GARNET AS AN AMYGDULE MINERAL[1,2]

EDWIN B. ECKEL
U. S. Geological Survey, Golden, Colorado.

INTRODUCTION

Garnet has been found as a contact metamorphic mineral in the amygdules of andesite in the lava flows of the San Juan Mountains of southwestern Colorado. It is believed that this is the first recorded American occurrence, though several analogous ones in the British Isles have been on record for a number of years.

The presence of garnet in the lava flows surrounding the Mt. Sneffels intrusive stock, about five miles southwest of Ouray, was discovered by W. S. Burbank and the writer in the course of a detailed study of the geology and ore deposits of the Ouray mining district. The project was a part of the cooperative program carried on by the State of Colorado, the Colorado Metal Mining Fund, and the U. S. Geological Survey. The writer wishes to express his appreciation to Mr. Burbank for helpful suggestions in both field and laboratory.

THE HOST ROCK

The rocks in the immediate vicinity of the Mt. Sneffels stock consist of a thick accumulation of volcanic flows, breccias, and tuffs which range from rhyolite to andesite in composition. These have been subdivided into three formations[3] of which the intermediate, or Silverton Series of Miocene age is composed essentially of andesitic and latitic flows and flow breccias. The pyroxene andesite of this series is the only rock that has been found to contain garnet. In its original condition the rock was rich in labradorite, with much less pale green augite, hypersthene, orthoclase, and quartz, and still less magnetite. It was considerably altered, how-

[1] Read before the Mineralogical Society at Tulsa, Oklahoma, December 30, 1931.

[2] Published by permission of the Director, U. S. Geological Survey, the Colorado State Geological Survey Board, and the Colorado Metal Mining Fund.

[3] For detailed discussions of the geology, see the following:

Whitman Cross, *U. S. Geol. Survey, Geol. Atlas, Telluride Folio,* (no. 57), **1899.**

Whitman Cross and Ernest Howe, *U. S. Geol. Survey, Geol. Atlas,* Silverton Folio, (no. 120), **1905.**

W. S. Burbank, Revision of geologic structure and stratigraphy in Ouray district of Colo.: *Proc. Colo. Sci. Soc.*, **12,** no. 6, 1930.

ever, by hydrothermal processes at about the time of the consolidation of the lava flows. Sericite, calcite, and chlorite were the chief products of alteration, and the hypersthene was almost entirely changed to serpentine.

The vesicles, which were abundant in several of the andesite flows, were partly filled with chlorite, quartz, calcite, and locally opal, chalcedony, barite, and magnetite during the same general period of alteration. Chlorite was the first mineral to form, lining the amygdules as aggregates of minute crystals which invariably show the anomalous "ultra-blue" interference color characteristic of the variety penninite. Two generations of quartz succeeded the chlorite. The first of these formed prisms laid parallel to the walls of the amygdules, while singly terminated prisms radiating from the walls were formed during the second generation. Calcite was the last mineral of importance to form in the amygdules and partly or completely fills the cavities. It is either massive or forms well-developed but simple rhombohedra or scalenohedra.

Contact Metamorphism

The nearly horizontal volcanic formations were intruded by the Mt. Sneffels gabbro-diorite stock, which caused the epidotization of the andesites and alteration of the original contents of the amygdules. The lavas for a distance of at least several thousand feet about the borders of the stock were considerably altered to epidote, which partly replaced practically all of the original minerals. Metamorphosed amygdules were found only on the northeast side of Mt. Sneffels, and never more than 1500 feet from the intrusive body. No minerals were developed in the non-amygdaloidal vesicles as a result of the contact metamorphic processes.

The metamorphosed amygdules are on casual examination similar to the original amygdules in that they are largely filled with chlorite, quartz, and calcite, but closer inspection reveals the presence of rather large numbers of crystals of garnet and of epidote. Garnet is embedded in both quartz and calcite, or projects as facetted crystals into the cavities. The crystals, with a maximum observed diameter of 3 millimeters, are invariably trapezohedra. This form is commonly striated, sometimes coarsely, by combination with the rhombic dodecahedron. Most of the crystals are clear yellowish-brown, others are green or light yellow. In thin section the garnet is light yellowish-brown and completely isotropic. The crystals are somewhat cracked, but zonal structure and inclusions are absent. The indices of refraction of two specimens, as determined by Miss J. J. Glass of the U. S. Geol. Survey, are 1.895 and 1.900, showing that the garnet corresponds closely in composition to the pure lime-iron variety, andradite.

Garnet was the first mineral to form in the amygdaloidal cavities as a result of contact metamorphism. It replaced quartz only slightly, but formed anhedral masses which filled the interstices between prisms of quartz. (See Figure 1.) Hexagonal outlines of crystals of quartz are usually sharply preserved by interstitial

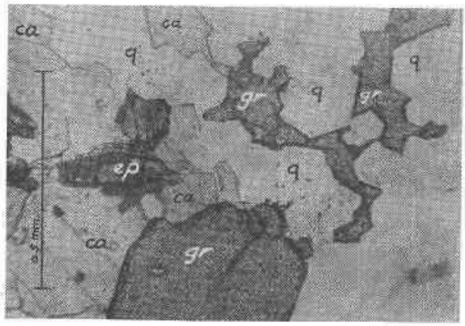

FIG. 1. Garnet (gr) and calcite (ca) interstitial to early quartz (q). The hexagonal outlines of prisms of quartz are in general sharply defined but occasionally show slight rounding and corrosion by the garnet. The interstitial masses of garnet may have filled open spaces among crystals of quartz or may have replaced calcite. Definite evidence of replacement of calcite by garnet is generally lacking in thin sections, but field evidence shows garnet to be later. A small amount of epidote (ep) is developed along cracks in calcite. Plain transmitted light. ×68.

masses of garnet, but occasionally show some corrosion by the garnet. Calcite, which also occurred interstitial to quartz, was readily replaced by the garnet. Wherever found in contact with calcite the garnet shows rounded or subhedral outlines in contrast to the irregular masses between crystals of quartz which depended almost entirely on the enclosing material for their form. Definite evidence of replacement of calcite by garnet is for the most part lacking in the thin sections examined, but reasoning based on field evidence, where it is known that calcite had been formed long before the igneous intrusion that caused the formation of garnet, strongly suggests that the garnet found in calcite was developed by replacement of that mineral. The similarity in occurrence of masses of garnet and calcite interstitial to quartz, well shown in Fig. 1, furnishes strong presumptive evidence of replacement of calcite by garnet. Facetted crystals apparently developed only in open spaces. Garnet has not been found in the body of the andesite.

Light green epidote succeeded and partly replaced the garnet. It occurs as crystalline aggregates or as groups of slender prismatic crystals several millimeters in length. Garnet is almost invariably corroded where in contact with epidote and in some places the garnet grains are almost completely replaced by it, as shown in Fig. 2. In addition to its rather vigorous attack on the garnet, epidote replaced calcite in the amygdules (Fig. 1), filled cracks and other openings, and partly replaced the constituent minerals of the andesite. Its formation was the most thorough and far reaching effect of the intrusion.

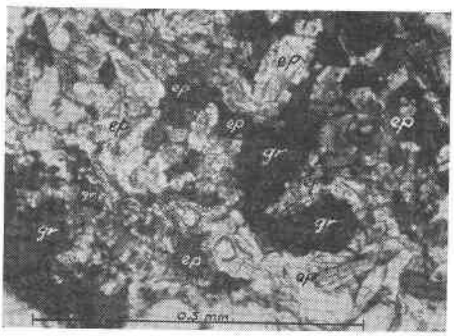

FIG. 2. Crystals of garnet (gr) largely replaced by crystalline aggregate of epidote (ep). Nicols nearly crossed. ×93.

In a period following that of epidotization, actinolite and quartz were formed at the expense of the earlier minerals. Actinolite has been observed only as microscopic needles enclosed in quartz, to which it imparts the porcelainic appearance characteristic of the late or contact-metamorphic quartz. The actinolite needles are too small to enable determination of all their optical properties, but the faint green color and pleochroism of the largest needles serve to identify the mineral as actinolite rather than tremolite. Much of the quartz-actinolite intergrowth, whose components probably formed almost simultaneously, was developed in open spaces, as is shown by the fact that masses of garnet, which are rounded and corroded by the intergrowth, often preserve distinct evidence of crystal outline. As facetted crystals of garnet only formed in open spaces it seems probable that the quartz-actinolite intergrowth filled remaining cavities and partly replaced such euhedral or subhedral crystals rather than that it was developed by replacement of residual calcite, in which the garnet never assumed crystal form. The relation of the intergrowth to garnet is shown in Figure 3.

Fig. 3. Garnet (gr) partly replaced by late (contact metamorphic) quartz-actinolite intergrowth (qa). The individual masses of garnet are rounded residua of subhedral crystals which were corroded by the quartz-actinolite intergrowth. The mass of garnet in the lower right hand corner preserves some corroded but recognizable crystal faces. Plain transmitted light. ×68.

The individual masses of garnet are rounded residua of facetted crystals which were corroded by the intergrowth. Most of the crystals in the photograph are too much corroded to show crystalline form, but that in the lower right hand corner preserves some recognizable crystal faces. Occasionally the late intergrowth filled cracks in crystals of garnet or partly replaced irregular veinlets of epidote cutting garnet.

Albite and prehnite have been found in some of the amygdules. It can be stated with some assurance that they are products of the contact metamorphism, but data are insufficient to place them properly in the sequence of deposition. Albite appears to be earlier than epidote, but has not been observed in contact with garnet.

Significance of the Occurrence

A number of interesting problems are suggested by the occurrences described above, and although their complete solution must wait further data, several tentative conclusions can be drawn that may be of value in studies of contact metamorphic processes. The metamorphism, though strong enough to produce such relatively high temperature minerals as garnet, epidote, and albite, in the amygdules, had but slight effect on the intruded rocks. The presence of easily replaceable calcite in the amygdules was probably largely responsible for this selective metamorphism. The composition of the intruding and intruded rocks was also a factor, as the gabbro-diorite of the Mt. Sneffels stock and the intruded pyroxene andesite are closely similar in composition and offered little opportunity for exchange of chemical elements. Furthermore, it is generally agreed that basic rocks seldom effect such extensive metamorphism as do more acidic ones.

A brief consideration of the possible temperature at which contact metamorphism took place may be of interest, although no definite data are available. It was shown by Merwin[4] and later accepted by Lindgren[5] that the anisotropic garnet of more typical contact metamorphic deposits was probably formed at a temperature below 800°. The lack of zonal structure and inclusions and the uniform isotropism of all the garnet examined suggest that it was formed under conditions different from those that obtain during the more usual types of contact metamorphism. Since none of the garnet is anisotropic the upper limit of temperature reached during the formation of the new minerals in the amygdules is indeterminable, but the absence of tridymite and the presence of low-iron actinolite, which is decomposed at 900°[6] imply that the temperature failed to exceed 800° appreciably.

Garnet apparently had a short range of stability as compared with that of epidote. It evidently depended upon calcite for its formation, but ceased to develop while considerable calcite remained unreplaced. It may be that the equilibrium relations between andradite and epidote were very sensitive, and that a slight change in physical conditions caused the cessation of garnet formation and the beginning of epidotization. The presence of alumina may also have been a controlling factor in the development of the two minerals. Its very high index of refraction shows that the

[4] C. W. Wright, Geology and ore deposits of Copper Mt. and Kasaan Peninsula: *U. S. Geol. Survey, Prof. Paper* **87,** 108, 1915.

[5] W. Lindgren, Mineral Deposits: *New York,* **1928,** p. 799.

[6] E. Posnjak and N. L. Bowen, The role of water in tremolite: *Am. Jour. Sci.,* (5) **22,** pp. 203–214, 1931.

garnet is a nearly pure lime-iron andradite, with no admixture of the lime-alumina, or grossularite, molecule.[7] Epidote, however, always contains alumina in considerable quantities. Since the presence of alumina in the epidote is the chief chemical difference between that mineral and the andradite, it seems reasonable to suppose that the beginning of introduction of alumina, either from alteration of the andesite or from the magmatic emanations, marked the end of stability for andradite.

Other Occurrences of Garnet in Igneous Rocks

Only a few of the known occurrences of garnet in the openings of igneous rocks are even remotely similar to the one that has been described. Perhaps the best known of such occurrences is that near Nathrop, Colorado, which was described by Cross.[8] Spessartite, topaz, and sanidine occur in the lithophysae of a rhyolite dike that cuts pre-Cambrian rocks. Many of the crystals of spessartite are of good size, and aside from its scientific interest the locality has attracted some attention as a source of gem material. Cross mentioned a similar occurrence at Silver Cliff, Colorado.[9] Garnet and topaz were found in the main rhyolite sheet near Silver Cliff in a lithophysal zone that overlies a zone notable for its content of large rhyolitic spherulites. According to Cross, however, the minerals in the lithophysae at both these localities were primary, having formed almost contemporaneously with the final consolidation of the host rocks. They present evidence of having been formed by sublimation, but cannot be connected with contact metamorphic processes.

Harker[10] has described an occurrence in England that is strikingly similar to that near Ouray. The intrusion of a granite mass into an olivine-free basalt, whose vesicles had previously been filled with chlorite, quartz, and calcite, caused extensive metamorphism of the rock and of the amygdules, in which grossularite,

[7] N. H. and A. N. Winchell, Elements of Optical Mineralogy, Part II, pp. 263–266, *New York*, **1927.**

[8] Whitman Cross, On the occurrence of topaz and garnet in lithophyses of rhyolite: *Am. Jour. Sci.*, (3) **31,** pp. 432–438, 1886.

[9] Whitman Cross, Geology of Silver Cliff and the Rosita Hills, Colo.: *U. S. Geol. Survey, Ann. Rept.*, **17,** pt. 2, pp. 263–403, 1896.

[10] Alfred Harker and J. E. Marr, Supplementary notes on the metamorphic rocks around the Shap granite: *Quart. Jour. Geol. Soc.*, London, **49,** pp. 360–364, 1893.

green hornblende, a colorless augite, epidote, and quartz were developed. With the exception of grossularite and quartz all these minerals entered the basalt, whose plagioclase phenocrysts and groundmass were entirely recrystallized during the metamorphism. An augite-andesite cut by the same granite was similarly altered, but because of its lower lime content few of the lime silicates were formed in it. Teall has described a similar occurrence in Scotland[11] where a lime-iron garnet and new feldspars were formed from the contents of the amygdules.

In both the British occurrences metamorphism was much more thorough than was that caused by the Mt. Sneffels stock near Ouray. This difference may have been due to the greater dissimilarity in composition of the intruding and the invaded rocks. In both occurrences the alteration of the amygdules extended farther from the intrusive body than did the alteration of the lavas themselves.

Summary

Near Ouray, Colorado, the intrusion of a gabbro-diorite stock into a pyroxene andesite rock caused metamorphism of amygdules in the andesite. The new minerals developed partly by replacement of the original chlorite, quartz, and calcite of the amygdules, and partly by filling of open spaces. It is believed that the presence of calcite was largely responsible for the development of garnet. Comparison with analogous occurrences in the British Isles, where alteration of the amygdules was of minor importance as compared to the metamorphism of the rock itself, leads to the belief that the metamorphism at Ouray was of comparatively slight extent and of somewhat unusual character.

[11] Teall, *Annual Report, Geol. Survey*, **1896,** p. 47.
Teall, *Memoirs, Geol. Survey;* Silurian Rocks of Scotland, pp. 647–650, **1899.**