two typical localities referred to are: for mica schist metamorphism, Cruger's Station; for limestone metamorphism, southern end of Verplanck Point.

I. *Contact-metamorphism in the Mica Schist.*

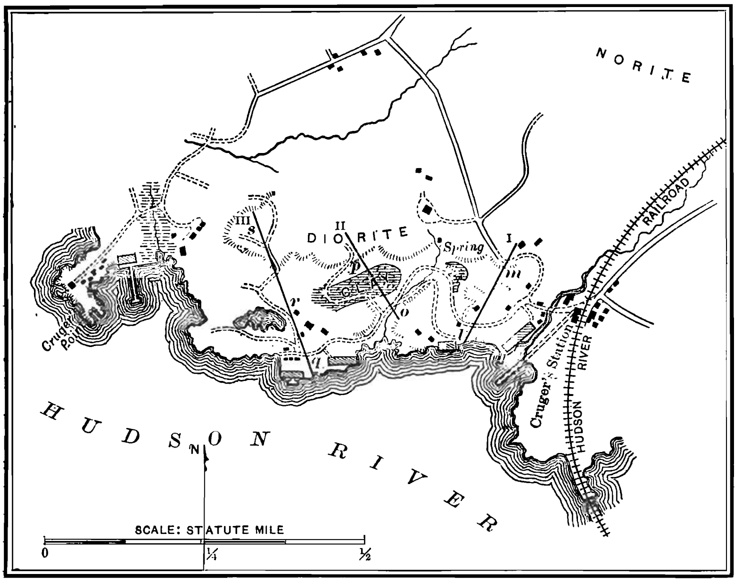
If we leave the train at Cruger's, a station on the Hudson River Railroad about four miles south of Peekskill, we find ourselves near the river-bank which at this point extends nearly west for about three fourths of a mile. Near the shore the rocks exposed are mica schists, but these are frequently covered by beds of clay which is used in the numerous brick-sheds of this region. Not over a few hundred yards from the shore rises a rocky wall which extends nearly parallel to the river bank until this bends toward the north. This wall coincides with the southern edge of the massive rocks of the "Cortlandt

* This Journal, III, xxxi, p. 26, Jan., 1886; ib., xxxiii, pp. 135 and 191, Feb. and March, 1887; ib., xxxv, p. 438, June, 1888.

† This Journal, III, xxxiii, p. 194, March, 1887.

Series," which here consist of mica-diorite or mica-hornblende-diorite. No exposure could display more favorably than this one the contact-phenomena between the massive rock and adjacent schists.

This small area is represented on Professor Dana's map,* but it is here reproduced on a much larger scale from the manuscript chart in the office of the U. S. Coast and Geodetic Survey in Washington. The particular points designated by let-



Map of the region near Cruger's Station.

ters are the same as those used by Professor Dana.* They represent three different sections across the schists, one 300--400 yards (*l-m*): one 700 yards (*o-p*); and are 900 yards (*q-s*) west of Cruger's Station, and are as good as any that could be selected.

The mica schists of this area adjoin conformably the small limestone area at Cruger's Station and have an average strike N. 70° E. and dip 75° N.; i. e. they strike nearly parallel to the river bank and dip toward the massive rocks. On the shore they are highly crystalline, but not much crumpled or metamorphosed. As we follow them, however, across the strike they become more and more puckered and filled with lenses or eyes of quartz containing garnet and other contact minerals. In the schists themselves are developed staurolite, sillimanite, cyanite and garnet. The intensity of the metamorphic changes is directly proportional to the nearness of the

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

schist to the massive rocks. Just at the contact the schistose structure almost wholly disappears and the rock becomes hard and massive.

In order to understand these interesting alterations more perfectly, we will examine each of the three above-mentioned sections somewhat in detail.

Section I.—At a point on the river shore just west of the first brick-yard (*l* on the map) mica schist is exposed at the water's edge. This stands nearly vertical and is finely banded and very schistose, but is hardly at all crumpled or even bent. A thin section, cut parallel to the bedding (No. 21), shows it to be composed of quartz, biotite, muscovite and feldspar, (both orthoclase and plagioclase) although the last-named mineral is comparatively rare. Tourmaline in well-formed crystals is common and zircon is also quite abundant, often occasioning the pleochroic aureoles in the biotite (Pl. VI, fig. 1).

Not far from here, limestone is exposed and some of this schist is so impregnated with calcium carbonate as to be over half calcite. A specimen of this (No. 22) shows under the microscope mainly quartz grains with some mica, both biotite and muscovite. The quartz is filled with black granules and contains an astonishing amount of rutile. This latter mineral occurs in sharp crystals, mostly twinned, which range from those thick enough to show a deep yellow color down to the minutest which the microscope can reveal.

No. 23 of the University, and K in Professor Dana's collection were obtained from a short distance north of those last described. They are somewhat more contorted and contain more abundant quartz nodules, but do not differ materially from the less-altered mica schists except in the fact that garnet has been quite abundantly developed in them. The quartz, both kinds of mica and the feldspar remain, but no tourmaline was observed. No. 24, from a point somewhere farther north, is a contorted muscovite-biotite-schist containing many quartz "eyes" together with an abundance of large dodecahedral red garnets.

A slide in Professor Dana's collection marked M and made from a specimen obtained on the line of section I, not far north of the brick-sheds, is of remarkable beauty. It represents the first phase of sillimanite-formation, where this mineral has room for its complete development (Pl. VI, fig. 2). The base of this rock seems to be quartz, triclinic feldspar and biotite. The first constituent is filled with the minute, hair-like microliths, which have been so often described but never yet determined. The biotite contains magnetite and an occasional zircon. The new products are sillimanite, garnet and rutile. The sillimanite forms thick brownish individuals which break up into radiating tufts at the extremities. They are arranged in every direction and penetrate equally all of the other constituents. Some of these tufts resemble in their appearance the radiating tourmaline in the well-known Luxullianite. The microscopic structure of the fibers is in all respects characteristic.* They vary from those of considerable thickness to microscopic hairs. The garnet presents no unusual features. The rutile forms often large but sharply defined crystals of a deep red color.

At a point ten yards from the contact (*m* on the map) on the line of section I, the schist is very much contorted, although still well bedded (No. 14). The microscope shows that the quartz and feldspar have been reduced to a minimum; while sillimanite, mica and garnet compose most of its substance. The sillimanite is arranged in radiating tufts made up of needles so minute that their crowded aggregation is hardly transparent even in the thinnest sections. Around the edge of these masses, however, where the delicate fibers project into the surrounding quartz or biotite, the characteristic structure of the sillimanite is at once apparent. The grayish tufts are so abundant as to compose a large proportion of the rock. Between them is a rich brown biotite, frequent large flakes of muscovite, garnet grains and crystals, and some quartz. Feldspar is rare, but opaque black grains of magnetite are thickly scattered through the mica. This aggregation produces a striking contact rock, but one which is quite constant along the whole extent of the Cruger's area. It is frequently modified by the presence of staurolite, as we shall see beyond.

Directly at the contact between the schists and massive rocks, at a point in the wall marked *m* on the map (Section I), the bedded rock appears to be more or less fused with the mica-diorite, which here itself becomes very garnetiferous. Even where the bedding of the original schist is still distinct, a great variety of mineral aggregates may be obtained. No. 18^b is essentially a mixture of staurolite, garnet and biotite, containing considerable quartz and feldspar. In this particular specimen there is very little sillimanite. No. 16, from this same exposure, shows the actual contact with the diorite in the hand specimen. The schist is here changed to an almost colorless pyroxene, with some dark green hornblende and a little quartz.

No. 18^d, a dark greenish rock from this same contact, proves, upon microscopical examination, to be of unusual interest. It contains a green diallage, in which both pinacoidal partings are well developed. This is pleochroic as follows: $\mathfrak{c}=\mathfrak{b}$, bluish green; $\mathfrak{a}$=yellow. This mineral occurs in rounded grains and

* cf. Kalkowsky: Die Gneissformation des Eulengebirges, Leipzig, 1878, p. 5, *et seq.*, Pl. I, figs. 1–4.

has a high angle of extinction. In different parts of the thin sections, however, it is associated with different minerals. In one place it occurs with a triclinic feldspar, like that characteristic of the adjoining diorite; in another it is associated with muscovite, and in a third with a colorless granular mineral, whose optical properties show it to be scapolite. Its grains show sometimes parallel, sometimes rectangular cleavage lines; its refractive index is low, but its interference colors (double refraction) very brilliant. Sections showing the rectangular cleavage are isotropic or nearly so and exhibit in convergent polarized light a negative uniaxial figure. The substance agrees perfectly in its appearance and optical behavior with the scapolite described by Michel-Lévy in the "*gefleckter Gabbro*" from Bamle in Norway.* Sphene, often associated with ilmenite, is also common in this rock.

Section II (*o–p* on the map), shows essentially the same series of changes as those described under Section I. No. 25, from the schist exposed at *o*, on the opposite side of the claybank from the wall *p*, is the same mica schist as occurs at *l* (Section I), with sillimanite and staurolite abundantly developed in it. (Pl. VI, fig. 3.) The quartz, biotite and muscovite are like those described in No. 21. The tourmaline, however, seems to be lacking in this section and the feldspar is rare. The sillimanite occurs in the gray radiating tufts as described inNo. 14; but the most abundant constituent of all is the staurolite. This occurs in rather large and stout, more or less perfectly rectangular sections, which possess a high index of refraction. They show no well-developed cleavage, but have an irregular cross-parting. The pleochroism is very marked, being parallel c̍, orange; parallel ă and b̄, pale yellow. The staurolite individuals are often filled with inclusions of quartz and magnetite.

As we pass across the strike of the schists from *o* toward *p* the contact (section II), the quartz steadily diminishes in quantity, and biotite and sillimanite are proportionately increased. Indeed, the mica schist finally becomes almost wholly a mixture of these two minerals, with a little garnet and magnetite.

No. 36, collected a short distance north of No. 25, is largely composed of brown biotite and gray tufted sillimanite, although considerable quartz, muscovite and staurolite still remain. Garnets and occasional small zircons are also present in this specimen. No. 37, however, from a point still nearer the contact, has lost almost every trace of the quartz, muscovite and feldspar of the original schist. The staurolite too has almost disappeared. Garnet, on the other hand, is largely de

* Bull. Soc. Min. de France, i, 43, 1878.

veloped, its crystals being penetrated by the biotite and sillimanite which compose most of the remainder of this rock. Another mineral, noted in this specimen for the first time, is cyanite. This occurs in thick, colorless crystals, with the prismatic planes well developed, but without terminal faces. The cleavage is marked by fine sharp lines parallel to the prism, and the parting parallel 0P, due to gliding, as shown by Bauer,* is also very distinct. (See Pl. VI, fig. 4.) The extinction is in all sections greatly inclined.

Specimen No. 27 shows the actual contact of the schist and the diorite. Even the thin section is composed half of diorite and half of the schist, which has here become, as in the case of rocks similarly situated at *m*, an aggregate of quartz, feldspar, colorless pyroxene and garnet (cf. Nos. 16 and 18[d]). Epidote, zoisite and calcite also occur in this section.

A study of the sections above described shows that there is an undoubted metamorphism in the mica schist, which increases regularly as the massive rocks are approached. This metamorphism consists of an addition of alumina and iron and the corresponding decrease in the proportions of silica and the alkalies. This is shown by the disappearance of the quartz and muscovite and the development of biotite, sillimanite, staurolite, cyanite and garnet.

The four following analyses, which were kindly made at my request by Mr. Frank L. Nason of the Troy Polytechnic Institute, clearly indicate the nature of the chemical changes which the schists have undergone.

	I.	II.	III.	IV.
SiO_2	62·980	61·570	55·120	40·160
Al_2O_3	16·881	19·529	24·320	29·500
Fe_2O_3	2·479	5·443	6·130	19·660
FeO	5·000	2·608	4·990	5 800
CaO	trace	trace	trace	trace
MgO	1·580	1·900	trace	0·850
Na_2O	3·020	3·480	2·712	1·460
K_2O	7·450	2·140	2 826	1·360
TiO_2	-----	1 530	2·460	-----
S	0·080	0·846	1·230	0·820
P	trace	trace	trace	trace
Total,	99·470	99·046	99·788	99·610

* Zeitschrift der deutschen geologischen Gesellschaft, xxx, p. 283, 1878.

I. No. 21. The least altered mica schist from the southern end of Section I. Contains quartz, orthoclase, biotite, muscovite; a little oligoclase, tourmaline and zircon.

II. No. 24. A much crumpled, garnetiferous mica schist, collected north of the road on Section I.

III. No. 25. Schist from *o* on Section II. Contains biotite, muscovite, quartz, sillimanite, garnet and very much staurolite.

IV. No. 37. Schist at the foot of the contact-wall, *p*. Section II. Composed of biotite, magnetite, sillimanite, cyanite and garnet.

It is not intended to imply that the successive layers of the schist may not have differed very materially in their original composition. That such was the case is shown by local variation in the relative proportions of the resultant minerals; but after allowing for all such differences, there is still a regular and progressive series of changes in the order above indicated.

Section III.—(*q-s* on the map.) This section is like the others in showing a gradual and constantly increasing metamorphism of the mica schist as we pass from the river bank at *q*, up the road which winds along the hill about half a mile west of the railroad station. Its main interest, however, is derived from the inclusions of the schist within the massive rock itself. These inclusions differ very much in size and character but they exhibit the extremest place of the metamorphic action. The largest inclusions are, as might be expected, nearest to the contact. Here some bands may be traced for a hundred feet or more, as though the molten rock had been forced between the schist strata without greatly displacing them. Farther within the contact line, on the top of the hill above Cruger's Point, many smaller inclusions of various shapes and sizes may be seen. They have been quite fully described by Professor Dana, at least so far as their macroscopic appearance goes.*

These included schist fragments are of great petrographical interest because of the variety of unusual mineral aggregates which they present. That these minerals are very largely new crystallizations produced by metamorphic action, is in some cases shown by their having an arrangement parallel to the boundaries of the fragment. The accompanying figure represents the banding in an inclusion about five feet long exposed on a glaciated surface of the mica-dorite, just where the road reaches the top of the hill. Toward the right the banding plainly follows the outline of the inclusion. Specimens No. 30 and 31 were taken from this inclusion.

Ascending the line of this section we came first (*r* on the map) to the exposure of highly contorted schist figured by Professor Dana.† A thin section of this (No. 5), cut across

* This Journal, III, xx, pp. 209–210, Sept. 1880. † Loc. cit. p. 209, fig. 11.

the grain, shows layers of varying composition, all however filled with metamorphic minerals. The original character of the mica schist with muscovite, biotite and a little tourmaline (cf. No. 21) is still well preserved, but the grain in the different layers differs very much, and in some garnet, and in others staurolite has been largely developed.

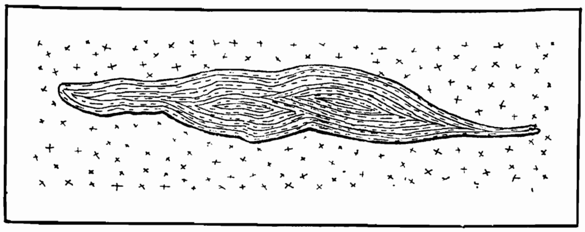


Fig. 1. Inclusion of schist in mica-diorite showing concentric arrangement of minerals. Length about five feet.

A short distance beyond this point the schists give place to the massive mica-diorite, when the inclusions become the object of special interest. These show such a manifold variety that hardly any two thin sections possess exactly the same mineral composition; still all the specimens collected fall naturally into four groups according to the nature of their prevailing constituents. These groups are as follows:

Group 1. Black inclusions consisting mostly of pleonaste and corundum.

Group 2. Inclusions consisting mostly of quartz grains.

Group 3. Inclusions consisting mostly of staurolite and green mica.

Group 4. Inclusions consisting mostly of margarite.

Group 1. The first inclusions encountered in following the road up the hill side are the small black ones disseminated through the mica-diorite. They are often arranged in rows more or less sinuous, as figured in Professor Dana's paper.* These are represented by Nos. 7, 7^a and 29 in the University collection, and by W and Cr. 7 in Professor Dana's. The microscope shows them to be composed mainly of pleonaste in octahedral crystals. With this is associated some magnetite, biotite and feldspar. In the densest of the pleonaste inclusions, colorless corundum is very abundant. This is notably the case in No. 29, where this mineral forms comparatively large and well-developed crystals. (Pl. VI, fig. 5.)

These isolated inclusions of spinel and corundum are almost identical with the more extensive deposits of the same character occurring near the southern border of the norite region

*Loc. cit., fig. 12.

farther to the east, and described at length in a former paper.* Their origin in both cases is without doubt essentially the same.

Group 2. Certain of the included masses in the diorite higher up the hill are composed mainly of quartz. Nos. 10, 30 and 31 represent this class. The quartz grains contain the well-known black, hair-like needles in greater perfection than any which have ever come under my notice. These are often arranged zonally forming a matted net-work, as it were, around the principal axis of the quartz crystal, while the interior and periphery are quite free from them. Many other accessory min erals were observed in these quartz inclusions. These vary very much in their amount and relative proportions. Those noticed were magnetite, pleonaste, zircon, apatite, sphene, garnet, tourmaline, muscovite, green mica, biotite, hornblende and plagioclase.

Group 3 of the inclusions in the diorite are principally made up of staurolite and a green mica, associated with a greater or less amount of sillimanite. Representatives of this class are found in sections Nos. 9 and 11 of the University collection, and among those belonging to Professor Dana, those marked EW, EW 1 and Cr. 8. The staurolite and sillimanite possess the same characteristics which have already been described in connection with the altered mica schists. The bright green, micaceous mineral is a member of the chlorite group, as is shown by its chemical behavior; while an optical examination serves to more specifically identify it as *ripidolite* or *clinochlore.* In prismatic sections it shows a decided pleochroism :—O = green, E = light yellowish green ; absorption O > E. Both its refractive index and its double refraction are very weak. Basal cleavage sections in converged polarized light show a positive interference figure with a small optical angle. The monoclinic character is apparent from the bisectrix not standing quite normal to the basal pinacoid. Cleavage flakes of a typical ripidolite specimen from Westchester, Pa., examined for comparison, yielded exactly similar results.

There is no doubt that this green mica has been derived from a brown biotite, for many incompletely changed crystals show a gradual transition from the one mineral to the other. The specific gravity of the green mica (2·9), which is exceptionally high for clinochlore, is probably due to the fact that it is still associated with more or less biotite. Accessory minerals observed in the thin sections of the inclusions belonging to Group 3 are garnet, tourmaline, corundum, quartz, feldspar,

* This Journal, III, xxxiii, p. 194, March, 1887.

biotite, magnetite, and margarite, which latter mineral will be particularly described under the next group.

Group 4 comprises inclusions which are largely composed of a micaceous mineral, bearing a close resemblance to muscovite. It forms a confused aggregate of flakes with no regularity in their arrangement, and is associated with varying amounts of green mica, tourmaline, magnetite, epidote, staurolite, etc. Specimen No. 32, taken from an inclusion in the mica-diorite near the head of the road leading up the hill at Cruger's Point (*s* on the map), is almost wholly composed of this mineral. Macroscopically it bears every evidence of being muscovite, but a careful examination shows that it possesses several characteristics which are foreign to this species.

Under the microscope the lath-shaped cross-sections at once appear different from muscovite by their high refractive index, which throws their boundaries and cleavage lines into high relief. Moreover they show between crossed nicols a distinctly inclined extinction, varying, when measured against the cleavage, from 6° to 10°. There is also a very frequent twinning parallel to the basal pinacoid. The interference colors in polarized light are as brilliant as those of muscovite, but the optical angle is far too large for that species. Measured in the air it gave a value of 114½°, while the limit for muscovite is 70°. The asymmetric position of the interference figure when examined in a cleavage flake also indicates that the bisectrix is considerably oblique to a normal to the basal plane. The character of the double refraction is, as in the case of muscovite, negative.

The optical properties here enumerated are seen to be intermediate between those of muscovite and the brittle micas or chloritoids. The same thing is true of the hardness (3·5–4) and specific gravity (3·1) of the mineral here under consideration. All of these physical characters, however, agree accurately with those given by Des Cloizeaux* and Tschermak† for the lime mica, margarite, (=Perlglimmer *Germ.*, Emerylite *Smith*), which is well known to occupy a position between true mica and chloritoid. This conclusion is fully substantiated by the following analysis (I), made by Mr. T. M. Chatard, of the U. S. Geological Survey at Washington. The rather small amount of material for this analysis (0·4212 gr.), was obtained from specimen No. 32 by as complete a separation as possible with the Thoulet solution. A very small proportion of black tourmaline still remained with the powder analyzed, which may in a measure account for the rather high percentage of iron.

* Manuel de Minéralogie, i, p. 501, 1862.

† Die Glimmergruppe: Zeitschr. für Krystallogr., ii, p. 48, 1877.

Owing to the small amount of material the alkalies were not determined:

	(I.)	(II.)
SiO_2	32·73	32·21
Al_2O_3	46·58	48·87
FeO	5·12	2·50
CaO	11·04	10·02
MgO	1·00	0·32
Na_2O	----	1·91
Li_2O	....	0·32
H_2O	4·49	4·61
	100·96	100·76

Under (II) is given for comparison an analysis of the margarite from Chester, Mass., made by the late Professor Lawrence Smith.*

The occurrence of margarite as a contact-mineral in the Cortlandt schist inclusions is interesting in connection with the occurrence under the same circumstances of corundum, with which margarite is always associated.

The amount of margarite in the schist inclusions varies very much in different specimens. In some cases it forms a large proportion of the entire mass, while in others it is associated with a greater or less amount of the other contact-minerals. In this manner the inclusions classed in this group grade insensibly into those of the other groups, although it is a noteworthy fact that the margarite was not observed in those particular inclusions in which corundum crystals were most abundant. The microscopic appearance of the margarite is shown in Plate VI, figure 6.

In many of its features the Cortlandt area is quite unique and yet it finds many close analogies in certain regions which have recently been made the subject of detailed petrographical study in Europe. The region which seems most closely to resemble the Cortlandt area is that so admirably described by Teller and von John, near Klausen in the Tyrol.† Here occurs a large eruptive mass exhibiting many facies and closely resembling the Cortlandt eruptives save in the absence of hornblendic and peridotitic types. The authors distinguish: Norite, Quartz-norite, Norite-porphyrite and Quartz-mica-diorite. In many instances also a monoclinic pyroxene is associated with the hypersthene and enstatite. The close resemblance of the Klausen to the Cortlandt area is furthermore increased by the contact-phenomena produced in the adjacent schists. These,

* This Journal, II, xlii, 1886. Original Researches, 1884, p. 120.

† Geologisch-petrographische Beiträge zur Kenntniss der dioritischen Gesteine von Klausen in Südtirol. Jahrb. der k. k. geol. Reichsanstalt, xxxii, 1882, pp. 589–684.

both as regards actual contact and inclusions, are much alike at the two localities—a fact that has already been noted by Professor Rosenbusch.*

Contact-phenomena have been so rarely studied in the crystalline schists that mention should also be made in this connection of the unusual mineral aggregates which were first observed by Professor Lossen in the kersantite of Michaelstein in the Harz Mountains.† These have recently been carefully studied by Dr. Max Koch of Berlin,‡ who suggests, as the most probable explanation of their anomalous character, that they are metamorphosed inclusions of crystalline schists. There are important individual differences between the Michaelstein and Cortlandt inclusions, but yet there is sufficient resemblance both in structure, mode of occurrence and mineral composition, to make it certain that the two belong to the same general category.§

For the sake of comparison a list of the metamorphic minerals (exclusive of quartz, feldspar and biotite, which are common to all), which have been observed at the three above named localities is here appended:

Cruger's.	Michaelstein.	Klausen.
Sillimanite,	sillimanite,	———
cyanite,	cyanite,	———
———	———	andalusite.
garnet,	garnet,	garnet.
staurolite,	staurolite,	———
tourmaline,	———	tourmaline.
pleonaste,	spinel,	pleonaste.
corundum,	corundum,	corundum.
margarite,	———	———
ripidolite,	———	———
rutile,	rutile,	rutile.
sphene,	anatase,	———
ilmenite,	ilmenite,	ilmenite.
zircon,	zircon,	zircon.
magnetite,	magnetite,	magnetite.
pale augite (on contact),	hypersthene,	———
scapolite (on contact),	———	———
zoisite,	calcite,	several undetermined minerals.
epidote.	apatite.	
18 species.	14 species.	9 species.

* Mikroskopische Physiographie der massigen Gesteine. 2d ed., p. 128.

† Geologische und petrographische Beiträge zur Kenntniss des Harzes. Jahrb. d. kön. preuss. geol. Landesanstalt für 1880.

‡ Die Kersantite des Unterharzes, I Theil, ib. für 1886, pp. 44–104.

§ The writer is indebted to Dr. Koch for an interesting suite of specimens illustrating the various kinds of inclusions found in the Harz kersantites. A study of these shows many points of difference, but nevertheless a strong general likeness to the Cortlandt inclusions.

Lossen and Koch also mention *cordierite* as an abundant constituent in the kersantite of Michaelstein, although this mineral does not appear in the inclusions.*

II. *Contact-metamorphism in the Limestone.*

The limestone beds associated with the gneisses and mica schists of Westchester County have been carefully mapped and described by Professor James D. Dana.† They are regarded by him as belonging to the Green Mountain system and as probably of Lower Silurian or Cambrian age. Some of this limestone appears within the limits of Cortlandt township, but it falls within the scope of this paper only in so far as it has been modified by the action of the intrusive rocks of the Cortlandt Series.

The western edge of Verplanck Point, which projects into the Hudson River south of Peekskill, is formed of the Tompkins Cove limestone, so admirably exposed in the large quarries on the opposite side of the river. At the southern end of the point the limestone is in contact with the massive rocks, which here display in the most unmistakable manner the evidence of their eruptive character. This fact is admitted by Professor Dana, although he is inclined to regard the dykes there exposed as softened or fused sedimentary material rather than truly exotic intrusives.‡

* At the close of his series of articles on the Westchester County rocks, Professor Dana has very admirably summarized all the essential contact phenomena displayed at Cruger's. (This Journal, III, xxii, p. 314, Oct. 1881.) He here also advances four considerations which he believes to be adverse to the idea that the contact-phenomena were produced by the action of an eruptive rock. These considerations are briefly as follows:

1. The crumpling of the schist must have been produced at the time of its metamorphism.
2. An intruded rock would have been too feeble an agent to produce this.
3. The increase of metamorphism would only have needed an increase in temperature, and this may have been caused by the crumpling of the strata.
4. Staurolite and fibrolite are widely distributed through the mica schists.

Evidently the metamorphism of the original rock—whatever its character—*into a mica schist* must have taken place at the time of its folding and crumpling. Now it is by no means certain that the forcible intrusion of a large body of molten rock, far below the surface, may not have exerted a pressure in accordance with laws of hydrostatics sufficient to have caused the local puckering to be seen at Cruger's. But this does not necessarily have any bearing on the question. The original rock may have been crumpled and changed to a mica schist by some orographic force, as Professor Dana thinks probable, and subsequently have undergone a further contact-metamorphism by the agency of the Cortlandt eruptives. The intrusion of the massive rock itself may have been—probably was—*the result* of orographic movements. This intrusion may or may not have caused the puckering, but the progressive metamorphism observed at Cruger's bears such a direct relation to the contact line that the conclusion seems unavoidable that at least the mineralogical changes above described are directly due to the influence of the eruptive rocks

† On the Geological Relations of the Limestone Belts of Westchester County, N. Y. This Journal, 1880 and 1881, vols. xx, xxi, xxii.

‡ This Journal, III, xx, pp. 200–203 and 216, Sept., 1880.

Near the foot of Broadway in Verplanck the limestone fragments occur imbedded in the norite as figured by Professor Dana,* while just behind and beyond the hotel branching dykes of the massive rocks, varying from a fraction of an inch to many yards in width, penetrate the limestone in different directions, though in the main they follow the direction of its bedding. The microscope shows that these dykes belong to many different rock types, as for instance gabbro (Nos. 109, 111), mica-hornblende-diorite (No. 80), hornblende-diorite (Nos. 82 and 83) and mica-diorite (No. 81).

The metamorphic action extends but a small distance from the actual contact, but is always unmistakable in its nature. The limestone is in almost all cases bleached and is frequently rendered more coarsely crystalline. There are new contact-minerals developed in it; among the most common of which are hornblende and pyroxene, both rich in lime and of a pale color.

In the narrowest dykes, the nature of the eruptive rock is also considerably modified. In one of these (No. 77), the entire width of the dyke (only one-eighth of an inch) is contained within the thin-section. The intrusive material consists of brown hornblende, biotite, triclinic feldspar, apatite and an abundance of a brightly polarizing, uniaxial, negative, colorless mineral, which is probably scapolite. The brown hornblende is concentrated along the edges of the dyke and often stands perpendicular to its walls. The limestone beside the eruptive material is highly crystalline and contains colorless pyroxene and muscovite.

In some cases, as for instance in a section of Professor Dana's collection, the metamorphic action is extremely slight even when seen under the microscope. This particular section contains the contact between a mica-hornblende-diorite and limestone. The only change in the former is a concentration of hornblende along the contact line, while the limestone has become slightly more crystalline and contains oval spots of serpentine.

In the cutting exposed on the West Shore Railroad at Stony Point, a narrow band of limestone is seen between the masses of mica-diorite and peridotite, which, but for this, come here in contact. This limestone is very crystalline and is filled with minerals doubtless derived from the eruptive rocks. There is a pale pyroxene (malacolite), a light green hornblende, zoisite, sphene, and quite abundant scapolite.

At the conclusion of this series of papers, it may be advisable to summarize the evidence in favor of the eruptive (igneous)

* This Journal, III, xx, p. 202, fig. 5.

origin of the massive members of the Cortlandt Series; this can be done as follows:—

1. The general character of the rocks themselves, which, both in structure and mineralogical composition, agree with well recognized eruptive types.
2. The differentiation of massive rocks into facies which occupy irregular areas; i. e. there is nothing in the alternation of the different types to suggest an originally sedimentary structure.
3. Occurrence of the massive rocks in well-defined dikes
   (*a*) in other massive rocks. Montrose Point and Stony Point.
   (*b*) in mica schist. Stony Point.
   (*c*) in limestone. Verplanck Point.
4. Occurrence of angular rock fragments (inclusions) in the massive rocks.
   (*a*) of crystalline schist. Cruger's.
   (*b*) of limestone. Verplanck Point.
5. Production of contact phenomena in the stratified rocks adjoining the massive ones:
   (*a*) in crystalline schists. Cruger's. Stony Point.
   (*b*) in limestone. Verplanck Point.

It is probable that the Cortlandt Area was once the scene of prolonged volcanic activity from several vents. There is, however, every reason to suppose that the rocks now exposed solidified at a considerable depth below the surface and have since been brought to light by erosion. This is indicated:—

1. By the coarse-grained structure of many of the massive rocks themselves, which gives to them a plutonic rather than a volcanic or superficial character.
2. By the absence of any tuff deposits or topographical resemblance to volcanoes.
3. By the presence of a marked contact zone, such as is only produced around deep-seated eruptive masses, where the enclosed vapors cannot readily escape.

The seat of intensest action would seem to have been near the center of Cortlandt township, where norite is the prevailing rock. The most diverse types are peripheral in their distribution, especially toward the west and south. In these quarters also occur frequent remains of the original country rock in the way of bands of limestone or patches of mica schist. These have all suffered more or less intense metamorphism. It also seems probable that the iron and emery beds along the southern and eastern portions of the massive area, are to be regarded as the result of metamorphic action upon preëxistent material.

Petrographical Laboratory, Johns Hopkins University, Baltimore, May, 1888.

Explanation of figures in Plate VI.

Fig. 1. Typical, unaltered mica schist. River bank near Cruger's Station ("*l*" on the map), No. 21. Section cut approximately parallel to the foliation, shows the biotite mostly in basal sections of varying thickness. Large flakes of muscovite irregularly scattered through the field. Occasional crystals of tourmaline and zircon. Groundmass mostly a granular aggregate of quartz with very little feldspar. (× 30).

Fig. 2. Fibrolitic schist, collected a short distance north of the last on the line of Section I (M. of Professor Dana's collection). Fibrolite very abundant in large sheaf-like bundles, and also in radiating tufts, garnet and biotite. Groundmass composed of coarse grains of quartz with some feldspar. (× 30).

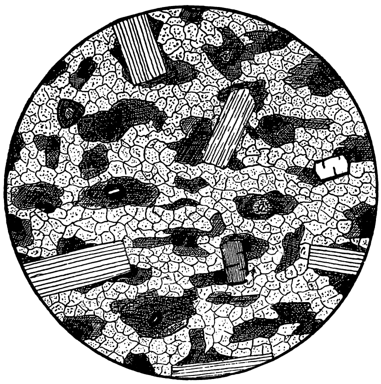
Fig. 3. Staurolitic mica schist ("*o*" on the map) No. 25. Large crystals of yellow staurolite with irregular boundaries and the usual quartz inclusions at their center scattered through a matrix of quartz and biotite. Some fibrolite in radiating tufts. (× 30).

Fig. 4. Fibrolitic schist from very near the contact ("*p*" on the map) No. 37. Rock very largely composed of fibrolite in feathery tufts, bundles and sheaves. Matrix almost wholly a brown mica. There also occur in lesser quantity cyanite, garnet and staurolite. (× 30).

Fig. 5. Black inclusion in the mica-diorite (near "*s*" on the map) No. 29. Composed mainly of pleonaste in small octahedral crystals among which are scattered larger crystals of colorless corundum. Where the section is sufficiently transparent, feldspar and biotite in small quantity may be recognized. (× 30).

Fig. 6. Inclusion in mica-diorite ("*s*" on the map) No. 12. The most important constituent is margarite in colorless crystals. Other minerals are green mica (ripidolite), biotite, quartz, feldspar and magnetite. Tourmaline and epidote also occur in these inclusions, although they are not represented in the figure. (× 30).

1.



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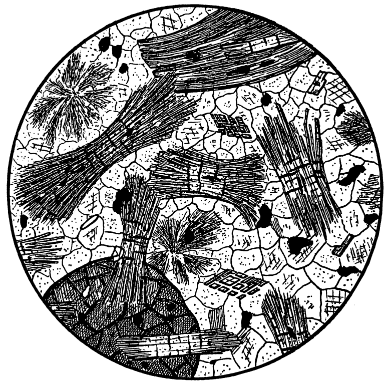

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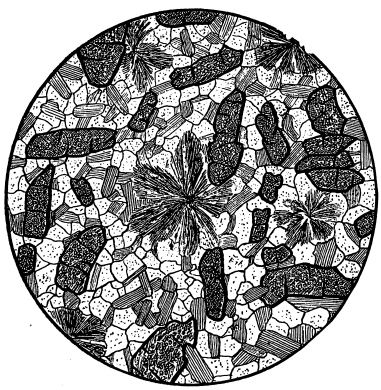

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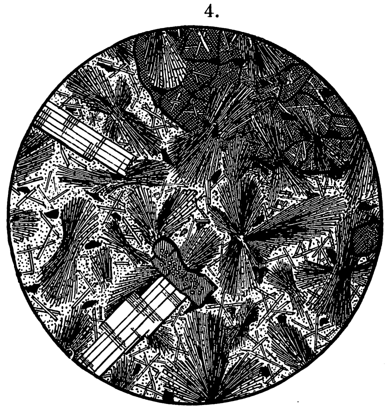

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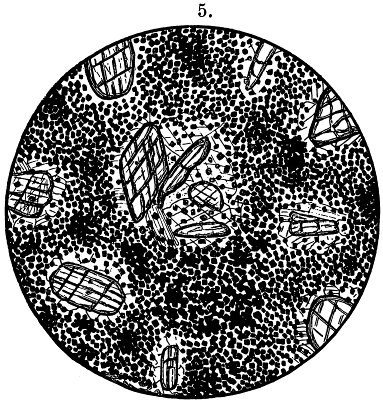

6.