GARNET CRYSTALS IN CAVITIES IN METAMORPHOSED TRIASSIC CONGLOMERATE IN YORK COUNTY, PENNSYLVANIA*

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GEOLOGY

Large well-formed crystals of garnet have been found in cavities in metamorphosed Triassic conglomerate in York County, Pennsylvania, 6 miles southeast of Harrisburg. The garnets were formed by contact metamorphism of intrusive diabase. The rounded cavities were produced by the solution of limestone pebbles in the conglomerate, and the the calcium of the limestone combined with silica and iron oxide to form garnet. A small amount of hematite is also present in the cavities.

Beds of conglomerate and coarse arkosic sandstone are prevalent in the Heidlersburg member of the Gettysburg shale in the Triassic area southeast of Harrisburg, and make rather high hills on the south side of Susquehanna River from a point one-half mile west of Frogtown to a point 2 miles south of Middletown, where the river turns abruptly south (Fig. 1). The unaltered rock is a gray to buff, granular, pebbly arkose with thin interbedded red shale. Most of the pebbles in the conglomerate are of rounded quartz or quartzite, which weather out and strew the surface of these hills, but occasional pebbles of limestone are generally present. Some layers have such an abundance of limestone pebbles that they have been quarried for lime. The Triassic sedimentary beds in this area strike about N. 80° E. and dip 45° to 60° N.

The sedimentary rocks are intruded by an irregular diabase dike, which cuts sharply across the strike of the sedimentary rocks. From the point 2 miles south of Middletown northwestward for 4 miles the diabase crops out along the south bank of the river, and trends N. 40° W. Its outcrop is here ⅓ mile wide. Southwest of Highspire the diabase bends southwestward with the strike, and then continues its northwest trend, and gradually thins to a few hundred feet in width south of New Cumberland. Here it again bends southwestward and widens locally to 1 mile. Northwest of Frogtown it bends sharply southeastward and is more variable in outline, but in general it trends S. 50° E. across the strike of the sedimentary rocks.

The diabase is bordered on both sides by a zone of baked shale and sandstone which varies from ⅛ to ½ mile in width. The metamorphosed

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[1] Geology by G. W. Stose, Mineralogy by J. J. Glass.

rock is more resistant than the unaltered sedimentary rock or the diabase, and makes the high ridge south of the diabase. The thicker red shales of the Gettysburg at the diabase contact are baked to hard bluish-black porcelanite with rounded segregations or knots of epidote. The arkose at the contact is silicified and hardened to a tough sandstone or quartzite and is bleached nearly white in places. Limestone pebbles in the arkose are either dissolved by the water accompanying the magma, or are silicified to a gray impure calcareous sandstone.

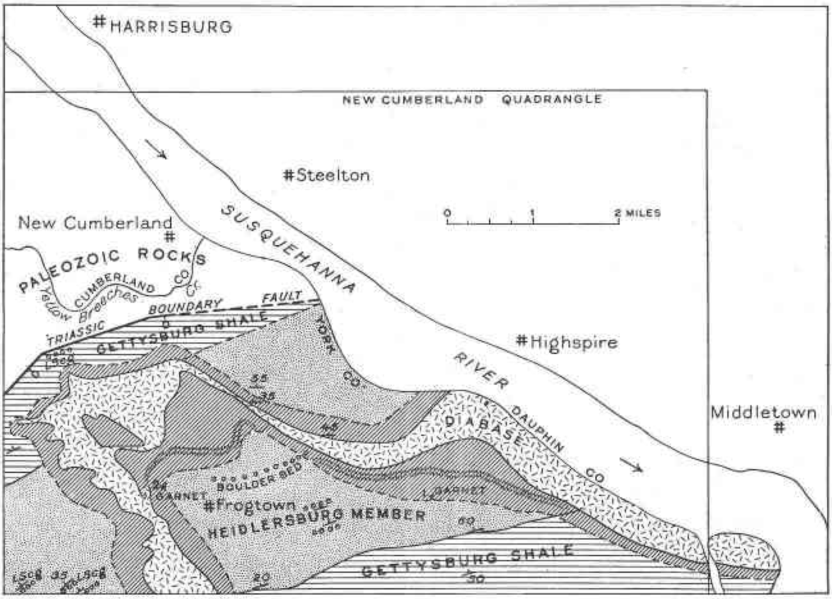

FIG. 1. Geologic map of the area of Triassic rocks southeast of Harrisburg, Pa. Crystals of garnet occur in the metamorphosed zone, shown by diagonal ruling, bordering the intrusive diabase.

The garnet was discovered by G. W. Stose and Malcomb H. Bissell during a geologic survey of the New Cumberland Quadrangle for the Pennsylvania Geological Survey. The best-formed garnets (Fig. 2) were found on the outer edge of the metamorphosed zone which forms the hill south of the diabase, south of Highspire, at the locality marked (1) on Fig. 1. Since its discovery, garnet has been found by Stose and Jonas at many localities to the east and west along the south edge of this metamorphosed zone to a point (locality 2, Fig. 1) on the Lisburn highway, $\frac{1}{2}$ mile west of Frogtown. Here some of the specimens studied by J. J. Glass were obtained. Many of the solution cavities in these rocks are coated with a thin layer of garnet and hematite. Large well-formed crystals were obtained only at locality No. 1, two miles south of Highspire.

Magnetite is a general constituent of the diabase in this region, and magnetite-rich solutions evidently accompanied, or followed, the intrusion of the diabase. At Dillsburg and several places to the southwest toward Fairfield, magnetite has replaced limestone in the walls of the intrusive diabase and formed commercial deposits of iron ore. These magnetite deposits occur adjacent to thick cross-cutting bodies of diabase believed[2] to be at, or near, the vents in the floor of the Triassic basin up which the magma ascended, and therefore, are closely connected with its source. These magnetite-rich solutions evidently also were the source of the iron that combined to form the andradite garnet at the contact of limestone with the intrusive diabase 2 to 3 miles north of Fairfield.

Garnet (probably andradite) associated with pyroxene, pyrite, and magnetite, is described by Harder[3] as occurring in the baked Triassic sandstone and shale in the magnetite mines at Dillsburg. Shannon[4] describes minute crystals of a lime-iron garnet (andradite) associated with magnetite and as slickenside coatings in fissures in limestone altered by diabase at Leesburg, Virginia.

Mineralogy

Properties of the Andradite Garnets

The garnets referred to above are the calcium-iron variety, andradite, and show the following properties:

Physical properties.—The garnet crystals in the rounded cavities (Fig. 2), from 2 miles south of Highspire, vary in size from 1 centimeter to nearly 2 centimeters in diameter. The upper three-quarters of each crystal is bounded by trapezohedral faces, and shows the *n*(211) simple form. The trapezohedral faces are all conspicuously striated. The striae are parallel to the longer diagonals on those faces whose edges are so joined that four corners form a point, and are parallel to the short diagonal on the other faces. The sides of the crystals attached to the walls of the cavity are flattened and show a series of striated divisions into segments that form angles resembling elbow-twinning patterns. No cleavage is observed, and none of the crystals show a tendency to separate along the bands of zoning nor along the individual segments or

[2] Stose, G. W., Fairfield-Gettysburg Folio, Pa.: *U. S. Geol. Surv.*, Folio **225**, p. 19, 1929.

[3] Harder, E. C., Structure and origin of the magnetite deposits near Dillsburg, York Co., Pa.: *Econ. Geol.*, vol. **1**, p. 619, 1910.

[4] Shannon, E. V., Mineralogy and petrography of Triassic limestone conglomerate metamorphosed by intrusive diabase at Leesburg, Va.: *Proc. U. S. Natl. Mus.*, vol. **66**, Art. 28, pp. 10–11, 1925.

twinning units. The specific gravity is 3.6. Hardness between 6 and 7. Luster resinous. Fuses to a black magnetic bead. The color of the crystals in mass is nearly black, but on thin edges is yellow to reddish brown.

Optical properties.—A thin section of one of these garnets examined under crossed nicols showed a sharply defined doubly refracting zone consisting of parallel bands or lamellae with varying faint extinction. The birefracting areas form the outer zone of the crystal and surround

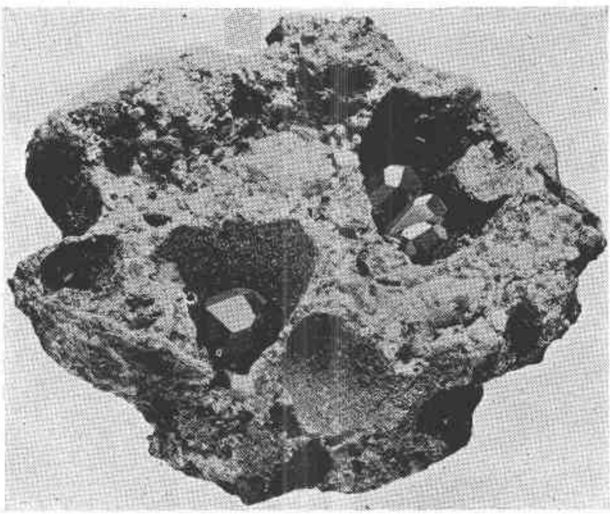

FIG. 2. Crystals of andradite garnet in cavities in metamorphosed Triassic conglomerate, 2 miles southwest of Highspire, Pa.

a completely isotropic central area, similar to the Fairfield garnet shown in Fig. 3. It has been noted in previous studies of andradite garnet that the crystals are often composed of parts which are anisotropic, together with others which are isotropic, in which the isometric form is said to be retained by twinning, the twinning units being pyramids whose vertices meet at the center and whose bases are the external faces of the isometric form. The garnets from 2 miles south of Highspire, however, do not consist of pyramids whose vertices meet at the center, but their twinning units form a border inclosing a central completely isotropic area that has a slightly higher index of refraction than does the border zone. The birefracting areas of the garnets from 2 miles south of Highspire are much less conspicuous than those from near Fairfield, described farther on. The contacts of the banded segments are not so sharply defined, and the segments do not assume the regular pattern arrangement that is characteristic of the Fairfield garnets shown in Fig. 3. There is no apparent zone of weakness, that is, a tendency for parting, at the boundary between the isotropic area and the anisotropic area as is frequently observed in the case of interrupted crystal growth.

In thin section the color is pale yellow to yellowish amber; in thicker grains the yellow shows a greenish tinge. In the doubly refracting areas the positive acute bisectrix is normal to the twinning lamellae; the optic plane is normal to the length of the broad birefracting bands next to the central area. The index of refraction for the isotropic areas is: $n=1.886$,

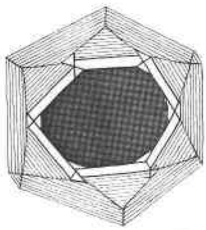

FIG. 3. Sketch of a thin section of andradite crystal (×16) which exhibits striking optical anomalies. The crystal is one of an aggregate of garnets found in contact rock 2 to 3 miles north of Fairfield, Pennsylvania. The central area of the crystal is completely isotropic, represented by the dark center in the diagram; the adjoining areas are anisotropic and are represented by the broad white bands and white triangles; and the outer zone is composed of narrow thread-like bands, alternating isotropic and anisotropic, resembling the lamellar twinning of plagioclase, and is represented by the ruling. The individual segments consist of adjoining outward and inward pointing triangles arranged in a nearly symmetrical hexagonal pattern.

and for the doubly refracting area is slightly lower, $n=1.865$, $B=$about .003. Garnet crystals collected $\frac{1}{2}$ mile west of Frogtown, in the same geologic relations, are identical with those from south of Highspire. Small crystals (1.5 mm.) of a yellow-green garnet associated with calcite and magnetite, collected at Grantham, also have the same optical properties as those from Highspire.

The garnet from near Fairfield occurs as a mass of small crystals of a coarse granular type of andradite, brownish yellow to dark reddish brown in color and resinous in luster (colophonite, named after the resin colophony). The trapezohedral faces persist in these garnets, each tiny individual crystal exhibiting the same external features as are seen on the larger crystals in the cavities south of Highspire. The optical properties, however, are slightly different. The anisotropic areas are distinctly banded, and the opposite segments extinguish evenly. The optical axial angle is small, in some crystals sensibly uniaxial. The sign is positive, and the indices of refraction are variable, from 1.870 to 1.850. Each small crystal is apparently homogeneous in composition, but the different crystals vary slightly from one another in index of refraction. This indicates a variation in composition from andradite, principally of the calcium-iron molecule, to andradite with a little of the calcium-aluminum molecule, grossularite.

A thin section of the contact rock at Fairfield, which is almost a solid mass of small garnet crystals, shows numerous examples of optical anomalies. The cross section of a typical andradite crystal from this contact rock is shown in Fig. 3. The crystals show segmented concentric structures composed of symmetrical triangular areas whose individual segments are made up of narrow alternate isotropic and anisotropic bands, which produce a lamellar twinning effect. This banded zone surrounds a completely isotropic central area. In transmitted light there is no distinguishable difference between the isotropic and anisotropic areas, neither in color nor in index of refraction. Under crossed nicols the two segments on opposite sides of the isotropic center extinguish simultaneously.

Experimental work by Merwin[5] at the Geophysical Laboratory of the Carnegie Institution, Washington, D.C., shows that birefringent types of garnets invert at about 800°C. to a strictly isotropic form. His experimental data indicate that the temperature of the environment in which these andradite garnets formed was lower than 800°C.

A similar experiment was performed by one of the authors (J. J. Glass) in the laboratory of Dr. Charles P. Saylor, at the U. S. Bureau of Standards, on a sample of the anisotropic andradite from York County, Pa. At 860°C. the anisotropic grains became isotropic, and did not invert on cooling down. The results of this experiment furnish some additional confirmatory evidence to support the work of Merwin, and indicates that a temperature factor is involved in the anisotropism of andradite, which may serve as a geological indicator.

[5] Merwin, H. E., *U. S. Geol. Survey, Professional Paper* **87**, p. 108, 1915.