PARAGENESIS OF THE GARNET AND ASSOCIATED MINERALS OF THE BARTON MINE NEAR NORTH CREEK, NEW YORK

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Abstract

The paragenetic sequence of the minerals of the Barton garnet mine shows that the crystallization of the mine rock started with the formation of a hornblende-diorite matrix and ended essentially with the crystallization of the large garnet grains and/or crystals within the hornblende rims. These rims or envelopes, which were formerly considered "reaction rims," are paragenetically earlier than the enclosed minerals. The hornblende envelopes and the minerals within the envelopes developed from retained isolated pegmatitic or deuteric solutions having more-or-less spherical outlines en•losed within the hornblende diorite. The crystallization of these isolated solutions produced first the hornblende envelopes followed by terminated crystals of hornblende and hypersthene, large grains of plagioclase, and intergrowths of hornblende and feldspar growing from the inside of the envelopes toward the center. The last mineral to form in any quantity was garnet, which covered the minerals attached to the interior of the envelopes and which also enclosed crystals of biotite, apatite, hypersthene, and rounded grains of pyrite which developed contemporaneously with the garnet.

There is no evidence of late introduction of material or of metasomatic action between any of the minerals present.

The term *deuterocryst* is proposed to apply to those crystals or large grains as hornblende, hypersthene, biotite, and garnet which developed from late pegmatitic or deuteric solutions retained within the parent rock. Such crystals are late in development in contrast to phenocrysts which appear early and are retained as conspicuous crystals or grains.

Introduction

The garnet deposits in the vicinity of North Creek, New York, are well known on account of their occurrence and economic importance. They have been frequently mentioned and briefly described in the literature.

The writer has examined the very interesting Barton Mine on Gore Mountain at intervals since 1920 and during the many visits he has searched the broken ore and quarry faces for critical evidence on the origin of the conspicuously large garnets and their hornblende rims. During the summer of 1947 additional new and important facts bearing on the paragenetic sequence of the garnet and associated minerals were discovered.

Previous Work in the Area of the Mine

Descriptions of the geology in the vicinity of the Barton garnet deposit, formerly called the Moore or Rogers Mine, have been presented by Miller (1, 2) and Krieger (3). None of the previous writers has given a detailed description of the order of crystallization of the garnet and associated minerals of the hornblende-rich diorite.

Concerning the geology of the mine and the immediate vicinity, Krieger (3, p. 109) states that:

The garnet-rich rock occurs as a narrow, lens-like mass about three-fourths of a mile long with a nearly east-west strike. It varies from 50 to 300 feet in width. It is in contact on the south side with syenite, on the west end with Marcy anorthosite, on the north with gabbro and Whiteface type anorthosite. The foliation of the syenite dips about 15° to the north. The contact between the syenite and mineable garnet is nearly vertical, sloping but slightly to the north.

Miller (1, pp. 499–500) states that the

garnets occur in lenses of Grenville sediments which were caught up or included in the great igneous masses at the time of their intrusion, the tremendous heat and pressure being especially favorable for a very complete rearrangement and crystallization of the masses (inclusions) of sediments which were pretty low in silica. . . .

The hornblende rims or envelopes are quite certainly great reaction rims around the garnets, but just at what stage of the metamorphism they were produced is not at all clear to the writer. The rounded character of the garnets shows pretty clearly that the rims of hornblende are of secondary origin and that they were formed sometime after the crystallization of the garnets and possibly at the time when the pressure producing the foliation of the rocks was brought to bear.

Miller (2, p. 406) modified his previous theory. He says that

before the intrusion of syenite magma, the southern border portion of the body of gabbro (probably metagabbro) was more or less intimately cut and assimilated by the anorthosite magma, producing a synthetic rock rich in fairly large garnets without hornblende envelopes, . . .

By metamorphism, induced by the rise of the great body of quartz syenite magma, the mine rock, with its large hornblende-enveloped garnets was produced along the southern side of the body of gabbro. . . . The composition of the mine rock indicates that little if any material was added to the gabbro by the syenite magma, and so the nature of the metamorphism was largely or wholly dynamothermal, . . .

As the previous studies on the garnet deposits of the area have been devoted to the broader aspects of the problem of the genesis of the garnet-bearing rock, the writer will not further review that phase of the problem as the foregoing will suffice as an introductory background to this interesting problem.

It is the writer's belief that the answers to the broader problems lie first in the correct interpretations of the final or end stages of the process, from which the earlier and broader phases may be more readily and accurately deduced. Neither the source of the materials of the garnet-bearing diorite nor the manner in which they reached their present position with respect to the adjoining rock types will be considered at this time.

Description of the Garnet-Bearing Rock and Associated Minerals

The mine rock is a dark-gray medium to coarse-grained hornblende-rich diorite containing large dark-red garnets surrounded by coarse-grained hornblende rims. In narrow zones along the north and south borders of the deposit the garnets are smaller and do not possess the conspicuous hornblende rims. The composition of the diorite, away from

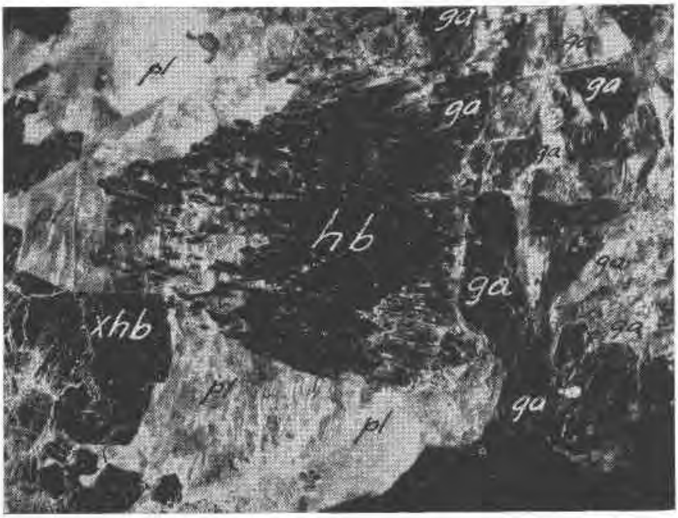

Fig. 1. A radial intergrowth of hornblende (hb) and plagioclase (pl) growing from the hornblende rim toward a large garnet grain (ga). The crystals of hornblende (xhb) of the rim are oriented with their terminal ends toward the garnet. They are covered with feldspar (pl). The sequence of mineral development is hornblende, feldspar, and then garnet, which is the last important mineral to crystallize. $\times = 2.0$.

the garnet and associated minerals, as determined from eight thin sections of average-appearing diorite is approximately 29% plagioclase, 56% hornblende, 13% hypersthene, 1% biotite; a little pyrite, apatite and magnetite are also present. According to Johannsen's classification the rock is a meladiorite (3212). The minerals of the matrix are unusually fresh; however, there is a slight peripheral alteration of some hornblende grains to chlorite and magnetite. The alteration products amount to 5.5% and are computed as hornblende. The larger garnets have thicker envelopes in which the *hornblende* grains are often 1½ to 2 inches across the cleavage faces. Most of the hornblende is xenomorphic granular. Near the garnet it occasionally forms radial intergrowths with the plagioclase feldspar. The intergrowths terminate with spherical surfaces against the garnet grains. Some terminated crystals of hornblende are occasionally present in association with plagioclase which covers the terminations and occupies a space between the terminal faces and the garnet, Fig. 1.

The only feldspar observed was *plagioclase* which has a composition between Ab_{55} An_{45} and Ab_{50} An_{50} in the diorite matrix between the large garnet grains. The grains of plagioclase, several inches across the cleavage faces, which occur next to the garnets as segments of the envelopes have a composition about Ab_{65} An_{35}. The feldspar had the longest period of crystallization. It appeared early as irregular grains in the diorite matrix

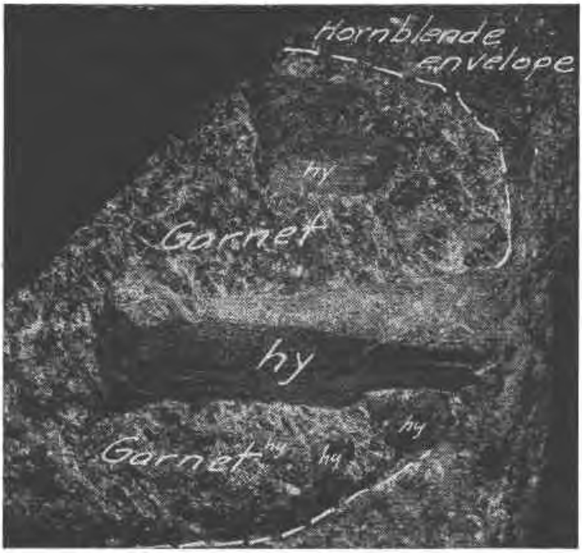

FIG. 2. A large garnet grain with a large crystal of hypersthene (hy) growing into the garnet from the hornblende rim. A number of smaller hypersthene crystals are also present and some of these are apparently surrounded by garnet which is outlined from the hornblende rim by the broken line. The large crystal is 4 inches long.

and also late as masses in the envelopes and as fillings in some of the wider fractures in the garnet and in the minerals of the rims. The larger grains of plagioclase are rather clear and glassy.

The *hypersthene* also had a relatively long period of crystallization. It occurred early as small interstitial grains in the diorite matrix where the pink-brown color of the mineral makes its recognition easy with a binocular microscope. The examination of the diorite specimens reveals the fact that the amount of hypersthene present varies greatly from one sample to another. In some of the hornblende envelopes the hypersthene is more abundant than in others. In the outer parts of the envelopes it retains its interstitial position between the hornblende grains. In the inner portion of the envelopes the hypersthene at times becomes relatively abundant, and in certain instances crystals up to 4 inches long Fig. 2, have grown from the inside of the envelope and developed terminated crystals that extend *centripetally* into the garnet. Essentially euhedral crystals of hypersthene up to 3 inches in length occur completely within the garnets, Fig. 3. A few small, well-developed, fresh crystals were also found as inclusions within the glassy feldspar between the hornblende of the envelopes and the garnet.

FIG. 3. Crystals of hypersthene which occur completely within the garnet grains. $\times = 1.4$.

Some of the hypersthene crystals in or near the feldspar and/or hornblende of the envelopes are considerably altered to chlorite and serpentine along fractures and cleavage planes. The hypersthene grains in the hornblende-feldspar matrix are fresh and unaltered even though the hornblende in contact with it may be slightly altered along the grain boundaries as described above.

The large, brilliant red *garnet* grains and crystals are the most spectacular and interesting mineralogical feature of the deposit. Their average size runs from four to six inches while garnets up to a foot in diameter are not uncommon. Krieger (3, p. 113) states that "garnets three feet in diameter and yielding about one and one-half tons of garnet have been taken out." Crystal faces as a rule are absent although a few individuals with rough dodecahedral forms are at times present even on the larger garnets. Each mass of garnet, regardless of size, appears to be a single crystalline unit and not a granular aggregate. This supposition is supported by two criteria: first, and most convincing is the presence of dodecahedral faces on a few of the larger pieces, and second, all grains, large and small, have more or less continuous fractures with even to conchoidal surfaces extending across the grains. Many small cross fractures with conchoidal surfaces are also present. The garnet fragments have the shape of very rough rectangular parallelopipeds instead of rounded subhedral grains as is not uncommon in garnet deposits in which the garnet masses consist of many small irregular grains.

Biotite is the commonest inclusion in the garnet. Irregular black crystals up to an inch in length and having rough and uneven crystal faces are not uncommon. Segments of coarse granular biotite occur sparingly in the envelopes next to the garnet. The biotite inclosed in the garnet, and most of that occurring in the envelopes, is of a deep brown color by transmitted light; however, occasional laminae of a bright green biotite occur interlaminated with sharp contacts with the brown variety in the envelopes. The birefringence in each case is the same. Only a relatively small amount of biotite occurs in the diorite matrix.

Small yellow transparent crystals of *apatite*, less than $\frac{5}{8}''$ long, occur as inclusions in the garnets usually near the contact with the envelope minerals. The crystals are occasionally doubly terminated and have rounded edges between the crystal faces. The apatite sometimes occurs in the hornblende or hypersthene. It is never abundant except in very small portions of the garnet.

Pyrite in small amounts is common in the diorite, hornblende envelopes, and as inclusions in the garnet. It also occurs as thin films in the fractures through the garnet and envelope minerals. As inclusions it always occurs as small rounded or irregular masses. Crystals were at no time observed. When the thin films in the fractures of the garnet were loosened the impressions of the conchoidal fractures could be clearly seen with a binocular microscope. The films of pyrite in fractures along the basal cleavage of the plagioclase show, in like manner, the impressions of the twinning striations which were molded onto the pyrite film.

Chlorite, serpentine and *magnetite* occur sparingly as alteration products of hornblende and hypersthene.

A little *calcite* is present along the fracture planes in the garnet and envelope minerals.

Two unknown minerals in very small amounts were observed. One occurs with pyrite, or alone, as thin films in fractures in the garnet and envelope minerals while the other forms the walls for a few very small crystal cavities of an unknown mineral.

Paragenesis of the Minerals

The structural, textural and mineralogical relationships previously described suggest that the progress of crystallization was from the medium-grained hornblende-feldspar matrix toward the coarse-grained hornblende envelopes, and ended with the large garnet grains and/or crystals. The coarse-grained envelopes of hornblende, feldspar, biotite and hypersthene, together with the garnet, represent a deuteric,* or in reality a retained *pegmatitic phase* of the diorite. Had this material accumulated in a fissure and crystallized under similar conditions a basic garnet-rich hornblende pegmatite would have undoubtedly resulted.

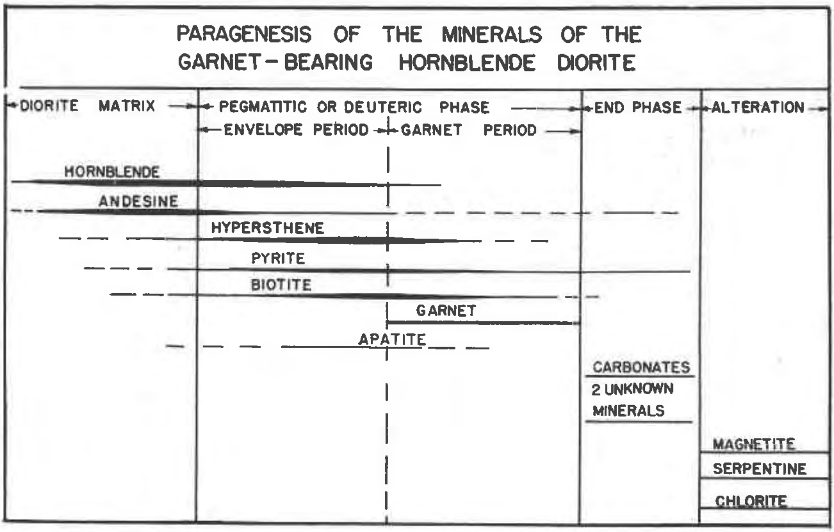

Fig. 4. Diagram showing the continuous and uninterrupted phases in the paragenesis of the garnet-rich hornblende diorite of the Barton Mine on Gore Mt., New York.

The paragenetic sequence of the minerals of this garnet-rich hornblende diorite is shown diagrammatically in Fig. 4. Crystallization began with the contemporaneous formation of hornblende and plagioclase feldspar which developed the xenomorphic mosaic of the ground mass or matrix. In addition, small amounts of hypersthene, pyrite, and biotite appeared interstitially between the hornblende and plagioclase.

* For the crystals, as hypersthene, biotite, garnet, apatite, and the terminated hornblende crystals which have been described above as having developed from late or deuteric solutions retained within the body of the rock, I propose the name *deuterocrysts*. Such crystals are late to develop as contrasted with phenocrysts which appear early and are retained as prominent or conspicuous crystals or grains.

The initial phase of crystallization began at essentially the same time throughout the mass of the mine rock resulting first in the formation of the solid matrix with the scattered, isolated, still unconsolidated phase consisting essentially of the envelope minerals, garnet and such materials which remained in the residual solution due to their low melting point or high solubility. These have been aptly called "fugitive constituents" by Shand (4, p. 34).

At the close of the matrix stage the andesine had become nearly exhausted and the remaining plagioclase in solution had become enriched in the albite molecule by the removal of the more calcic andesine. The crystallization of the substances in the late phase, or deuteric solutions, started the second or pegmatitic phase with the development of the coarse-grained hornblende envelopes in contact everywhere with the matrix. In this stage the crystallization was distinctly *centripetal*, that is, the crystallization progressed toward the center of the residual isolated solution confined in more-or-less spherical masses within the already solid matrix. The situation is not unlike the crystallization of a filled-fissure vein or a pegmatite dike, in which the direction of crystallization is toward the center of the vein or dike. The difference is chiefly in the shape of the retaining walls. In pegmatite dikes and other tabular vein-like mineral deposits the terminated minerals extend from the walls or centers of support in the direction of their growth. Likewise in the hornblende envelopes the minerals that are terminated have their terminations directed toward the center. In chemistry the process of separating subtances by crystallization of the less soluble ones from a common solution is called fractional crystallization. The hornblende remaining in the pegmatitic or deuteric phase was removed by his process of fractionation during the formation of the envelopes, leaving a residual solution confined within the envelopes consisting chiefly of garnet with some hypersthene, pyrite, biotite, andesine, calcite and possibly minor amounts of other carbonates. Small amounts of fine-grained materials not determined and also small amounts of the fugitive constituents invariably associated with silicate solutions were also undoubtedly present.

In addition to the rock containing hornblende-rimmed garnets, two additional types of garnet-bearing hornblende diorite are present in the mine. The most abundant of the two occurs in a zone along the north side of the deposit. It is similar to that of the main body of diorite but contains numerous small garnets up to an inch or two in diameter but without the prominent hornblende rims. The total amount of hornblende and plagioclase feldspar appears to be nearly the same but at the end of the crystallization of the matrix there was not an accumulation of a hornblende-garnet-rich pegmatitic phase. There is, however, a hornblende-feldspar intergrowth along the periphery of many of the garnets similar to the intergrowths around the large ones that are hornblende-rimmed. Except for the envelope minerals and the inclusions in the large garnets already described, the paragenesis of this phase is the same.

Another less common and more irregularly distributed type of garnet-bearing rock in the mine consists essentially of an irregular, granular aggregate of hornblende, hypersthene, and garnet. The material is both medium and coarse-grained. It is believed to represent material belonging to the pegmatitic or deuteric phase which had accumulated in considerable volume of irregular shape. The paragenetic sequence of these masses is the same as that of the hornblende-rimmed garnet masses, except that the hornblende produced a granular slush-structure throughout the mass instead of developing rims or envelopes. Both hypersthene and garnet occupy the interstitial spaces between the hornblende grains.

The mine manager, Charles Barton, stated that a "vein of garnet" at one time appeared in one of the quarry faces. An occurrence of this kind would be expected in the event a fracture developed at a time when and where the late garnet solution could fill it.

Summary of Evidences Supporting the Paragenetic Relationship Described Above

1. The shift in the composition of the plagioclase feldspar from Ab_{59} in the matrix to Ab_{65} for the large grains in the envelopes and in contact with the garnet shows that the matrix is earlier.

2. The greatly increased size of the mineral grains in the envelopes compared with that of the minerals in the matrix indicates a late stage of crystallization in the presence of a greater amount of mineralizers.

3. The presence of hornblende-feldspar and biotite-feldspar intergrowths in the zone next to the garnet indicates a eutectic-like phase of these minerals and a late phase of their development.

4. The radial intergrowths of hornblende and feldspar (Fig. 2) indicate that they grew centripetally from the interior of the hornblende envelopes toward the garnet.

5. The subhedral hornblende oriented with its terminal faces directed toward the garnet indicates that the direction of growth of the hornblende on the inside of the envelopes was toward the garnet centers.

6. Hypersthene, a late interstitial mineral in the matrix, becomes more abundant interstitially in some of the envelopes. When the amount of hypersthene in the envelopes is large, it frequently develops large crystals projecting from the inside of the hornblende envelopes into the garnet which shows unmistakably the direction of crystal growth. The last of the hypersthene developed contemporaneously with the garnet

and produced euhedral crystals attached to the simultaneously crystallizing garnet which completely enclosed the hypersthene crystals.

7. The sequence of crystallization of hypersthene from interstitial grains in the matrix to euhedral hypersthene in the garnet indicates an important series of events in the paragenesis of this mineral which shows its crystallization to have started in the matrix and ended with the euhedral "deuterocrysts" in the garnet.

8. The occurrence of coarse-grained masses of biotite, a hydrous mineral, in large grains next to the garnets as segments of the hornblende envelopes indicates a late stage for the crystallization of the envelopes.

9. The increasing amount of pyrite, occurring as rounded inclusions, in hornblende, hypersthene, feldspar, and garnet, and also as films filling narrow fractures in the garnet and the associated minerals of the envelopes indicates that the coarse-grained envelopes and the inclosed minerals were the last to crystallize.

10. Films of pyrite, feldspar, and other minerals in the garnet fractures show casts of the conchoidal fractures, and the pyrite in the fractures of the plagioclase masses near or in contact with the garnet, frequently shows casts of the twinning striations when occupying fractures along the basal cleavage. This relationship shows conclusively that the last substances to solidify simply filled the fractures without reacting with the wall materials, and that the introduction of new materials or the reworking of earlier minerals by metasomatic processes had not occurred.

Acknowledgments

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