

Growth structure and crystal symmetry of grossular garnets from the Jeffrey mine, Asbestos, Quebec, Canada

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ABSTRACT

Birefringent, orange grossular garnets from the Jeffrey mine, Asbestos, Quebec, Canada, have noncubic ordered arrangements of the Al^{3+} , Fe^{3+} , and/or OH^- ions and rhombic growth hillock with four vicinal faces on the (110) face. The surface features correspond to internal growth patterns observed in thin section between crossed polarizers. The growth steps are symmetrically inclined to the (001) and $(1\bar{1}0)$ planes on the (110) face, and the ordered arrangement of Al^{3+} , Fe^{3+} , and/or OH^- ions is symmetrical with respect to these planes, which produces sectoral twins on the crystal face. The twofold axis (b axis) is normal to the (110) growth face; therefore the crystal symmetry is monoclinic. Colorless and green grossular garnets show fine growth steps parallel to $[001]$ on the (110) face; therefore their crystal symmetry is orthorhombic, although some parts are strained.

INTRODUCTION

Optically noncubic garnets have been studied by many mineralogists during the past century. Brauns (1891) summarized optical studies of birefringent garnets with sectors, and Meagher (1980) reviewed recent studies. Takéuchi et al. (1982) observed ordered arrangements of octahedral Fe^{3+} and Al^{3+} in nonisotropic grossular garnets. Akizuki (1984) observed one-to-one correspondence between features on the growth surface and internal patterns in grossular garnets and suggested that monoclinic and triclinic symmetries of grossular garnets are attributed to the ordered arrangement of Al^{3+} and Fe^{3+} that is produced on the side faces of the growth steps because of differences in Al^{3+} and Fe^{3+} ionic radii. Rossman and Aines (1986) studied birefringent, orange grossular garnets from the Jeffrey mine, Asbestos, Quebec, Canada, which are the same crystals studied in this paper, and suggested that the birefringence arises from a noncubic orientation of the OH^- groups, not from an ordered arrangement of Al^{3+} and Fe^{3+} ions. Also, Allen and Buseck (1988) observed a noncubic distribution of OH^- groups in an Asbestos specimen by IR absorption and found that the IR symmetry does not correlate to the monoclinic and triclinic sector twins.

The objective of the present paper is to describe the growth sectors and optical characteristics of grossular-andradite garnet from the Jeffrey mine, Asbestos, Quebec, Canada, and to explain the crystal symmetry from the standpoint of an order-disorder growth mechanism suggested originally by Akizuki and Sunagawa (1978).

SPECIMENS

Grice and Williams (1979) and Allen and Buseck (1988) described the crystal morphology and chemical compositions of orange, light green, and colorless grossular gar-

nets from the Jeffrey mine, Asbestos, Quebec, Canada. Orange-colored grossular (var. hessonite) has flat (110) faces and striated (211) faces (Fig. 1). Colorless and green-colored crystals consist of (110) faces, and (211) faces with striations are not observed. The crystals used for the study are ~3–4 mm in diameter.

OBSERVATIONS

The crystal surfaces of grossular were observed by interference-contrast optical microscopy. The growth surface or the surface after polishing was affixed to a glass slide, and thin sections were prepared. The thin sections were observed between crossed polarizers, and the internal patterns were compared with the surface features.

Orange grossular

The morphology of orange grossular, consisting of (110) and (211) faces, is shown in Figure 1. The (211) face is composed of striations with (110) and (101) faces. Figure

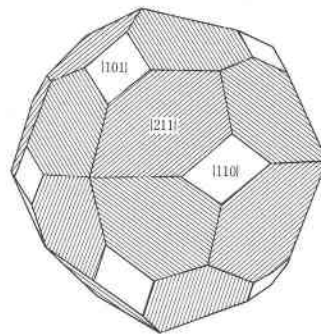


Fig. 1. Crystal form of orange grossular garnet from the Jeffrey mine, Asbestos, Quebec, Canada. Modified from Grice and Williams (1979).

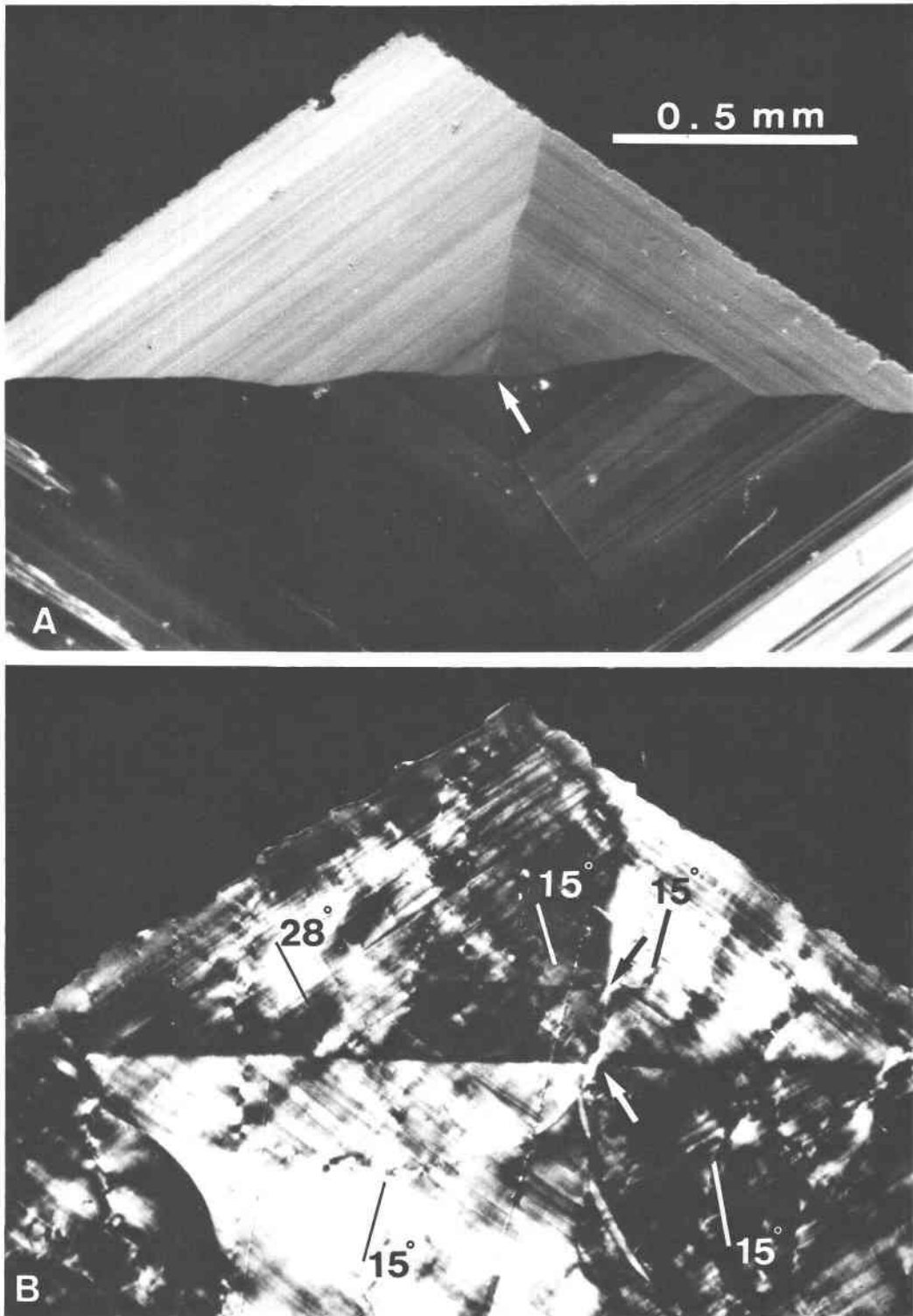


Fig. 2. Reflection-interference-contrast photomicrograph of the (110) growth surface of the orange grossular (A) and cross-polarized optical micrograph of the corresponding thin section (B). [001] is vertical. Extinction directions with the angles are shown. White arrows show corresponding growth centers, and black arrow represents a growth center that is not observed on the surface.

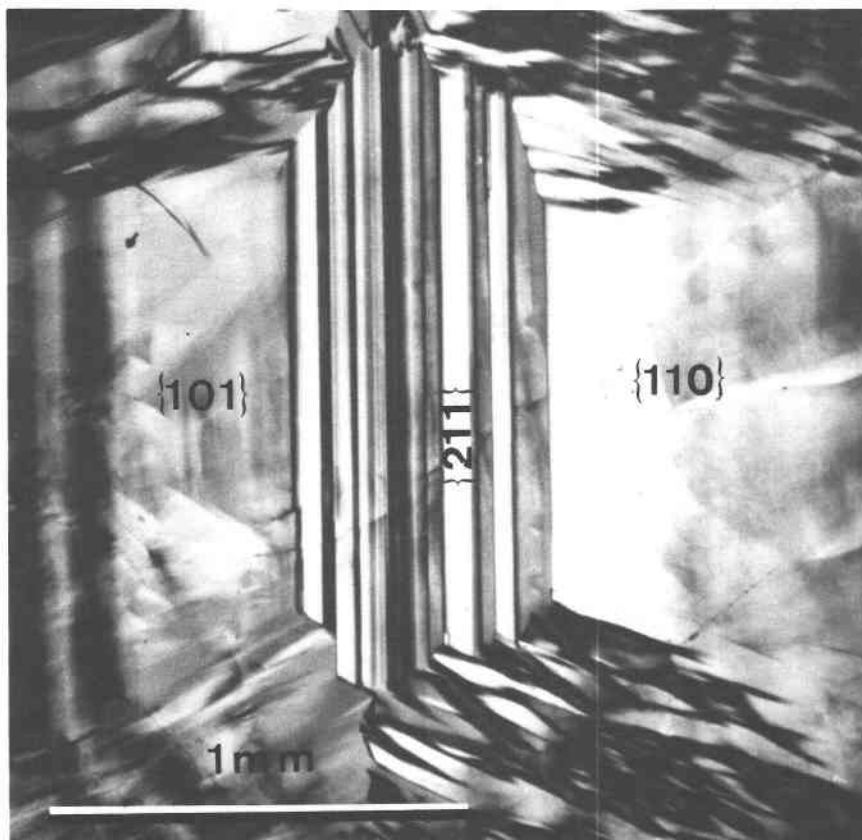


Fig. 3. Cross-polarized photomicrograph of the thin section that was prepared from the orange grossular crystal cut parallel to (211). Two {110} sectors are observed on both the left and right sides. The {211} sector consists of oscillating {110} sectors. Other orientations are seen at the top and bottom of the photomicrograph.

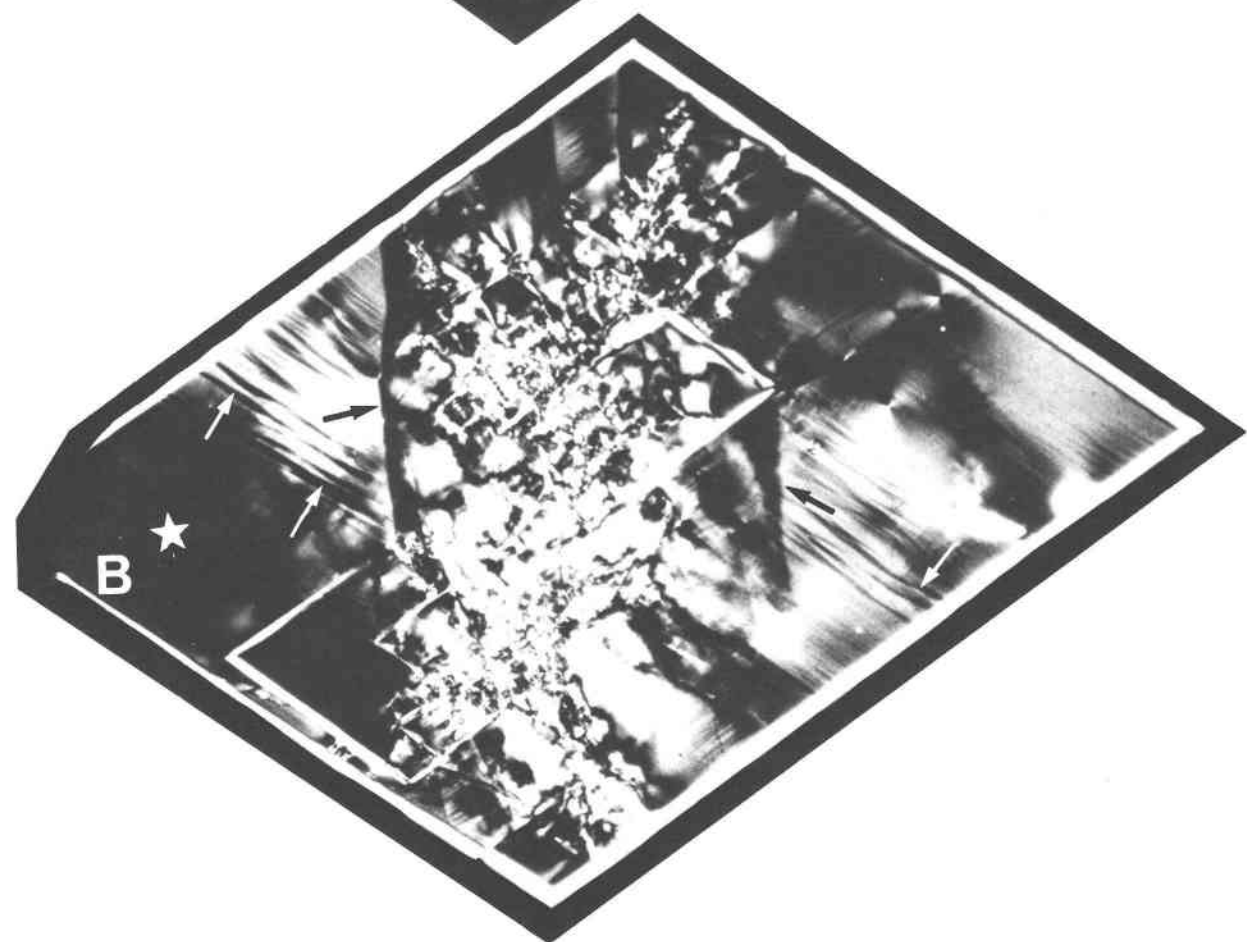
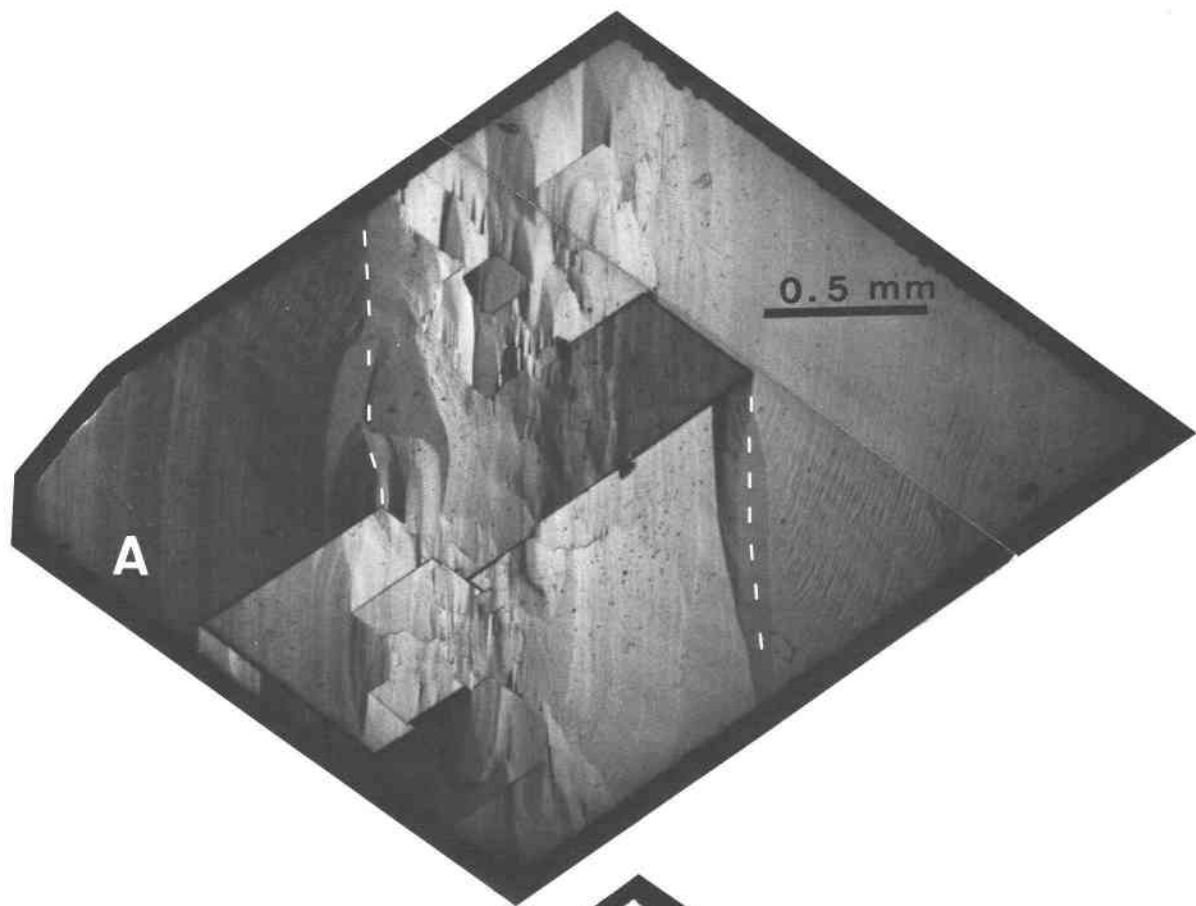
2A shows a growth hillock with four vicinal faces on the (110) surface. The steps are parallel to the crystal edges of {110} form and are symmetrically inclined with respect to (001) and (1 $\bar{1}$ 0) planes on the four vicinal faces. The white arrow shows the summit of the hillock. A thin section was made after the surface was slightly polished (Fig. 2B). The internal patterns correspond to the surface features: the summit of the hillock corresponds to the growth center shown by the white arrow in Figure 2B. In principle, the optic vibration direction Y is normal to the (110) growth face. The other two directions vary slightly from place to place in one sector on the (110) face. The orientation suggests that the crystal is monoclinic and the twofold axis (b axis) is normal to the (110) growth face. The optical orientations are *roughly* symmetrical with respect to the (1 $\bar{1}$ 0) and (001) sector boundaries, suggesting a twin relationship. Another growth center is indicated by a black arrow in Figure 2B, though the corresponding hillock is not observed on the surface. Two growth sectors overlap in the section.

Figure 3 shows the internal pattern in the thin section from a crystal cut parallel to a (211) face with striations. The {211} sector consists of fine twins parallel to the striations. The optical orientations show that the stria-

tions on the surface result from oscillatory combinations of the {110} and {101} sectors.

Colorless and green grossular garnets

Colorless and green grossular garnets show growth patterns on the (110) face that are different from the orange garnet. Figure 4A shows the growth pattern on the (110) face of a colorless grossular. The central area consists of several blocks, and the outer area shows a few growth hillocks with vicinal faces. Because the growth hillocks are elongated parallel to the a axis of cubic garnet (vertical), most of the fine steps are roughly parallel to the a axis. No rhombic growth hillocks with summits as seen in Figure 2A exist on the surface. The central lines of elongated hillocks are shown by dashed white lines. The surface was affixed to a glass slide after slight polishing, and a thin section was prepared (Fig. 4B). The sector boundary shown by black arrows in Figure 4B exists along the central line of the growth hillock, which is shown by the dashed white line in Figure 4A. Also, lamellae parallel to the crystal edge are observed at the outer part of the crystal (white arrows in Fig. 4B), and they modify the growth steps on the surface (Fig. 4A). The lamellae develop from the sector boundary and do not cross the boundary. This rela-



tion was observed in grossular garnets from other localities as well (Akizuki, 1984). The internal growth patterns, however, do not always correspond to the surface features. The central area shows complicated, irregular patterns that seem strained (Fig. 4B). The optical extinction is slightly inclined to [001] in the strained central area as well as the lamellae of the outer area (shown by white arrows), suggesting monoclinic or triclinic symmetry.

The crystal is optically biaxial, and the *Y* vibration direction is normal to the (110) growth face in the optically homogeneous area shown by the star in Figure 4B. The *X* and *Z* vibration directions are parallel to $[1\bar{1}0]$ and [001], respectively, suggesting orthorhombic symmetry. The surface corresponding to the homogeneous area consists of fine growth steps parallel to the [001] direction.

DISCUSSION

The crystal symmetry of certain aluminosilicates is determined by the growth direction of steps on the crystal surface. The crystal symmetry is a result of ordered arrangement of alkali, Al^{3+} , and Si^{4+} ions in an effort to satisfy electric charge balance (Akizuki, 1981). The anomalous optical properties of topaz, on the other hand, were explained by ordered arrangement of F^- and OH^- ions (Akizuki et al., 1979). If growth steps are parallel or inclined to a mirror plane, the mirror plane will change into a twin plane, and if the growth steps are normal to the mirror plane, the mirror plane will be maintained during growth. The correlation between the growth direction and symmetry suggests that aluminosilicates with sectors are metastably produced at low temperature. The optical anisotropy of garnet has been attributed to ordered arrangements of Al^{3+} , Fe^{3+} , and/or OH^- groups. These concepts are applied to grossular garnet from the Jeffery mine, Asbestos, Quebec.

Orange grossular garnet

The Al^{3+} , Fe^{3+} , and OH^- ions are ordered on the side faces of the inclined growth steps on the (110) face, resulting in monoclinic symmetry, and the degree of ordering varies with the rate of advancement of the step. Since the rate of advancement is not always constant during growth, the ordering varies in the direction normal to the inclined step, not along the step, resulting in fine zonal structure parallel to the growth step. Thus, the growth hillock consists of four symmetrical sectors with monoclinic structure (Fig. 2B).

Because the two-dimensional atomic arrangement on the crystal surface is different for the (110) and (211) faces,

the atomic ordering will be different between the two. Thus, the optical properties vary for the growth faces because of differences in growth direction and growth rate. The (211) face consists of oscillatory combinations of the (110) and (101) faces; therefore the {211} sector shows polysynthetic twinning of the {110} sectors (Fig. 3).

Since surface growth features vary because of fluctuating growth conditions, the internal growth patterns and symmetries produced in grossular crystals are highly varied. If the thin section parallel to the (110) growth surface includes the several growth layers, one will observe the optical anisotropy through the several layers under an optical microscope.

Since growth features vary during growth, the internal patterns in thin section do not always correspond with the surface features. A small hillock with a summit (shown by the black arrow in Fig. 2B) would exist just below the surface in the process of crystal growth, though it is not found on the surface (Fig. 2A). The ordered arrangement of Al^{3+} , Fe^{3+} , and OH^- ions may be affected by the flow direction of fluid around each grossular crystal. Therefore the optical orientations are not always strictly symmetrical with respect to the sector boundary.

Colorless and green grossular garnets

Both colorless and green grossular crystals show morphology and growth features similar to one another on the surface. The complicated pattern, which is observed on the central area in Figure 4B, may be attributed to strain in the crystal that developed during cooling. The lamellae, which are shown by white arrows in Figure 4B, are common in grossular (Akizuki, 1984; Akizuki et al., 1984; Hirai et al., 1982). Because the lamellae alter the growth steps and develop from the sector boundary in this specimen as well as in other specimens (Akizuki, 1984), it is thought that the lamellae developed during growth, though Hirai et al. (1982) believed that the lamellae were produced during exsolution.

Fine growth steps developed parallel to the [001] direction on the growth (110) face in the colorless and green garnets, although some steps are normal or inclined to the direction. The orthorhombic symmetry is correlated with this growth direction, but the monoclinic structure is produced on the curved step.

Rossmann and Aines (1986) thought that Fe^{3+} and Al^{3+} ions were not ordered in the Asbestos specimen, but this ordering is common in grossular (Takeuchi et al., 1982). The symmetry of IR absorptions does not explain the monoclinic or triclinic sector twins (Allen and Buseck, 1988). A detailed study of crystal structures is required for these grossular specimens.

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Fig. 4. Reflection-interference-contrast photomicrograph of the (110) growth surface (A) and the corresponding cross-polarized photomicrograph (B) of the colorless grossular garnet. [001] is vertical. The black contrasted area with a star in Fig. 4B is orthorhombic. See text for details.

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