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ORIGIN OF THE EMERY DEPOSITS NEAR PEEKSKILL, NEW YORK*

JOHN W. BUTLER, JR., *Columbia University, New York City.*

CONTENTS

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ABSTRACT

Several theories of origin have been proposed for the emery deposits associated with the Cortlandt series of basic plutonics which lie south and east of Peekskill, New York. These are: (1) magmatic segregation; (2) absorption (assimilation) of aluminous sedimentary material (Manhattan schist); and (3) contact-metamorphism, under which two different stages of development have been considered—(a) hydrothermal contact-metamorphism; and (b) deposition in marginally solidified endomorphosed norite and exomorphosed schist by emanations released from the still-liquid portions of the magma.

Detailed field and petrologic studies of the emery have been made at Emery Hill, where the principal deposits are located. New evidence disclosed objections to the earlier theories and led to the formulation of a revised theory of genesis. The emery deposits are believed to be contact-metamorphic (pyrometasomatic) in origin, but were formed at a much earlier stage than previously thought. They are believed to have been formed by emanations that were released by the magma during intrusion and these emanations passed through the country rock (Manhattan schist) only a short distance in advance of the magma. Thus, the formation of emery took place during the early liquid-magmatic stage of the basic Cortlandt intrusives.

Detailed descriptions of the emery, the rock types, and their relations are given. Reference is made to usage of the terms "hornfels" and "endomorphism" because of their significance to a study of the emery deposits.

INTRODUCTION

One of the few commercial emery deposits in America is associated with the complex post-Ordovician Cortlandt series of basic plutonics south and east of Peekskill, New York. Several theories of origin have been proposed for the deposits. In brief, these are: (1) magmatic segregation; (2) absorption (assimilation) of aluminous sedimentary material; and (3) contact-metamorphism, under which two different stages of development have been considered. Additional information, disclosed by the writer's studies of the emery deposits, requires a modified theory of origin which is presented in this paper.

A historical review of the literature shows that Williams[1] suggested (1887) that the emery deposits were due to magmatic segregation, but a year later, following a more complete petrographic study of the Cort-

[1] Williams, G. H., Norites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **33**, p. 194, 1887.

landt series,[2] he favored contact-metamorphism.[3] Rogers,[4] as a result of areal and petrographic studies (1911) favored the theory of the absorption of sedimentary material. In his opinion, the absorption of aluminous sedimentary xenoliths or wall rock (Manhattan schist) formed aluminous segregations in the magma which crystallized to form emery. He made a strong point of the fact that experiments on artificial production of corundum by Morozewicz[5] supported his conclusion. Berkey and Rice[6] and Bowen[7] closely followed Rogers' ideas. Larsen[8] (1928) revived Williams' concept of contact-metamorphic origin, specifically favoring a hydrothermal phase. Two years later, Gillson and Kania[9] studied the emery deposits in the northeast corner of the Cortlandt series and concluded that they were contact-metamorphic but "were formed by gaseous or liquid emanations from the magma reservoir, which passed upward through the already solid border of the igneous mass, and into the schist, depositing the ore minerals in both endomorphic and exomorphic zones."

Field and petrologic studies by the writer lead him to believe that the emery deposits near Peekskill are contact-metamorphic in origin, but were formed at a much earlier stage than previously thought. The emery is believed to have been formed by emanations that were released by the magma during intrusion and which essentially passed through the country rock (Manhattan schist) a short distance in advance of the magma.

The study of the problem covered one field season and numerous subsequent trips to the district. A topographic map of the principal emery producing area (Plate I) was made on the scale of 200 feet to the inch with a five foot contour interval, and a detailed geologic map (Plate

[2] Williams, G. H., Peridotites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **31,** p. 26, 1886.

Williams, G. H., Gabbros and diorites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **35,** p. 438, 1888.

[3] Williams, G. H., Contact metamorphism produced in the adjoining mica schist and limestone by the rocks of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **36,** p. 268, 1888.

[4] Rogers, G. S., Geology of the Cortlandt series and its emery deposits: *Annals New York Acad. Sci.*, vol. **21,** pp. 11–86, 1911.

[5] Morozewicz, J., Experiment. Untersuchungen über d. Bildung d. Mineralien im Magma: *Tschermak's min., und pet. Mitt.*, vol. **18,** pp. 1–90 and pp. 105–240, 1898.

[6] Berkey, C. P., and Rice, Marion, Geology of West Point quadrangle: *New York State Museum Bull.*, Nos. 225–226, p. 90, 1919.

[7] Bowen, N. L., The behavior of inclusions in igneous magmas: *Jour. Geology*, vol. **30,** pp. 550–560, 1922.

[8] Larsen, E. S., A hydrothermal origin of corundum and albitite bodies: *Economic Geology*, vol. **23,** p. 429, 1928.

[9] Gillson, J. L., and Kania, J. E. A., Genesis of the emery deposits near Peekskill, New York: *Economic Geology*, vol. **25,** pp. 506–527, 1930.

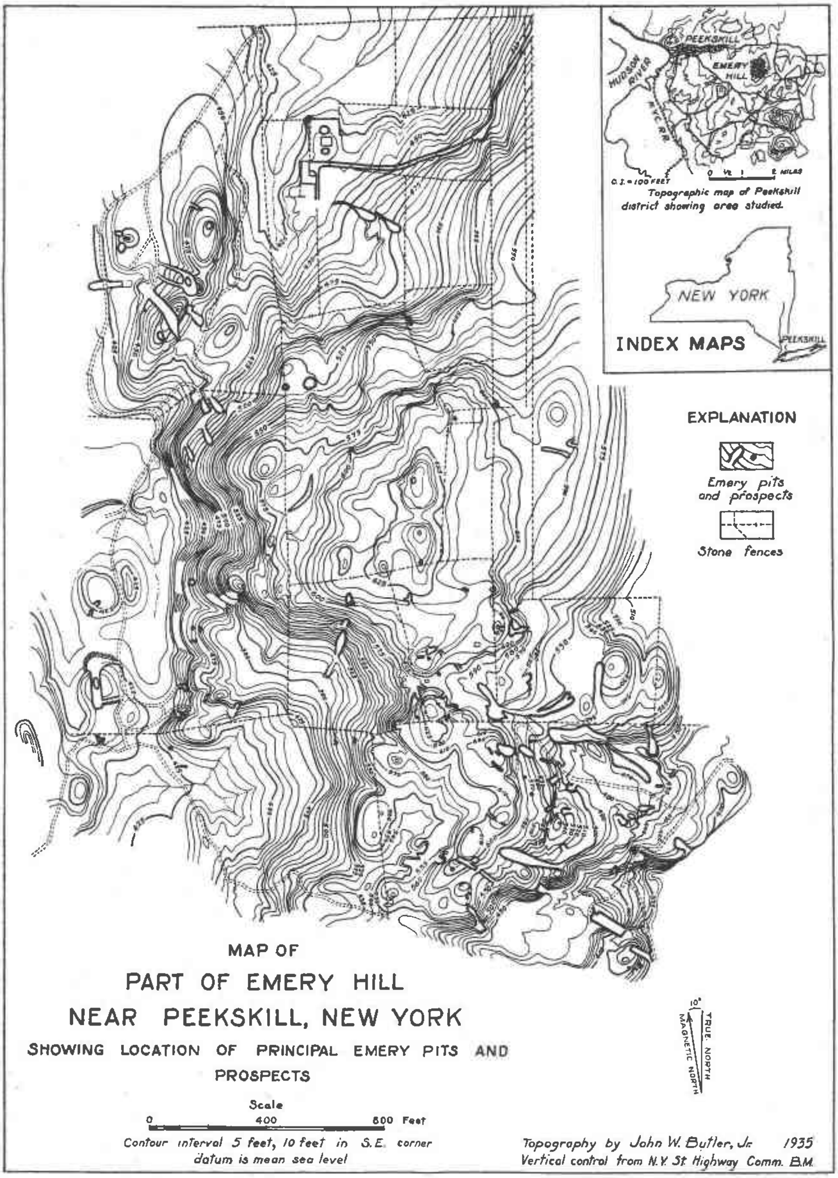


PLATE I

II) was plotted on this base. The area studied includes 54 major emery pits and 55 prospects. Many specimens were collected and more than a hundred of these were selected for thin-section and polished surface studies.

FIELD RELATIONSHIPS

General Statement

The emery deposits are associated with the complex Cortlandt series of basic igneous rocks which was intruded into the tightly folded Manhattan schist—Inwood marble series of southeastern New York. The Cortlandt series has an areal extent of between 25 and 30 square miles, and crops out in an ovate east-west area which transects the north-northeast regional strike of the metamorphics. Manhattan schist surrounds the series except for three-quarters of a mile on the northeast, where Peekskill granite is mapped adjacent, and two and a half miles of the southern boundary, where Inwood marble has been intruded. Xenoliths of schist and marble are included in the Cortlandt plutonics. The commercial deposits of emery (a mixture of pleonaste, corundum, and iron ores) occur as pods and lenses associated with the exomorphosed schist and an endomorphosed igneous rock in the pyroxenite areas of the Cortlandt series, a fact observed by Rogers, and by Gillson and Kania.

The Manhattan schist deserves special attention. Its aluminous character, and the fact that the alumina and the iron content increase in the exomorphosed schist progressively toward contacts with the igneous rock, form the basis for fundamental arguments in favor of the absorption theory of emery origin. Therefore, the study of mineralogical changes accompanying contact metamorphism of the schist is particularly significant. Discussions and conclusions favoring origins of emery by magmatic segregation or any stage of contact-metamorphism require a general understanding of the complex nature and relationships of the Cortlandt series. For these reasons, brief descriptions of the Manhattan schist and the Cortlandt series are given to serve as a background for observations to follow.

Geological Formations

Manhattan Schist

The average specimen of Manhattan schist is a quartz-mica schist, completely recrystallized, distinctly foliated, and dominantly micaceous. Muscovite is the most characteristic mineral; biotite is common. Feldspar is found in many specimens, andesine being the most common variety, though the range from orthoclase to labradorite is reported.[10] Garnet is the chief accessory mineral and often carries inclusions such as quartz, magnetite, and biotite. Other accessory minerals include tourmaline, staurolite, sillimanite, apatite, kyanite, zircon, zoisite, rutile, pyrite, and magnetite, which are found alone or together in a variety of

[10] Fettke, Chas., The Manhattan schist of southeastern New York State and its associated igneous rocks: *Annals New York Acad. Sci.*, vol. **23**, pp. 193–260, 1914.

combinations and proportions. Pegmatitic injections and quartz veins are plentiful in certain areas and in those places the schist generally becomes feldspathic. It intergrades at the contact with the underlying dolomitic Inwood marble.

Cortlandt Series

Dana[11] recognized the unique quality of the Cortlandt series and named it for Cortlandt township in which it occurs. Other areas of similar lithology are at Stony Point, across the Hudson River, and at Rosetown, New York,[12] a mile west. Connecticut[13] contains two areas of similar rocks; one about 5 miles west of Litchfield, and the other north of Danbury.

The complexity and quality of the series changes rapidly from outcrop to outcrop and even within the range of a single exposure. Many rock types exist; Rogers described granite, syenite, sodalite syenite, diorite, gabbro, several varieties of norite and pyroxenite, peridotite, and hornblende. Dike rocks include aplite, pegmatite, dacite porphyry, dioritic and gabbroic dikes, hornblendite, and serpentine (altered peridotite).

Rogers has shown that noritic rocks constitute the bulk of the Cortlandt series and are centrally located with respect to related rock types; pyroxenitic and peridotitic rocks form the eastern third of the area and the southwestern portion contains the largest diorite area, numerous schist and marble xenoliths, and pyroxenite and peridotite rock types which crop out near the Hudson River. It is significant to the present problem that the noritic rocks solidified after the pyroxenite types had developed. The Peekskill granite, which according to Berkey[14] is related to the series because of mutual high soda content, forms a separate mass to the northeast of the basic area; no mutual field relations with the basic Cortlandt rocks have been observed.

ROCK TYPES OF EMERY HILL

GENERAL STATEMENT

Three principal emery producing districts have been found within the Cortlandt series: (1) the southwestern part of the igneous area in the

[11] Dana, James Dwight, Geological relations of the limestone belts of Westchester Co., New York: *Am. Jour. Sci.*, Series 3, vol. **20**, p. 194, 1880.

[12] Kemp, J. F., On the Rosetown extension of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **36**, p. 247, 1888.

[13] Hobbs, W. H., On two new occurrences of the "Cortlandt Series" of rocks within the State of Connecticut: *Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch*, E. Schweizerbartsche Verlagsbuchhandlung, Stuttgart. p. 25, **(1906)**

[14] Berkey, C. P., The acid extreme of the Cortlandt series: *Science*, vol. **28**, p. 575, 1908.

vicinity of Crugers, (2) the southeastern part in the vicinity of Salt Hill, and (3) Emery Hill (also known as Garnet Hill) in the northeastern part, where the detailed investigations set forth in this paper were made. The first was least important and the last was by far the most important producer. All three districts are associated with areas of pyroxenite, as

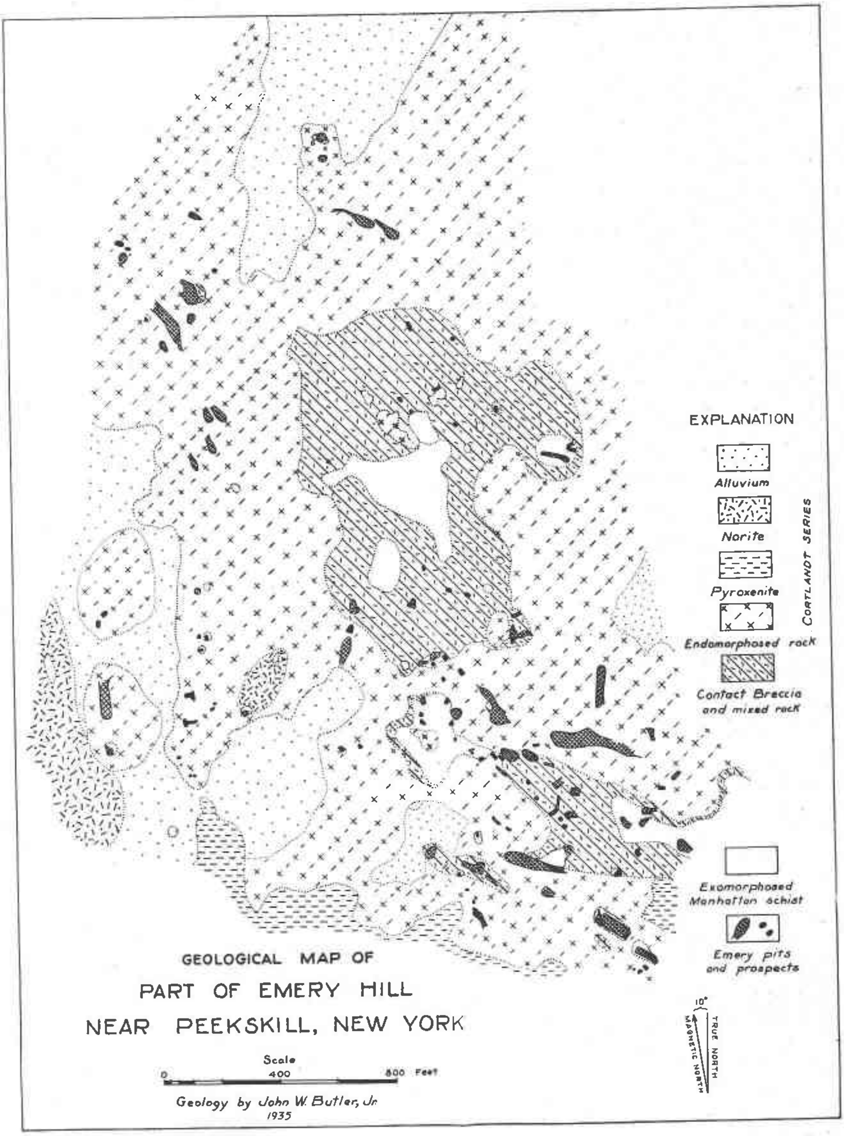


PLATE II

delineated by Rogers, and are near the borders of the intrusive series.

Emery Hill, where the chief emery deposits are found, lies nearly two and a half miles east of Peekskill. The Crompond Road from the village passes directly north of it. The hill attains an altitude of 650 feet and is a conspicuous topographic feature in its vicinity where the maximum relief averages about 225 feet.

The rock types of Emery Hill (Plate II) record significant details concerning the origin of the emery deposits and are worthy of separate description after this brief statement of their mutual relations.

A contact zone is present and includes: (1) exomorphosed Manhattan schist which forms the crest of Emery Hill; (2) a variable bordering zone of contact breccia and mixed rock; and (3) endomorphosed norite. These divisions are separated in some places by sharp boundaries, but in general, grade imperceptibly into each other. The commercial deposits of emery are in the exomorphosed and endomorphosed rocks. Contact metamorphic processes and modifications (including assimilation), especially as related to emery formation, are clearly illustrated in this zone.

After consolidation had begun, emanations from the still liquid magma passed through the marginally solidified rocks and modified them appreciably, in a patchy manner. Gillson and Kania relate the formation of emery to this stage.

Cortlandt rock types in the district that developed by differentiation include: (1) pyroxenite, which crops out to the east and southwest of Emery Hill; (2) later formed noritic rocks, which are exposed to the southwest and west; and (3) several types of related lamprophyric dikes. These rocks were studied to discover if the differentiation trend of the Cortlandt series was toward a final concentration of emery-forming products.

Xenoliths of exomorphosed schist, especially emery-bearing types, are abundant in the contact breccia, endomorphosed norite, and later formed norites. Their different behavior during the changing magmatic conditions from early to late crystallization stages has a direct bearing on the formulation of a theory of genesis for the emery deposits.

Healed fracture systems exist in the early solidified portions of the intrusive. These fractures were opened by cooling shrinkage and were healed by a flood of deuteric substances passing off from the still liquid portions of the magma. The healed fractures are significant because they followed the formation of emery, showing that the ore was an early development and that late-consolidation emanations were not responsible for its formation.

New information of general interest, but with indirect bearing on the problem, has been included in some of the detailed descriptions of rock types in order to present a more complete picture of the geological relations.

Contact Zone Rock Types

Exomorphosed Schist or Metaschist

Contact-metamorphism has changed the schist to a tough, dense, grayish to pinkish rock that is variable in its texture, structure, and mineralogical composition. The finest textured portions are composed of a mass of parallel fibers of sillimanite; coarser types contain blades of kyanite exceeding an inch in length, and garnets an inch and a half in diameter. Sillimanite-rich types preserve the foliation of the schist better than do the coarser-textured, patchy types rich in garnet, kyanite, or staurolite. Differential weathering has pitted and roughened most of the rock and has accentuated the preserved or pseudomorphic schistosity, which is generally obscure on fresh surfaces (Plate III, Fig. 1). This rock has been called a hornfels[15] but the general conception of a hornfels[16] is that of a dense, fine- to sugary-textured rock, which has been completely recrystallized by contact-metamorphism so that any cleavage or incipient schistosity of the parent rock has been obliterated. In this paper, the exomorphosed schist will be referred to as "metaschist," a name suggested as a loose contraction of "contact-metamorphosed schist." It is used to designate that part of the schist which has been recrystallized by contact action so that it contains a mineral assemblage which is new either in variety or in obvious proportions, and which is not properly classified as "hornfels" because of its coarseness of texture and/or preserved or newly acquired structural characters.

The metaschist was early recognized as a contact-metamorphic product. However, Bowen explained the mineralogical changes as due to reaction between the schist and liquid magma, the process involving solution of soluble oxides from the schist and recrystallization of surplus material as a sillimanitic rock. Gillson and Kania pointed out the im-

[15] Gillson, J. L., and Kania, J. E. A., *Op. cit.*, p. 517, 1930.

[16] Grout, F. F., Petrography and Petrology. McGraw-Hill Book Co., Inc., p. 370–372, **1932.**

Grout, F. F., Contact metamorphism of the slates of Minnesota by granite and by gabbro magmas: *Bull. Geol. Soc. Am.*, vol. **44**, p. 999, 1933.

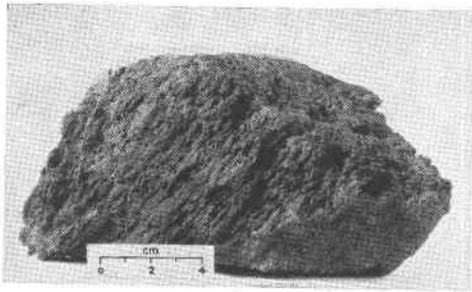
Harker, A., Metamorphism. Methuen & Co., Ltd., London, pp. 5, 23, 35, 39, 97, 333. **1932.**

Harker, A., Petrology for Students. Cambridge Univ. Press, p. 271. **1919.**

Holmes, A., The Nomenclature of Petrology. Thomas Murby & Co., London, p. 119. **1928.**

Shand, S. J., The Study of Rocks. Thomas Murby & Co., London, p. 179. **1931.**

Tyrrell, G. W., The Principles of Petrology. E. P. Dutton & Co., Inc., New York, pp. 271, 272, 291, 295, 305. **1929.**



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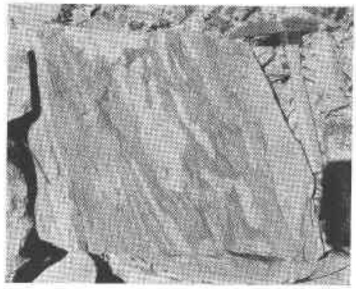

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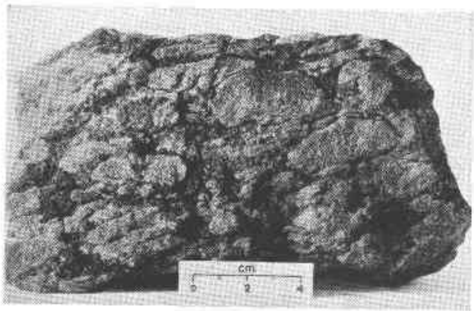

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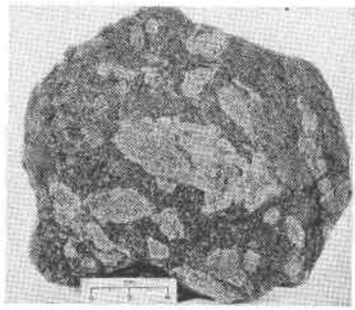

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PLATE III

Plate III, Fig. 1. Sillimanitic type of exomorphosed schist, showing the preserved, or "pseudomorphic" schistosity which is accentuated by differential weathering.

Plate III, Fig. 2. Banded feldspathic emery from southern part of Emery Hill area. Note how emery (dark) tends to follow the contortions of the former foliation; it also tends to cut some of the feldspathic streaks. A zone of healed fractures cuts the block parallel to its lower side.

Plate III, Fig. 3. Specimen B-9. Contact breccia with parallel, elongate, corroded inclusions. The intruding Cortlandt magma apparently filtered into the rock along structural weaknesses such as the foliation.

Plate III, Fig. 4. Specimen 151. Contact breccia facies in which sufficient magma had been intruded to make the mass mobile and destroy the parallel alignment of the tiny xenoliths before final solidification. The igneous rock is more feldspathic than in the facies illustrated in Plate III, Fig. 3. Note the narrow feldspathic border which is conspicuously developed around some xenoliths.

possibility of such a process modifying the schist "tens of feet from the contacts." Emanations released during the course of intrusion and solidification of the Cortlandt magma were undoubtedly largely responsible for the aureole of exomorphosed schist.

The mineral assemblage in the metaschist is large, and detailed paragenetic relations are obscure; they seem to vary throughout. This is because the paths of emanations escaping from the magma were not uniformly distributed throughout the schist and they tended to shift from time to time, so that the mineral products of their activity are irregular in distribution and concentration. In general, it can be said that garnet (almandite?), some biotite, and some minor accessories such as zircon, are relics of the schist and are products of regional metamorphism. Some feldspar and quartz may have the same history.

Sillimanite, kyanite, staurolite, cordierite, biotite, chlorite, sapphirine, chloritoid, and possibly some garnet and feldspar are products of neomineralization or recrystallization caused by contact-metamorphism. Amphibole, some biotite, andesine and sodic labradorite (extinction on (100) albite twin lamellae = 30°), tourmaline, allanite, and possibly quartz have been introduced from the Cortlandt magma.

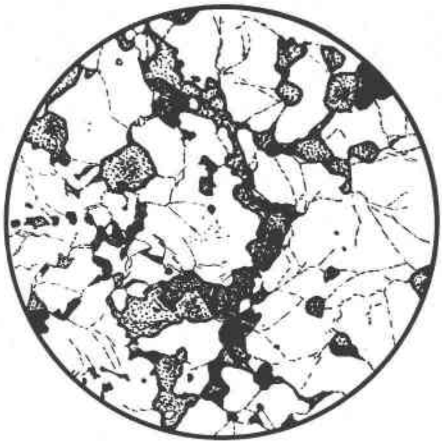

FIG. 1. Illustration of the penetrating and introduced character of emery minerals in the exomorphosed schist. Pleonaste, some högbomite (both stippled), and iron ores (black) have been introduced along fractures in garnet (white) which is practically the only relic mineral of the Manhattan schist that is left. A later developed fracturing is also present in the garnet.

Finally, pleonaste, högbomite, corundum, iron ores, some biotite, and an associated low birefringent amphibole with optical properties approaching pargasite belong to the stage of emery development. The iron ores cut everything, except in several cases where amphibole appeared last. In places, intergrowths of amphibole and spinel are found between plagioclase and emery. Emery minerals have been introduced into old fractures in the garnet (Fig. 1).

The dissemination of emery minerals throughout the metaschist cannot be explained by the absorption theory. The ore must have been formed or introduced by magmatic emanations at some time during the process of exomorphism.

Contact Breccia

A variable zone of contact breccia and associated mixed rock (schist and pyroxenite, or norite) exists between the metaschist and the endomorphosed norite. The contact breccia is crowded with tiny corrosion-rounded inclusions (Plate III, Figs. 3, 4) and in many places near the contact, the xenoliths are often spaced so closely that they simulate a conglomerate. The contact breccia, although limited in extent, is important because it presents the opportunity to study the gradual changes xenoliths undergo after being immersed in the basic magma. Petrologic observations relative to the development of emery are stated under the subject of xenoliths.

Outcrops of the contact breccia on Emery Hill exhibit features suggesting that many inclusions were formed not so much by shattering of the metaschist as by gradual separation and isolation of fragments by a seeping and permeating magma. The magma accomplished this by filtering into the rock along foliation and other structures (Plate III, Fig. 3). The rounding and reduction of the boundaries of fragments by magmatic corrosion or absorption occurred with the continuation of the process. If sufficient magma was forced between inclusions, the whole became mobile as a unit. Continued influx of magma diluted the contact breccia and ultimately formed rock facies in which xenoliths are widely scattered.

In this zone intrusion evidently took place in pulsations because rock crowded with xenoliths may be found intruded by a dike or mass of rock containing fewer inclusions, and this in turn may be cut by other igneous intrusions containing still fewer xenoliths. The boundaries are sharp or gradational. Where sharp, xenoliths in the earlier formed rock may be transected. Dikes composed entirely of igneous rock may intrude everything.

In some places, magmatic aggression proceeded faster into the metaschist than in adjacent areas; as a result, some larger blocks of metaschist gradually became surrounded by contact breccia and magma and were thus ultimately engulfed in the advancing magma by this stoping process.

Endomorphosed Rock

Many variations in appearance and composition of the endomorphosed rock are expectable. Syntexis developed a variable rock, which was further modified after solidification, by emanations passing through it from the still-liquid magma below. A short description can be only a generalization.

The most impressive facies of the endomorphosed rock is a darkcolored porphyritic type in which the phenocrysts are large poikilitic black hornblende or, rarely, biotite, set in a much finer-textured groundmass of feldspar and pyroxene. Many of the glistening cleavage faces of hornblende are 2.0 cm. across. Extreme widths of 9.0 cm. are found elsewhere in the series. They stand out in relief on some weathered surfaces. Biotite phenocrysts are smaller. The groundmass minerals in these varieties rarely exceed one millimeter in diameter, but generally become larger as the phenocrysts become smaller. Some portions of the rock are quite micaceous. As a rule, the igneous rock adjacent to xenoliths or emery pits is fine- to medium-grained, and feldspathic to the point of having a "salt and pepper" appearance. Outcrops have a dark, dirty appearance. Rogers[17] and Gillson and Kania[18] made special reference to this type.

In addition to hornblende, augite, pigeonite, hypersthene, enstatite and biotite, the variable endomorphosed rock contains apatite, some epidote, zoisite, and unabsorbed garnets held over from assimilated schist. Quartz is common. There is generally no more than 15 per cent feldspar in the basic varieties of rock. It is labradorite and more sodic varieties, and many of these have been corroded or partly replaced by more sodic feldspar, brought in by passing emanations. In such cases, the poikilitic hornblende is also altered to uralite and a low birefringent amphibole.

The poikilitic hornblende deserves attention because of its relation to the contact zone. Various writers[19] have considered it to be a late crystallizing orthotectic mineral, or deuteric in origin. It replaces, embays, corrodes, and includes pyroxenes, and doubtless is of deuteric origin in the most limited sense of the term. However, it not only occupies pyroxene replacement areas, but has filled interstitial spaces as well.

The writer suggests that the igneous poikilitic hornblende in the endomorphosed zone is an index of that zone because the mineral developed under the special conditions prevailing there, and its substance would have crystallized as pyroxene under conditions prevailing farther within the magma chamber. The fact that the formation of hornblende was retarded may be attributed, in part, to lag of the magma in responding to the newer conditions, among which were lower temperatures and

[17] Rogers, G. S., *Op. cit.*[4], pp. 35, 70, 73, 1911.

[18] Gillson, J. L., and Kania, J. E. A., *Op. cit.*[9], pp. 513–517, 1930.

[19] Williams, G. H., Peridotites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **31**, p. 30, 1886.

Rogers, G. S., *Op. cit.*[4], pp. 36, 43, 1911

Gillson, J. L., and Kania, J. E. A., *Op. cit.*[9], p. 511, 1930.

Howe, Ernest, Sulphide-bearing rocks from Litchfield, Conn.: *Economic Geology*, vol. **10**, p. 333, 1915.

the increasing amounts of mineralizers present. Kennedy's[20] recent study of factors influencing the development of hornblende or pyroxene in igneous rocks supports this hypothesis, as does earlier work by Allen, Wright, and Clement.[21] A brief field examination in other parts of the Cortlandt series confirmed the view that the poikilitic hornblende may be one of the indicators of the endomorphosed zone.

The criterion used by Gillson and Kania to distinguish endomorphosed rock from their fresh "mela-norite," which also contained poikilitic hornblende, was that the post-consolidation emanations had modified the former. The changes described are similar to those associated with deuteric effects. They also considered the presence of hydrothermal or pneumatolytic quartz as indicative of the process of endomorphism. They pictured the process as taking place after a marginal zone of the intrusive had solidified. Residual emanations, which passed up from the magma chamber, through the crystallized margins and into the country rock, brought about these modifications and made the consolidated border zone an "endomorphosed rock."

Such a procession of events is evident, but it is only fair to question the application of the term "endomorphism"[22] to post-consolidation

[20] Kennedy, W. Q., The influence of chemical factors on the crystallization of hornblende in igneous rocks: *Mineral. Mag.*, vol. **24,** pp. 203–207, 1935.

[21] Allen, E. T., Wright, F. E., and Clement, J. K., Minerals of the composition $MgSiO_3$; A case of tetramorphism: *Am. Jour. Sci.*, Series 4, vol. **22,** pp. 385–438, 1906.

[22] This confusion concerning the significance of the term "endomorphism" has crept into the literature since the time Spurr, Garry and Fenner [Spurr, J. E., Garry, G. H., and Fenner, C. N., A contact metamorphic ore deposit, the Dolores Mine at Matehuala, San Luis Potosi, Mexico: *Economic Geology*, vol. **7,** pp. 471–474, 1912] set forth their important observations on contact metamorphism at the Dolores Mine, San Luis Potosi, Mexico. Subsequent comments by Spurr [Spurr, J. E., Theory of ore deposition: *Economic Geology*, vol. **7,** p. 485, 1912], Umpleby [Umpleby, J. B., Geology and ore deposits of the Mackay Region, Idaho: *U. S. Geol. Survey, Professional Paper* **97,** p. 65, 1917], Eckermann [Eckermann, Harry von, The rocks and contact minerals of the Mansjö Mountains: *Geol. Fören. Förh.*, p. 343, **1922**], and Gillson [Gillson, J. L., Contact metamorphism of the rocks in the Pend Oreille District, Northern Idaho: *U. S. Geol. Survey, Professional Paper* **158-F,** 1929], carried this trend of thought down to Gillson and Kania's application of the same in the Emery Hill district. However, Umpleby did distinguish between an earlier "contact metamorphism" and a later post-consolidation "contact metasomatism."

Holmes [Holmes, A., *The Nomenclature of Petrology.* Thos. Murby & Co., London, p. 90, 1928], following Fournet's original definition [*Bull. Geol. Soc. de France*, vol. **4,** series 2, p. 243, 1847], defines "endomorphism" as follows:

"The modification produced in an igneous rock due to the partial or complete absorption (assimilation) of portions of rocks invaded by its magma; a phase of contact-metamorphism in which attention is directed to the changes suffered by the intrusion instead of to those produced in the invaded formations."

To the above possible modifications can be added contact chilling effects such as would affect texture of the intrusive or the kind of minerals crystallizing during consolidation.

modification of an igneous rock by its own final consolidation residues. Endomorphism (contact-metamorphism within the intrusive) is established in the literature as signifying the modifications in an igneous rock which are influenced by the country rock. The process ceases when the marginal portions of an intrusive have become inactive and solidified. Thus, post-consolidation modifications of an igneous rock by its own final consolidation residues are strictly magmatic effects and do not result from any influence of the country rock.

Close study failed to disclose a zone of "endomorphosed norite" between fresh "mela-norite" and the schist contact, as Gillson and Kania intimate. The "mela-norite," or fresh norite, is often found closer to the contact than is the "endomorphosed norite." Field relations and petrologic study revealed that the "mela-norite" does not represent a distinct and later-formed rock which was in places intruded into the endomorphosed rock, but it is part of the marginal solidified zone, or endomorphic rock. The apparent incompatible distribution of "mela-norite" and "endomorphosed norite" is explained by the fact that the paths followed by the modifying emanations through the solidified border zone were selective and irregular; consequently, modifications are distributed in a patchy manner throughout that zone. It is believed that the modifications attributed to endomorphism by Gillson and Kania are properly classified as later developments in the endomorphosed rock.

Differentiated Rock Types

Pyroxenite

Pyroxenite rock types crop out east and southeast of Emery Hill. Fresh specimens are dark, coarse- to fine-grained, massive, granitoid rock. They may weather reddish or grayish.

Both monoclinic and orthorhombic subhedral and anhedral pyroxenes are the essential constituents. Augite is most plentiful and has simple and polysynthetic twinning parallel to (100). A strongly pleochroic monoclinic pyroxene (X=pink, Y=light pink, Z=greenish) is present in subordinate amounts. It has a small optic angle, is optically positive, and its birefringence is closer to that of augite than to that of hypersthene. The optical data suggest that it is pigeonite. Hypersthene is present in varying amounts, in some places subordinate to pigeonite. Many of the larger pyroxenes have wavy extinction, and tiny needle-like inclusions and schiller structures are plentiful.

Minor amounts of deep-brown, strongly pleochroic, biotite occur as final consolidation replacements or alterations of pyroxene.

These additions follow the thought in the last clause of Holmes' definition. This understanding of endomorphism will be used through the paper.

The amount of olivine varies in these rocks. It is optically positive; irregular in outline; and its fractures are generally filled with serpentine.

Some small patchy sericitic aggregates mark last crystallizing areas in this rock. The centers of these areas are usually medium basic plagioclase, seldom larger than 0.3 mm. in diameter. The lingering residual liquids have clearly altered the surrounding pyroxene or olivine in the immediate vicinity to irregular aggregates of magnetite, biotite, serpentine, sericite (?), and uralite. Sometimes carbonate is present. No orthotectic or deuteric development of spinel or corundum was observed.

Norite

With increase of feldspar the pyroxenite rock types grade into noritic types, which crop out on the southwestern side of Emery Hill and westward. These rocks are medium- to coarse-grained and dark gray, though much lighter on the weathered surface than are the pyroxenitic types. Schlieren, flaser, and other mineral orientation structures are well developed. Many xenoliths are present. Emery-bearing types are common, and autoliths of pyroxenite indicate that norite crystallized after the pyroxenitic rock types. The noritic magma was still liquid when the margins of the intrusive had solidified and so released emanations which passed through the already solidified rock types.

The mineral components include varying amounts of plagioclase, ranging from medium labradorite (extinction on albite twin lamellae normal to (010) zone$=35°$) to oligoclase, pyroxene in the form of augite, pigeonite and hypersthene, and biotite. Some pale blue-green pleochroic uralite has developed from the pyroxene. Ilmenite and apatite are characteristic accessories of the noritic rocks. The former is mostly associated with the ferromagnesian minerals, and cuts across them.

Myrmekite and quartz-biotite-symplektite are scattered throughout the rocks. These final-consolidation products cut into earlier-formed minerals. They are deuteric in the most limited sense of the term and show that while consolidating, the norite followed the normal differentiation trend from ferromagnesian and lime-rich minerals to sodic and silicic minerals. No indications observed in the composite mineral assemblage suggest that the norite magma differentiated toward an unusual alumina-rich residue, as should be the case if the emery minerals were deposited by escaping "gaseous or liquid emanations" passing through two rocks as different as the endomorphosed norite and the metaschist.

Dikes

Dark, fine- to medium-textured lamprophyric dikes, up to 6 inches wide, are present, especially in the foliated norite. They resemble kersantite and spessartite varieties. Field relations indicate that they had formed as units and began intruding the norite while it was still somewhat plastic, the intrusion continuing after the norite had solidified, or at least behaved as a solidified crystalline rock.

Some similar, but much more feldspathic, dikes are found cutting emery in several of the emery pits, especially those west of Emery Hill. The relationships will be described later.

Dikes rich in feldspar, and containing hornblende crystals up to 4.0 or 5.0 cm. long, are found in the southeastern portion of the mapped area on the hillside, at about altitude 540 feet. They penetrate the contact breccia and adjacent igneous rock.

Small myrmekite and myrmekite-like patches are common in the dikes. Quartz and oligoclase are abundant as final-crystallization and replacing minerals. It is significant that the final-consolidation products are silicic and alkalic minerals. The differentiation which developed the magmas of the dikes apparently did not develop a concentration of emery mineral constituents. No corundum or spinel is present except in xenoliths.

Emery-Bearing Xenoliths

Small xenoliths from the contact breccia, endomorphosed rock, and various portions of the noritic rock types were examined with special reference to the genesis of the emery minerals. The contact breccia has been described. The endomorphosed rock and norite contain many small xenoliths which include: (1) rare quartzose inclusions, which probably are remnants of quartz veins or pegmatites originally in the schist (a green chloritic or uralitic border surrounds them); (2) feldspathic inclusions, usually containing small amounts of disseminated emery minerals; and (3) emery-rich inclusions, with which we are now concerned.

The small emery-rich inclusions in the endomorphosed rock have ovate, or lens-shaped forms, or are tabular masses up to a foot or two long and nearly an inch wide. Many xenoliths have an internal laminated structure due to the varied concentration of component minerals. Large pyroxene or biotite crystals are found in some xenoliths. A feldspar border, one to two millimeters thick, surrounds the inclusions. Between this feldspathic border and the coarser-grained endomorphosed rock is a variable zone, up to an inch wide, of "salt and pepper" type of feldspathic norite. The "salt and pepper" zone calls to mind Bowen's[23] deductions concerning the precipitation of calcic plagioclase and hyper-

[23] Bowen, N. L., *Op. cit.*, 1922.

sthene during the advance stages of assimilation. Read[24] recently described patches of this character in the norite of the Haddo House District, Aberdeenshire, and interpreted them as of xenolithic origin.

In places, tabular emery masses and many other small inclusions are grouped crudely parallel in the endomorphosed rock, in a manner suggesting that they form a zone of pinching and swelling veins of emery. However, closer inspection discloses that a few of the tabular masses are abruptly terminated at one end, showing that they are not veins, but have been broken from a larger mass and are xenoliths.

Many of the emery-rich xenoliths are believed to be unassimilated emery-bearing remnants of larger masses.

Petrologic study suggests that the conditions important in the development of the emery were so closely related to the conditions prevailing during the immersion of the xenoliths in the liquid magma that, in many instances, it is difficult to judge whether the surrounding magma caused emery minerals to develop, or whether it caused them to be disaggregated and destroyed. However, wherever the surrounding magma was rich in mineralizers, or flooded by emanations after solidification, the emery minerals tended to be destroyed.

The disaggregation of emery is observed in many small inclusions from the contact breccia. The tiny xenoliths are mostly masses of medium basic plagioclase anhedra through which the emery is disseminated. The ore has separated into tiny aggregates composed of various combinations of corundum, iron ore, and spinel, with a few projecting fibers of sillimanite and biotite, and possibly a clinging fragment of associated low birefringent amphibole. The intruded basic igneous rock has been uralitized and modified by magmatic emanations.

Earlier stages of the process are exhibited. Tiny xenoliths in specimen No. 151 (Plate III, Fig. 4), from just west of the crest of Emery Hill, contain several granular aggregates of corundum, metallic minerals, and feldspar, all gathered in the shape of corundum crystals (Plate IV, Fig. 1). Corundum grains in the aggregates have various optical orientations and are embayed so that they have ramifying forms. It is apparent that these granular aggregates are not synneusis clusters, or corundum crystals in the process of development. They are interpreted as an arrested early stage in the disintegration or disaggregation of corundum crystals.

[24] Read, H. H., The gabbros and associated xenolithic complexes of the Haddo House District, Aberdeenshire: *Quart. Jour. Geol. Soc. London*, vol. **91**, part 4, pp. 608, 609, 620–622, 629–630, 1935.

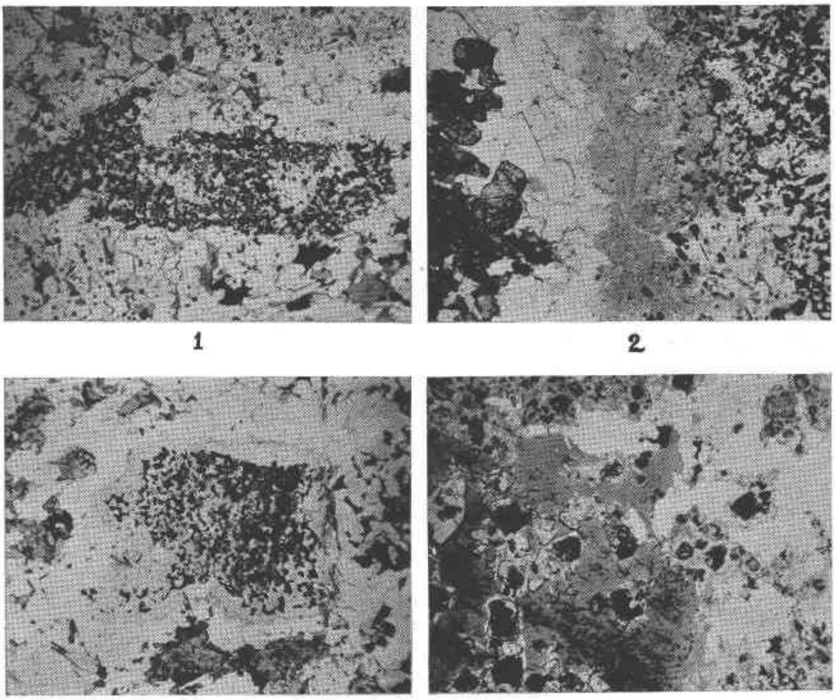

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PLATE IV

Plate IV, Fig. 1. Photomicrograph (×16) illustrating what are believed to be corundum crystals in an early state of disaggregation and destruction, as found in small xenoliths in the contact breccia (Spec. 151). The aggregates in the shapes of corundum crystals (cf. Plate V, Fig. 3) consist of corroded corundum aggregates, iron ores, and feldspar. Emery minerals are disseminated generally throughout the feldspathic inclusion shown.

Plate IV, Fig. 2. Photomicrograph (×18) illustrating the zoning which is developed in xenoliths by magmatic immersion. Dark minerals on the left are pyrozene of the endomorphosed rock; to the right is a narrow border of plagioclase; then, a section of the sericitic aureole around the inclusion; and farthest to the right is the main body of the inclusion which consists of large feldspar and biotite crystals through which pleonaste and iron ores (both black) are disseminated.

Plate IV, Fig. 3. Photomicrograph (×17) illustrating a microscopic xenolith of exomorphosed schist in norite from southwest of Emery Hill. The inclusion has become so small that the former aureole of micaceous material now forms the entire goundmass. Emery minerals are black and have ramifying forms. Some zoisite and epidote, and meshes of sillimanite fibers are present.

Plate IV, Fig. 4. Photomicrograph (×17) illustrating pleonaste altered by magmatic emanations. The pleonaste was disseminated through a xenolith composed principally of plagioclase and biotite. Outlines of former spinel grains are preserved by a metallic dust and a mesh of sillimanite fibers, biotite and possibly cordierite or feldspar. A few cores of unaltered pleonaste remain. Larger biotite crystals and the sillimanite fibers developed during the process of spinel alteration. The endomorphic rock surrounding this xenolith was also modified by deuteric emanations.

The process of liquid-magmatic modification of xenoliths has also developed a zoning in many while they were being corroded or absorbed. The zones consist of a narrow outer border of tiny plagioclase crystals, which gives place inwardly to a sericitic aureole. The interiors of the inclusions generally are composed of larger plagioclase and brown biotite, which contain scattered individuals of spinel, up to 0.2 mm. in width, in a poikilitic structure (Plate IV, Fig. 2). This modification process seems to continue until the inclusions are reduced to microscopic size (Plate IV, Fig. 3) and finally disappear.

Passing emanations alter the emery minerals. Spinel, especially, is changed to a residue of metallic dust and a mesh of sillimanite fibers, biotite, and possibly cordierite or feldspar (Plate IV, Fig. 4). Thus, emery minerals seem to be developed in xenoliths by the earliest stages of igneous metamorphism and are destroyed by the later magmatic processes.

Healed Fractures

One of the most persistent features in the western pyroxenite area, and one which has not been hitherto described, is the multitude of light-green vein-like lines, or narrow bands, that are spread like an irregular network over the outcrops. These "vein-like" features appear to represent a system of cooling-shrinkage fractures in early solidified igneous rock, which have been healed by a flood of deuteric emanations passing off from the yet-liquid magma chamber. The development and healing of the fractures took place after solidification of the endomorphosed rock, pyroxenite, some norite and lamprophyres, and, most important of all, *after formation of the emery*. It is especially significant from the standpoint of genesis that: (1) emery is cut by the healed fractures, thus showing that the ore had formed before the healed fractures developed; that (2) the fractures were healed with deuteric substances; and that (3) the deuteric substances tended to *destroy*, rather than to *develop* emery, so are eliminated as agents of emery formation.

The following petrographic descriptions of the healed fractures are given to show the deuteric nature of the healing emanations and how they modified, rather than developed emery.

In the pyroxenite and endomorphosed rock, the healed fractures may stand up in slight relief on weathered surfaces. The green bands vary in width from hair-lines to rare maximum widths of $3\frac{3}{4}$ inches. Most of them are less than an inch wide. A narrow central portion is white deuteric feldspar that has healed the fractures. The first deuteric crystals to form were sodic labradorite. Cores of that mineral were surrounded, embayed, transected, and replaced by progressively more sodic plagio-

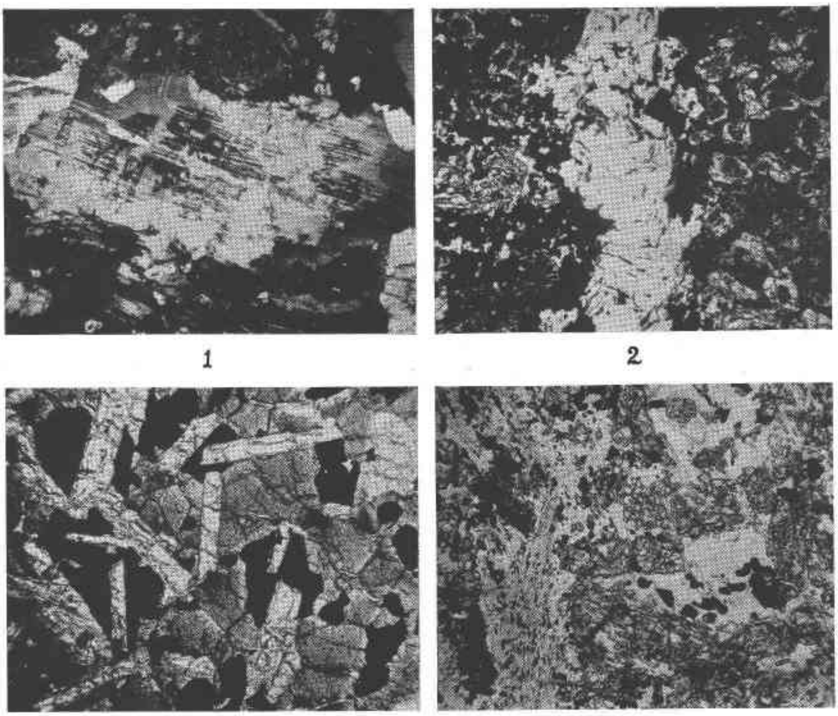

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PLATE V

Plate V, Fig. 1. Photomicrograph (×18, crossed nicols) illustrating deuteric plagioclase which heals many fractures and joints in the district. It is believed that the healed fracture systems were opened by cooling-shrinkage in early solidified Cortlandt rocks. The cores are sodic labradorite (extinction on albite twin lamellae normal to (100) zone=30°) and the corroding and replacing feldspar is progressively more sodic up to oligoclase.

Plate V, Fig. 2. Photomicrograph (×18) illustrating a healed fracture cutting emery. The fracture is filled with corundophyllite instead of the usual deuteric feldspar which is present where these fractures cut the igneous rock. Emery minerals have been cut through, altered, and replaced. All the spinel nearby has been changed to dusty black metallic matter. Some clouded corundum crystals and chlorite patches remain. Iron ores are black.

Plate V, Fig. 3. Photomicrograph (×33) illustrating gangue-free emery from west side of Emery Hill. Corundum (white) is elongated in basal plates, pleonaste (gray) is the most plentiful component, and iron ores (black—include: magnetite, specularite, and ilmenite) are generally in close association with, or surround the corundum.

Plate V, Fig. 4. Photomicrograph (×18) of a specimen from the large "keystone" emery block which remains in Strang's "Long Pit" to show that the ore is a mineralized exomorphosed schist xenolith and not a vein. The ore has been modified by magmatic emanations which passed through the early solidified endomorphosed rock from the still liquid magma. Pseudomorphic schistosity is preserved by unaltered sillimanite in the left side of the picture. Several broken and disaggregated crystals of corundum are in the center and top of the picture. Staurolite is in the lower center and right; light gray groundmess is chlorite. The black mineral is ilmenite.

clase up to oligoclase (Plate V, Fig. 1). Cloudy remnants of older feldspars exhibit deformation fractures and bent twin lamellae, and some of these stress structures are preserved by replacing feldspar. Accessory minerals are apatite, epidote, and zoisite. Apatite is most abundant and forms synneusis clusters.

The green megascopic appearance of the healed fractures is caused by wide borders of uralitized and chloritized wall rock. This alteration of the ferromagnesian minerals was effected by the soda-bearing deuteric emanations that passed along the fractures and penetrated their walls.

Wherever the healed fractures cross emery they contract to 1.0 mm. and less in width and corundophyllite with optical properties between protochlorite and ripidolite is present instead of feldspar (Plate V, Fig. 2). The emery is altered on either side of the "veinlets" for a distance of about 2.5 mm. Corundum is more resistant to alteration than the spinel. Corundum-rich emery is changed to dusty aggregates of magnetite and corundum. Spinel-rich emery is similarly altered, but also contains a few tiny blue corundum crystals or larger corundum crystals in which only small spots are a deep blue. Spinel is completely altered to dusty aggregates and small chlorite patches are disseminated throughout.

EMERY DEPOSITS

General Statement

Emery pits and prospects in the northeastern part of the Cortlandt series are distributed mainly along the east and west flanks of Emery Hill and across the southern part of the crest (Plate I); glacial overburden conceals the rocks underlying the smooth north slope. Only one pit has recently been in part time operation. The others evidently were abandoned shortly after the close of the World War period of activity. As pointed out by previous writers, the emery deposits form irregular pods, lenses, and vein-like masses, both in the metaschist and in the endomorphosed rock. However, the larger pits, with few exceptions, are narrow, long, and deep. Strang's "Long Pit" (Fig. 2) is a specific example. It is over 130 feet long, 10 to 30 feet wide, and was excavated to an approximate depth of 25 feet. A number of pits are larger than this, especially in the matter of depth, one in the southeastern part of the Emery Hill district being 80 feet deep. The elongate shape is generally characteristic whether the pits are in endomorphosed rock or in metaschist.

Mineralogy and Structure of the Emery

Pure Peekskill emery in the hand specimen is a heavy, massive, black, fine-textured aggregate. In some samples, corundum crystals (most of them white, but in some specimens pink or blue) are large enough to be

Fig. 2. Strang's "Long Pit," looking northwest. An illustration of the elongate shape of many major emery pits.

distinguished. The ore is tough and breaks with an irregular fracture. Pure emery is rare, and the presence of gangue minerals of different kinds or proportions modify its appearance. Gangue minerals characteristic of the metaschist tend to preserve a pseudoschistosity or banded structure in the ore and lighten its color to gray. Emery containing abundant garnet has a pinkish cast, and quartz and feldspar give the ore a streaked appearance.

Under the microscope, the Peekskill ore shows varying proportions of pleonaste, corundum, and the metallic iron ores (Plate V, Fig. 3). Rogers' analyses[25] showed the spinel to be a magnesia-poor variety of pleonaste. It owes its abrasive quality to a hardness of 8, and is the principal emery mineral of the district. The metallic minerals include magnetite, specularite, and ilmenite. Corundum varies in amount; it may be absent, or it may displace pleonaste entirely. It is euhedral and is developed in elongated basal plates. In places, högbomite (hardness = 6.5) is associated with the spinel in minor amounts, especially where the emery is in metaschist.

The iron minerals were usually the last to form, filling interstices between spinel and corundum. The metallic minerals often bound the euhedral or subhedral corundum, as though the latter had influenced their precipitation. Some polished surfaces show that magnetite completed its development before ilmenite and specularite, both of which marginally replace it to a certain extent in places. Exsolution structures of these minerals in each other are common. There is some good dactylitic development of magnetite and ilmenite.

Gangue minerals vary according to the local geologic history. They include various combinations and proportions of sillimanite, garnet, biotite, cordierite, staurolite, kyanite, feldspar, amphibole, pyroxene, quartz, chlorite, and chloritoid (?). Apatite is not present as an associate of the iron ores, except under conditions in which it may be traced to adjacent norite.

The emery has a banded structure, which suggested to previous writers a relationship between the ore and the schist. This banding varies in width from a millimeter to several centimeters. It is especially noticeable in sillimanitic ore, in which the bands tend to be parallel to the pseudomorphic schistosity of the exomorphosed rock. Even in most specimens of pure emery the concentration of spinel, corundum, and metallic minerals varies enough to produce a noticeable laminated structure. Most of the corundum crystals are oriented more or less parallel to the banded structure.

Description of Emery Deposits

Most of the emery pits have wall rocks of both metaschist and igneous rock; a few are entirely in metaschist; and a few are entirely in igneous (endomorphosed) rock, though never farther than about 100 feet from

[25] Rogers, G. S., *Op. cit.*, p. 69, 1911. (Two analyses).

xenoliths of metaschist. Important differences, significant enough to justify special consideration, exist between the emery deposits in metaschist and those in endomorphosed igneous rock.

Emery Deposits in Metaschist

The few emery pits which are cut in metaschist are found in the southeastern portion of the area mapped (Plate II).

In sillimanite-rich types of metaschist, the ore has a pronounced banding usually parallel to the pseudomorphic schistosity. In patchy types of metaschist rich in garnet, kyanite, or staurolite, and in mixed rock, the pseudomorphic foliation is less uniformly preserved, and emery has a sharp cross-cutting habit. Bordering zones of biotite and amphibole are characteristically associated with the latter deposits and are believed to have been developed by emanations accompanying those that introduced the emery. This association is not found when the emery deposits are entirely in igneous rock. Rogers observed the abundance of biotite in this section of the emery district, but he did not point out this interpretation of its significance and special relationship to the emery.

Syntectic igneous rock usually crops out close to deposits. Thus, the emery seems to have been formed or deposited by emanations from an igneous source passing through the mixed rock and into the exomorphosed schist. The aluminous country rock apparently was a favorable body for "fixing" or retaining the emery components of the emanations and may have contributed material, at one point or another, which helped to establish the aluminous character of the ore ultimately deposited.

An example of cross-cutting emery in the patchy type of metaschist is in the excavation at about 450 feet altitude, in the southeast corner of the area. The emery occurs near the bottom of the high northwest wall and is entirely in metaschist. Irregular apophyses extend upward and outward from the main mass. The contacts are sharp. Above the emery, for a varying width, approaching and exceeding three feet, is a zone of coarse-grained biotite and associated dark greenish-black hornblende. A similar, but less extensive, zone exists below the emery. The wall rock has a "mixed" appearance and is essentially a garnetiferous, feldspathic metaschist. Contact-metamorphism has destroyed the old schistosity or modified it into patchy structures. The plagioclase is calcic andesine, deuterically modified by later-crystallizing more sodic plagioclase. Here and there, it is found in fractures of the garnet, as are, also, blue-green hornblende and a few scattered grains of staurolite. Ilmenite and magnetite are found together in a pronounced dactylitic structure. The eastern portion of the north wall is syntectic igneous rock.

The large pit at the west end of this same outcrop also has much mica associated with the emery. Garnets, surrounded here by the metallic-rich emery, have a conspicuous kelyphitic rim of chlorite. Much mica is also found at the pit in the southern portion of the map, altitude 600 feet. This deposit is in thoroughly mixed schist and igneous rock.

The banded character of the ore is well illustrated in the longest pit at the southern edge of the map. The pseudomorphic foliation strikes northwest and has a vertical dip. Mining has followed a narrow zone, between 15 and 20 feet wide, about 125 feet long, and about 50 feet deep. The banded sillimanitic emery ore passes to a banded emery-bearing sillimanitic metaschist at the margins of the pit.

Emery Deposits in Endomorphosed Rock

Emery deposits in the endomorphosed rock were found to be xenoliths of mineralized metaschist, rather than veins as has been suggested.[26] It is believed that geologic relations suggest that the emery was essentially developed before the xenoliths were engulfed by the magma. During magmatic immersion, the emery appears to have been less susceptible to absorption than was the metaschist, and sometimes only a residue of irregular-shaped masses of ore remain. In places, later deuteric emanations passed through the early solidified endomorphosed rock from the still-liquid portions of the magma chamber, and modified both the emery and the endomorphosed rock. Several of the deposits are cut by siliceous dikes of the Cortlandt series, containing minerals that exhibit deuteric modifications. Likewise, fracture systems, which opened by cooling shrinkage and were later healed with deuteric substances, cut the emery in some of the pits. Petrologic examination indicates that deuteric substances and late magmatic emanations modified or destroyed the emery rather than deposited it. These observations fail to agree with the theories that emery developed from emanations after marginal solidification of the intrusive, as suggested by Larsen and by Gillson and Kania.

Banded sillimanitic emery deposits are common in the endomorphosed rock. Such a structural arrangement is not a likely result of crystallization from a magma and seems logically explained only as the result of mineralizing emanations penetrating the metaschist along the preserved foliation. Thus, the structure of emery deposits presents significant evidence against the absorption theory of origin. These observations date the formation of emery close to (if not before) the earliest stages of Cortlandt intrusion. The criteria on which these conclusions are based are set forth below.

[26] Gillson, J. L., and Kania, J. E. A., *Op. cit.*, p. 523, 1930.

The xenolithic nature of emery deposits in the endomorphosed rock, and characters which help to date the formation of the ore, are illustrated in Strang's "Long Pit" (Fig. 2) which is cut in the hillock at the northwest base of Emery Hill. The walls are endomorphosed rock of the poikilitic hornblende type and patches of emery still cling to them. Both emery and wall rock show deuteric modification and alteration by emanations. An undermined keystone-shaped block of ore remains in the southeast end of the long pit (Fig. 3). The general appearance of the deposit is suggestive of a large emery vein, but petrologic examination revealed that the ore is a modified xenolith of mineralized metaschist (Plate V, Fig. 4). Pseudomorphic schistosity characteristic of the metaschist is still preserved, especially where sillimanite needles have escaped alteration. Emanations developed a groundmass rich in chlorite. Corundum is disaggregated along partings and fractures, and is replaced, in part, by staurolite and chlorite. Staurolite is the most conspicuous mineral in the rock; its amount is surprisingly large. Masses of it interfinger with corundum or form either large (1.5 mm. by 0.5 mm.) solid or skeleton crystals. Cordierite is present; accessories are rutile, zircon, and tourmaline. Spongy ilmenite is the sole metallic mineral.

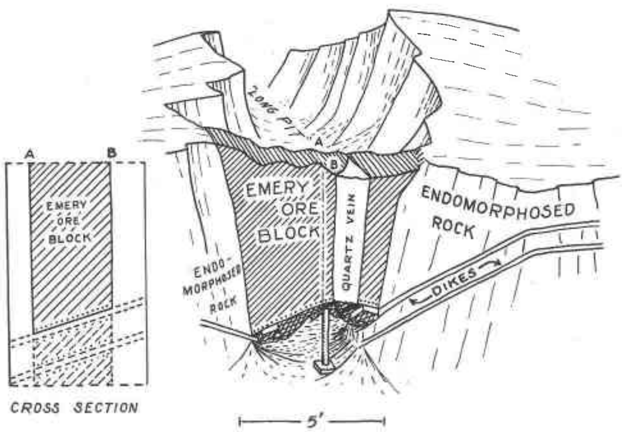

FIG. 3. Diagram to illustrate relationships between keystone block of emery ore and cross-cutting Cortlandt series dikes at the southeast end of Strang's "Long Pit."

A half-inch wide, northwest dipping dike cuts the present bottom of the block of emery. The fine-textured dike averages 23 per cent quartz, 63 per cent feldspar (sodic andesine to oligoclase) and the rest is hornblende and green biotite. Where it cuts the emery, the dike narrows to one-quarter of an inch in width, becomes more feldspathic, and develops chloritic borders. Deuteric effects were found in the dike.

"The cross-cutting vein" character of the emery in endomorphosed rock was pointed out by Gillson and Kania. They figured a specimen of ore-bearing norite from this vicinity, which showed a "vein" of emery extending from a larger mass of ore. The figure illustrated that "the emery occurs in the endomorphosed igneous rock as a sharply cross-cutting vein, not as a remnant of a partially absorbed inclusion of schist."[26]

Similar specimens have been collected by the writer, but close examination has always revealed a narrow border of feldspar surrounding the

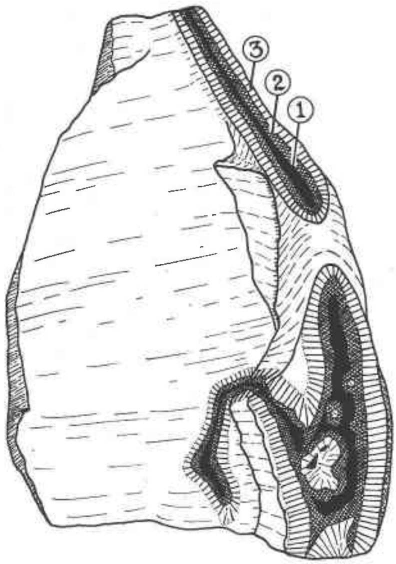

Fig. 4. Diagram illustrating modified xenoliths of emery-rich exomorphosed schist which imitate veins in endomorphosed rock. Specimen collected from wall of Strang's "Long Pit." Deuterically modified emery is separated from deuterically modified endomorphosed rock by a corundophyllite border. Microscopic examination revealed remnants and chlorite pseudomorphs of sillimanite and biotite in the emery. (1) is "fresh" emery, (2) is border of emory modified by igneous emanations, (3) is border of corundophyllite, all are enclosed by endomorphosed rock.

emery. This border is separated from coarser-textured endomorphosed rock by a narrow zone of medium-grained "salt and pepper" feldspathic endomorphosed rock. Identical feldspathic borders and zones are found surrounding undoubted xenoliths, as previously described. This suggests that the irregular ore masses, instead of being emery veins cutting previously formed endomorphosed rock, may be irregular masses of emery or emery-bearing rock which were caught up in magma that absorbed them in part and ultimately solidified around them.

A small vein-like mass of emery in endomorphosed rock (Fig. 4), taken from the north wall of Strang's "Long Pit," is of special interest in this respect. Its irregular shape does not resemble the remnant of a xenolith engulfed in the noritic magma, but suggests agreement with Gillson and Kania's conclusion. However, close study reveals that a border of green corundophyllite separates the emery from the igneous rock. The peripheral portions of the emery "vein" have a dull black appearance, but the central portion is bright, fresh, shiny black. In thin-section, the dull-appearing outer border of emery is revealed as ore that has been altered in the same manner as emery modified by the deuteric emanations that travelled along the healed fracture "veins" through the ore (Plate V, Fig. 2). Some pseudomorphs of chlorite after sillimanite and biotite, both of which minerals are characteristic associates of emery deposits in metaschist, are present. A residue of sagenite preserves the shapes of biotite flakes in some places. In spite of the first impression that this specimen of emery is a vein with a cross-cutting relationship to the endomorphosed rock, one must conclude that the emery is a remnant of ore originally developed in metaschist which was later engulfed by the magma and partially absorbed and altered to its present state by the enveloping igneous substances.

The banded structure of emery parallel to the pseudomorphic schistosity of inclusions is illustrated in a significant prospect at the southwest base of Emery Hill, some 250 feet east of Strang's "Horseshoe Pit." The wall rock is endomorphosed norite containing numerous small xenoliths. The prospected material is a metaschist xenolith in which the pseudomorphic schistosity is exceedingly well preserved; a few small garnets are scattered through it. The emery is found in a number of bands, which are parallel to the structure, but are not abundant enough to make commerical ore of the block. A "salt and pepper" zone of endomorphosed norite surrounds the metaschist block, in the manner described as characteristic around smaller xenoliths.

The significant feature, however, is that the pseudomorphic schistosity is unmistakably transected by the sharp contact of the emery-bearing metaschist with the igneous rock. In some places, the pseudomorphic schistosity makes an angle of between 25 and 30 degrees with the contact. Some of the transected bands are emery. Crystallization of the emery in this structure from a magma, as suggested by the absorption theory of origin, is impossible. It is also definitely shown that the emery does not form cross-cutting veins through the endomorphosed rock and into the metaschist along certain favorable channels. The emery is restricted to the metaschist block, except for small xenoliths scattered about in the igneous rock.

The time of emery development in the above described xenolith essentially may have been either: (1) after the xenolith became immersed in the magma, in which case ore-developing emanations were drawn directly from the magma in contact, or (2) before the block of metaschist was engulfed in the magma, and while emery-developing emanations were penetrating the country rock.

The second hypothesis seems more reasonable because: (a) Elsewhere, emery is found in portions of the metaschist in proximity, but not necessarily immediately surrounded by, or in contact with, igneous rock; hence, contact with magma does not seem necessary to develop emery. (b) Some xenoliths of exomorphosed schist are found well within the igneous rock, so that they had ample opportunity to drain emery forming substances from the liquid magma; nevertheless, they do not contain much emery. (c) No concentrations of emery or emery-rich components were observed ponded in the igneous rock bordering the emery bands in metaschist, as might be the case if the rock solidified before the process of emery introduction had exhausted itself. (d) The emery in this block is in bands more widely separated than are the perceptible differences in schist or metaschist. It is difficult to explain why the magma should be so extremely selective when so close at hand. Such selectiveness seems more likely if the magmatic source were distant. In fact, emery ore in deposits with metaschist wall rocks shows closer spacing of emery bands than this xenolith does. (e) Both emery and metaschist bands are transected abruptly at the edge of the xenolith. (f) No continuous zone or margin of emery penetration was observed around the periphery of the metaschist block.

Formation of emery previous to immersion of xenoliths in the Cortlandt magma, in part at least, is illustrated on the west wall of the large emery pit, 80 feet north of Strang's "Long Pit." The endomorphosed rock cuts through an emery layer, $3\frac{1}{2}$ inches wide, and includes fragments of the emery as pieces of an igneous breccia. The fragments are surrounded by feldspathic borders and zones of "salt and pepper" norite characteristic of xenoliths in the endomorphosed rock.

A narrow zone of disintegrating, crumbling rock usually surrounds emery deposits in the endomorphosed rock. So far as could be determined, this is largely due to a relative concentration of sulphides in the igneous rock neighboring the ore-bearing xenoliths. Sulphides are abundant enough so that weathering of them often yields conspicuous patches of hydrous iron sulphate. The chemical, and attendant physical, changes produced by weathering of the sulphides may account for the disintegration. The effects of dynamic action in the form of shearing and crushing around emery workings were pointed out by Rogers.

Evidence of Structural Control

A general consideration of the strikes and locations of the 54 major emery pits and the 55 smaller prospects in the district mapped (Plate I) suggests that mineralization might have been along several northwesterly-southeasterly striking zones rather than in random locations. The area was studied in an endeavor to determine whether or not a structural control actually existed and, if so, its cause. The map suggests that one possible zone of pits extends northwest from the southeast corner of the area. Another, less well defined, seems to extend southeasterly from the buildings on the Horowitz property to the crest of the hill. Several good-sized pits lie some distance east of the area mapped and would seem to fit with a projection of this zone if it were warped to strike between S. 65° E. and S. 75° E.

Strang's "Horseshoe Pit" and others in the southwestern portion of the map may lie in a northwest-southeast striking zone that crosses a small patch of swamp, and includes several small pits just beyond the southern edge of the area.

To test the existence and extent of these possible zones, their strikes were followed northwest and southeast, beyond the immediate area, but no conclusive evidence was found.

Several explanations may be advanced to account for what appears to be an alignment or structural control over the location of emery deposits. The "zones" may follow: (1) *lines of fracture or structural weakness;* (2) favorable *beds* in the metaschist; (3) *contacts* of metaschist and igneous rock; or (4) the *local strike* of the pseudomorphic schistosity in the metaschist. Lastly, (5) the "zones" may be only apparent, rather than real.

Lines of fracture or structural weakness have doubtful support as factors controlling emery deposition. To have been effective, they must have existed before intrusion of the Cortlandt series, because of the early date of emery mineralization. In that case, they would have been obliterated in the area occupied by the intrusive. Furthermore, the xenolithic nature of deposits in the igneous rock discounts the value of citing such pits in proving the existence of this, or any other, type of zone. Linear pits in the endomorphosed rock owe their shape to the original form of the emery-bearing xenoliths engulfed in the magma. Structural features in the metaschist are, thus, involved to whatever extent they guided developing the shapes of the xenoliths.

As for the second hypothesis, no distinctive beds have been found in the metaschist in units large enough to be traceable. Thus, field evidence discounts this possibility.

All emery deposits are not found at the contact of the igneous rock and metaschist, even though they are near the igneous rock; thus, the third hypothesis cannot be accepted as a generalization.

It has been shown that emery does follow the pseudomorphic schistosity in the metaschist, and that the ore shoots are parallel to this structure where it is well developed. However, this structure is not always well preserved, nor does it have a uniform strike throughout the area.

Careful analysis has led the writer to conclude that the zoning is more apparent than real, and that the chance location of mineralized xenoliths, some favorable contacts, and the strike of pseudomorphic schistosity have co-operated to suggest structural alignment.

ORIGIN OF THE EMERY

The theories of origin suggested for the emery deposits near Peekskill by previous writers include: (1) magmatic segregation; (2) absorption (assimilation) of aluminous country rock (Manhattan schist); and (3) contact-metamorphism, under which two different stages of development have been considered—(a) hydrothermal contact-metamorphism, and (b) deposition by magmatic emanations released after marginal consolidation of the Cortlandt plutonics was completed. The latter can be called a late-crystallization stage contact-metamorphic, or a "deuteric" contact-metamorphic theory of origin.

The present study of rock types and emery deposits in the Emery Hill district has revealed new evidence which indicates that the emery was developed earlier than was formerly believed, and, thus, a revised theory of origin is required. The possibility that emery was deposited previous to intrusion of the basic Cortlandt series is discussed, but it is concluded that deposition of the ore took place during intrusion of the Cortlandt plutonics, at an earlier stage than previously believed.

Magmatic Segregation

In 1887, Williams[27] suggested magmatic segregation as the genesis of the emery. Although he changed his view in favor of contact-metamorphism the following year, his first conclusion was cited in the literature for a number of years. His earliest hypothesis is now given attention only on historical grounds. The fact that emery deposits are in exomorphosed schist rules out this hypothesis. Rogers[28] has presented other objections in greater detail.

Absorption (Assimilation) of Aluminous Rock

In 1911, Rogers suggested that the emery was formed by absorption of aluminous Manhattan-schist xenoliths in the basic Cortlandt series

[27] Williams, G. H., *Op. cit.*, 1887.
[28] Rogers, G. S., *Op. cit.*, p. 80, 1911.

magma, thereby developing a magma supersaturated in iron and alumina, "from which the emery would separate out according to the laws formulated by Morozewicz." Much of Rogers' argument was based on the artificial production of corundum, especially following the experiments of Morozewicz,[29] which showed that corundum, sillimanite, or cordierite will form in a melt, depending upon the variation in proportions of alumina, silica, magnesia, and iron oxide.

Rogers recognized differences between the mineralogical features of the emery and the laboratory products. Nevertheless, he was disposed to believe that the emery was formed by reaction between magma and aluminous country rock, because the clay crucibles used by Morozewicz were attacked at a high temperature by melts rich in magnesia and poor in alumina and alkalis.

Berkey and Rice[30] followed Rogers' conclusions. Bowen[31] accepted this theory and presented a theoretical discussion of probable reactions which would account for certain mineralogical relationships.

In spite of such acceptance, the magmatic absorption theory has unsurmountable difficulties, chief among which is the fact that emery is found in the exomorphosed schist *removed from contact with the magma.* Nor does this theory explain the occurrence of emery in distinct narrow bands paralleling the pseudomorphic schistosity in the metaschist, even where the latter is found as xenoliths. The presence of quartzose streaks in the emery, whose minerals (corundum and spinel) are silica-poor, is incompatible with the theory of assimilation. Furthermore, a study of emery-bearing xenoliths, from different points within the series, demonstrates that the ultimate tendency of the surrounding magma was to *destroy* the emery, *not to develop it.*

A sharp distinction has been drawn between contact-metamorphism and assimilation, but the two processes actually grade into each other. Assimilation is simply the ultimate of exomorphism and is possible only where the country rock is in contact with the active magma.

Contact-Metamorphism

"Deuteric" Contact-Metamorphism

In 1930, Gillson and Kania[32] concluded that:

> "The Peekskill emery deposits are contact-metamorphic in origin and were formed by gaseous or liquid emanations from the magma reservoir, which passed upward through the already solid border of the igneous mass, and into the schists, depositing the ore minerals in both the endomorphic and exomorphic zones."

[29] Morozewicz, J., *Op. cit.*, 1898.
[30] Berkey, C. P., and Rice, M., *Op. cit.*, 1919.
[31] Bowen, N. L., *Op. cit.*, 1922.
[32] Gillson, J. L., and Kania, J. E. A., *Op. cit.*, 1930, p. 526.

The observations on which their conclusions were based may be summarized as follows:

(1) Emery is present only in a post-consolidation endomorphosed rock and exomorphosed schist. It is not in contact with fresh melanorite.

(2) Ore and gangue minerals are contact-metamorphic minerals.

(3) Sequence of mineralization is characteristic of contact-metamorphic processes.

(4) The character and location of the emery deposits, especially within the wall rock, precludes the possibility of its formation by magmatic reaction.

(5) Feldspar of the emery is andesine. Andesinization was a post-consolidation process, yet the formation of the emery followed it.

(6) Quartz and corundum are found in the same thin-section of endomorphosed igneous rock. This would be impossible if the ore were formed by assimilation.

(7) Many minerals present are characteristic of emanations.

(8) The deposits are analogous to contact-metamorphic deposits.

In general, these arguments support a contact-metamorphic theory of origin for the emery. Only the first and fifth arguments favor deposition during that specific stage of magmatic history during which emanations passed from the still-liquid magma chamber through the solidified endomorphosed rock and into the exomorphosed schist. However, the present study has shown that the emery had essentially formed before the endomorphosed rock was entirely solidified. Furthermore, the emery deposits in the endomorphosed rock are engulfed blocks of emerytized metaschist, and not veins. No emery observed by the writer in the igneous rock has been deposited along undoubted veins or channels, by solutions or emanations from the still-liquid magma. Many small emery-bearing xenoliths are present in the later-crystallized norites, as well as in the early solidified endomorphosed rock. This association would not seem possible if ore deposition began only after the margins of the intrusive consolidated.

The writer found no undisputable basis for concluding that the formation of emery followed a post-consolidation andesinization. The process of emery formation, as outlined by Gillson and Kania, must be essentially one of deposition, rather than reaction, for it is difficult to conceive of emanations producing the same end-product by reaction with such different types of rocks as endomorphosed norite and schist. Petrologic studies showed no tendency in the Cortlandt rocks to differentiate toward a highly aluminous residue, especially of deuteric nature. Furthermore, some emery deposits in endomorphosed rock are cut across by dikes of Cortlandt material, as well as by fractures healed with deuteric substances. The latter tend to destroy the emery, rather than to form it, and the sequence of formation indicates that emery was present before pronounced deuteric activity took place.

The theory that the emery was formed as a contact-metamorphic deposit during the stage when final consolidation emanations were passing upward from the magma reservoir through the already solidified endomorphosed rock and schist must be modified.

Hydrothermal Contact-Metamorphism

In connection with his study of corundum and albitite bodies, Larsen[33] made a brief visit to the field and concluded that the Peekskill emery deposits were hydrothermal contact-metamorphic in origin. The hydrothermal stage is later in magmatic history than the stage proposed by Gillson and Kania; hence, the objections previously stated relative to their theory apply in this case. Furthermore, the mineral association of the emery has higher temperature and pressure characteristics than that found even in high-temperature hydrothermal deposits. The only cases of hydrothermal mineral association the writer has seen at Emery Hill are later developments and are not related to the formation of the emery.

Possible Pre-Cortlandt Deposition of Emery

Certain evidence suggests that the emery may have developed *previous* to the intrusion of the Cortlandt series and that possibility deserves consideration. Favoring this idea is the fact that emery is found as bodies in the metaschist but exists only as xenoliths in the endomorphosed and the later-consolidated Cortlandt series rocks. Furthermore, a continuous aureole of emery does not surround the Cortlandt series at its contacts with the Manhattan schist, but the emery is apparently spasmodically distributed.

The ore has igneous associations. In casting about for some other igneous source, attention falls upon the Peekskill granite[34] as the only possibility near at hand. A brief review of the literature lends support to this suggested source because it reveals that emery deposits elsewhere commonly have granitic sources.

The Naxos and Smyrna deposits are reported to be in crystalline

[33] Larsen, E. S., *Op. cit.*, 1928.

[34] The Peekskill granite is considered by Berkey (*Op. cit.*[14], 1908), however, to be the acid extreme of the Cortlandt series because of mutual high soda content. No mutual field relationships have been observed.

limestones near granite intrusions and are more or less closely associated with granite pegmatites.[35]

The Chester, Massachusetts, deposits are along a narrow belt of foliated amphibolite, lying within sericite schist of Silurian age. They are thought to have been developed chiefly by desilication of a granite pegmatite.[36]

The Whittles, Pittsylvania County, Virginia, deposits are reported to be probably contact-metamorphic, developed as lens-shaped bodies chiefly in schist but to some extent in granite near the schist-granite contact. Field relations show that the emery was pre-pegmatite.[37]

In order to check this possibility, a study was made of the Peekskill granite-Manhattan schist contact. A fair exposure, with a pegmatite dike extending from granite into the schist, crops out on the northeast corner of Millstone Hill, directly east of Emery Hill. However, specimens collected at intervals across the contact showed no development of emery minerals. Exposures in recent road-cuts of the Bronx River Parkway extension, from this vicinity to Jacob's Hill, east of Peekskill, revealed large xenoliths of schist engulfed in a granite resembling the Peekskill granite. These inclusions showed no signs of emery development.

Critical re-examination of the emery deposits shows that they are closely associated with the contacts of the schist and the basic Cortlandt series, even though the emery does not necessarily form a continuous aureole around the intrusive. All known major emery deposits are in pyroxenite areas near contacts with the schist. The association is too evident to be a coincidence. Thus, field evidence fails to support the view that emery was formed previous to intrusion of the Cortlandt series.

Conclusion Concerning Origin

All theories which appear worthy of serious consideration limit the formation of the emery to Cortlandt time. Theories based upon magmatic segregation, absorption, and contact-metamorphism—both early "deuteric" and late hydrothermal—leave several observed facts unexplained. After a description of the conditions under which the emery is found and a discussion of the inadequacy of the theories of origin already proposed, it seems only proper to present a theory of origin which, it is believed, takes into account all the facts observed.

[35] Papavasiliou, S. A., Die Smirgellagerstätten von Naxos selbst denjengen von Iraklia und Sekinos: *Zeit. Deut. Geol. Ges.*, Bd. **65**, Abh., pp. 1–123, 1914.

[36] Gordon, S. G., Desilicated granitic pegmatites: *Proc. Acad. Nat. Sci., Philadelphia*, vol. **73**, Part I, pp. 185–186, 1921.

[37] Watson, T. L., A contribution to the geology of the Virginia emery deposits: *Economic Geology*, vol. **18**, pp. 53–76, 1923.

Such a theory must satisfy the conclusions and supporting observations outlined below.

(1) The commercial emery deposits at Emery Hill are of two types: (a) concentrations introduced either into the country rock of exomorphosed schist, or into mixed igneous and metamorphic rock; and (b) mineralized xenoliths of exomorphosed schist surrounded by endomorphosed rock.

(2) The emery was formed by contact-metamorphic (pyrometasomatic) action of the basic Cortlandt intrusive on Manhattan schist, because:

(a) The major emery deposits are strictly associated with the Cortlandt intrusives, especially with the early formed pyroxenites.

(b) The emery and associated gangue minerals have contact metamorphic affinities. The former consists of corundum, pleonaste, magnetite, specularite, and ilmenite; the latter include sillimanite, kyanite, staurolite, and cordierite.

(c) The occurrence of emery seems limited to the exomorphosed Manhattan schist. Ore deposits are either concentrations introduced into the country rock of schist, or are mineralized xenoliths of schist that have been engulfed in endomorphosed igneous rock.

(3) Emery was apparently formed or deposited by favorable emanations, liquid or gaseous, released from the intruding magma, as is indicated by collective consideration of the following facts:

(a) In deposits in the exomorphosed schist much of the ore embays and cuts into silicates, showing that it had been introduced.

(b) The emery deposits in exomorphosed schist and mixed rock are close to the contact with igneous rock.

(c) Much of the emery forms bands parallel to the pseudoschistosity of the exomorphosed schist. This structure is noticeable in deposits in the endomorphosed norite, and could not develop by crystallization of aluminous segregations in the magma.

(d) Many xenoliths and contacts of schist do not exhibit much emery mineralization, thereby indicating that mere contact with magma did not cause withdrawal of much emery from it. A concentration of favorable emanations was necessary.

(4) The release of the emery depositing emanations from the Cortlandt magma took place early during intrusion. The emanations, at most, did not travel far in advance of the magma. This is demonstrated by the combined facts that:

(a) Emery deposits in exomorphosed schist and mixed rock are close to the contact with igneous rock.

(b) Emery deposits in igneous rock are mineralized xenoliths engulfed by the advancing magma.

(5) The emery deposits were formed previous to solidification of the endomorphosed rock, because:

(a) The emery is present in the endomorphosed rock only in xenoliths of exomorphosed schist. It also is found in the later consolidated norite as smaller xenoliths, which are oriented with igneous structures, such as schlieren.
(b) No veins of emery were found in the endomorphosed rock.
(c) Endomorphosed rock cuts through some of the emery lenses in emery pits and includes fragments of the intruded emery as fragments in contact breccia.
(d) Emery bodies in the endomorphosed rock are transected by Cortlandt dikes and by cooling shrinkage fractures healed with minerals of deuteric origin.
(e) Deuteric and late-stage consolidation emanations tended to destroy, rather than to develop, emery.

The results of the present study seem to justify the conclusion that the Peekskill emery deposits are contact-metamorphic (pyrometasomatic) in origin, and were formed, essentially, in the Manhattan schist country rock by favorable emanations released from the Cortlandt magma *during* intrusion. This is an earlier stage of "contact-metamorphism" than has been previously suggested. It is believed that the emery developed near the contact and not far ahead of the intruding magma which, as it advanced, engulfed some ore in the form of xenolithic blocks. This theory does not assume that the development of emery ceased the moment xenoliths formed, but it is believed that the mineralization took place early and was not continued to a late magmatic stage, having come to completion by the time the marginal endomorphosed rock had solidified.

The fact that emery does not form a continuous aureole around the contact of the Cortlandt series with the Manhattan schist, but is spasmodic, may be due to (1) the varying concentration of appropriate constituents in the emanations, and (2) unfavorable characteristics of the country rock.

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