American Mineralogist, Volume 58, pages 840–842, 1973

Zoned Garnet from Crested Butte, Colorado

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Abstract

Anisotropic andradite from Crested Butte, Colorado, shows oscillatory zoning and dodecahedral twinning. Microprobe analyses reveal alternating zones that vary between nearly pure andradite and andradite$_{50}$-grossularite$_{50}$. Rapid changes in chemical composition of hydrothermal solutions or oxidation state of iron may explain the zoning.

Introduction

Zoned crystals, which intrigue geologists primarily because they contain information concerning mineral genesis, can be found in extrusive rocks, hydrothermal ore veins, igneous plutons, and metamorphic rocks. Their occurrence has been used as evidence for disequilibrium as well as equilibrium conditions of formation (Barton *et al,* 1963). For most zoned garnets reported in the literature, zoning is neither visible nor oscillatory and requires microprobe analysis for detection (Hollister, 1966, 1969; Atherton and Edmunds, 1966; Atherton, 1968; Gomes, 1969; Brown, 1969). The garnets reported here are unusual in that they display visible oscillatory zoning and dodecahedral twinning.

General Geology

The garnet sample was collected from the Forest Queen Mine at Irwin, five miles west of Crested Butte, Colorado, and given to the writers for study. This mine is located near the contact of porphyrite and the Rudy Formation (Emmons, Cross, and Eldridge, 1894). A northeast-trending fault cuts through the mine area. From descriptions given us, we believe that the garnets came from a hydrothermal vein, but the possibility of a skarn deposit, as Emmons noted at Italian Mountain, can not be ruled out.

Optical Studies and Twinning

The garnets from Crested Butte form clusters of yellow-brown euhedral dodecahedrons up to 3 mm in diameter. Petrographically, they display oscillatory zoning and dodecahedral twinning (Fig. 1). About 90 percent of the zones are anisotropic with first and second order colors, whereas the remaining portion is nearly isotropic. The mean index of refraction is 1.880 ± 0.002. Several zones show biaxial character with $2V$ of 90° ± 5°. All anisotropic zones are length slow and display extinction parallel to zone contacts. Individual zones correlate across twin planes and also across the crystal boundaries (Fig. 1) when these planes are vertically oriented on a U-stage.

The twinning appears identical to that observed by Holser (1950) and Kennedy (1953) and is referred to as dodecahedral twinning. The 12 rhomb-shaped faces represent bases of pyramids with apexes that meet at the center of the crystal and thus give the illusion of cyclic twinning. The number of individual twins and intersecting angles observed (Fig. 1) depends on the orientation of a thin section and on the number of crystals that have grown together. Factors that control such a twin development are not understood at the present time. Visually, the dodecahedral twinning in these garnets appears similar to the sectors in staurolite described by Hollister (1970) and Hollister and Bence (1967); however, we have not sectioned these garnets to confirm this.

Chemistry

A cross sectional profile of chemical composition across one grain (Fig. 2) was determined by electron microprobe. Analyses were performed at 6 micron

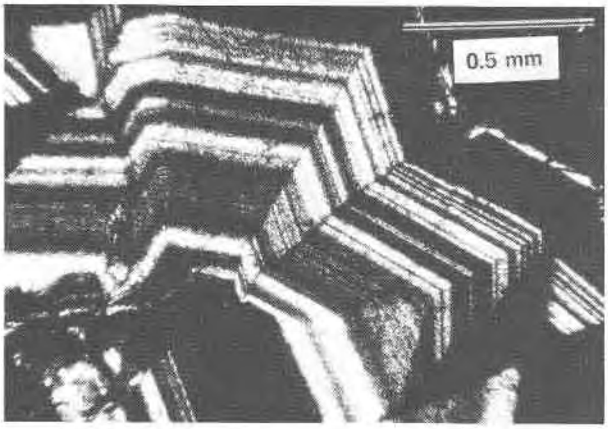

FIG. 1. Zoned andradite showing dodecahedral twinning and anisotropism (crossed nicols). Crystal boundaries are distinguished from twin planes by a reentrant at the crystal surface.

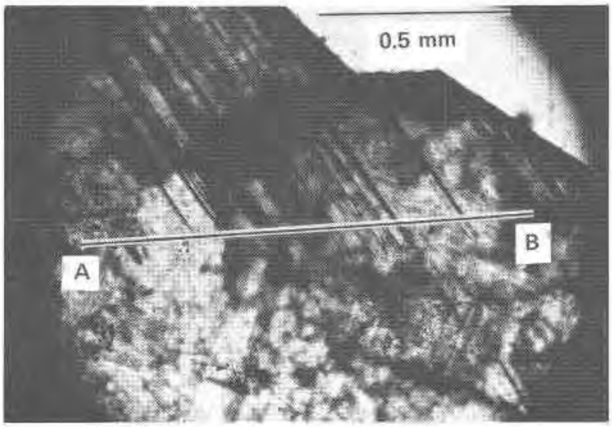

FIG. 2. Analyzed andradite showing probe scan from A to B (plane polarized light).

intervals along a 1.25 mm traverse. Two garnet standards were used; almandine (Yale No. 287) and grossularite (Yale No. 285). Analyses are presented in Table 1 and their locations indicated in Figure 3. A spectrochemical analysis on a bulk sample showed TiO_2 and Cr_2O_3 were both less than 0.01 percent and no other trace elements were detected.

The only major chemical variation along the analyzed section is an inverse relation between Al_2O_3 and Fe_2O_3 (Fig. 3). MnO shows minor sympathetic increases with Al_2O_3, SiO_2, and CaO. Individual dark zone-lamellae in Figure 2 (*i.e.,* those nearly isotropic) correspond to relatively high aluminum concentrations.

Powder X-ray diffraction investigations indicate 95 percent of the bulk sample is andradite. The microprobe analyses verify the X-ray diffraction data and show that the oscillatory zoning fluctuates between almost pure andradite and andradite$_{50}$-grossularite$_{50}$. The grossularite molecule represents a maximum of 50 percent by weight in the nearly isotropic zones studied, but the amount may vary considerably in other samples.

Discussion

The occurrence of euhedral crystals is characteristic of uninhibited growth in a hydrothermal vein typical of the Crested Butte area (Emmons *et al,* 1894). Such a genesis does not favor anisotropism because of the lack of a stress component. Furthermore, twin planes are prevalent across both isotropic and anisotropic zones, negating the possibility of a stress-induced anisotropism by twinning. The ionic size of ferric iron and aluminum differ appreciably (25 percent); therefore, their substitution in the garnet lattice may account for the stress necessary to cause the observed anisotropism. The possibility of an order-disorder relationship, as in the feldspars, must also be considered.

The zonal fluctuation may be explained by cyclical variations in the composition of the hydrothermal solutions. These variations might involve a decrease in the amount of iron coupled with an increase of aluminum, or possibly a change in oxidation of iron. Ferric iron will fit into the R^{+3} lattice site of garnet, but ferrous iron does not normally enter this site.

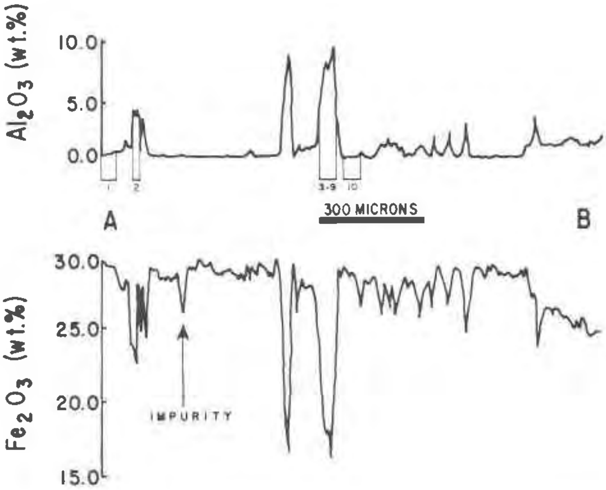

FIG. 3. Electron microprobe profiles of Fe_2O_3 and Al_2O_3 (in weight percent) across garnet in Figure 2. Positions of analyses in Table 1 are indicated.

TABLE 1. Microprobe Chemical Analyses of Garnet Shown in Figure 2
(Numbers in parentheses refer to the number of adjacent probe points averaged by computer.)
(Two end member garnets are included for reference.)

	1	2	3	4	5	6	7	8	9	10	A*	B*
Number of probe points	5	3	1	1	1	1	1	1	1	8	--	--
SiO_2	35.37	35.89	35.88	35.72	36.04	36.40	36.54	36.68	35.00	34.63	39.30	34.91
Al_2O_3	0.23	4.79	5.34	7.08	9.36	8.75	9.77	9.94	4.60	0.06	21.93	0.69
Fe_2O_3	29.62	23.62	20.62	18.80	17.93	18.00	15.96	19.42	23.58	29.01	0.80	30.40
MnO	0.16	0.18	0.14	0.15	0.47	0.42	0.75	0.75	0.18	0.13	0.0	0.0
MgO	n.d.	n.d.	n.d.	0.03	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	tr	0.58
CaO	34.75	34.87	35.79	35.17	36.15	35.88	35.72	36.21	35.14	34.23	37.10	33.20
Total	100.13	99.35	97.79	96.94	99.96	99.45	98.74	103.01	98.50	98.07	99.54	99.78

n.d. = not detected

* Two end member garnets are included for reference: A = grossularite, after Deer *et al* (1962, p. 94, Table 16, No. 1) also includes 0.28 FeO, 0.13 Cr_2O_3, and 0.30 H_2O. B = andradite, after Deer *et al* (1962, p. 90, Table 15, No. 1) also includes 0.19 H_2O and trace of TiO_2.

Optical examination of the oscillatory zones (Fig. 1) shows that many are quite narrow and most exhibit sharp contacts. This would suggest rapid crystal growth and/or rapid changes of composition in the hydrothermal solutions to preserve these delicate lamellae. An examination of Figure 3 shows that the chemical variations are not gradational, but abrupt, and thus further support a relatively rapid isolation of crystallizing garnet from the hydrothermal solutions. Whether rapid crystal growth and chemical changes of the hydrothermal solutions were concomitant is unknown, but the net effect would support this condition.

Acknowledgment

The writers wish to thank Louis A. Fernandez for the microprobe analyses. Milton T. Heald critically read the manuscript and offered valuable suggestions.

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Manuscript received, February 14, 1973; accepted for publication, May 22, 1973.