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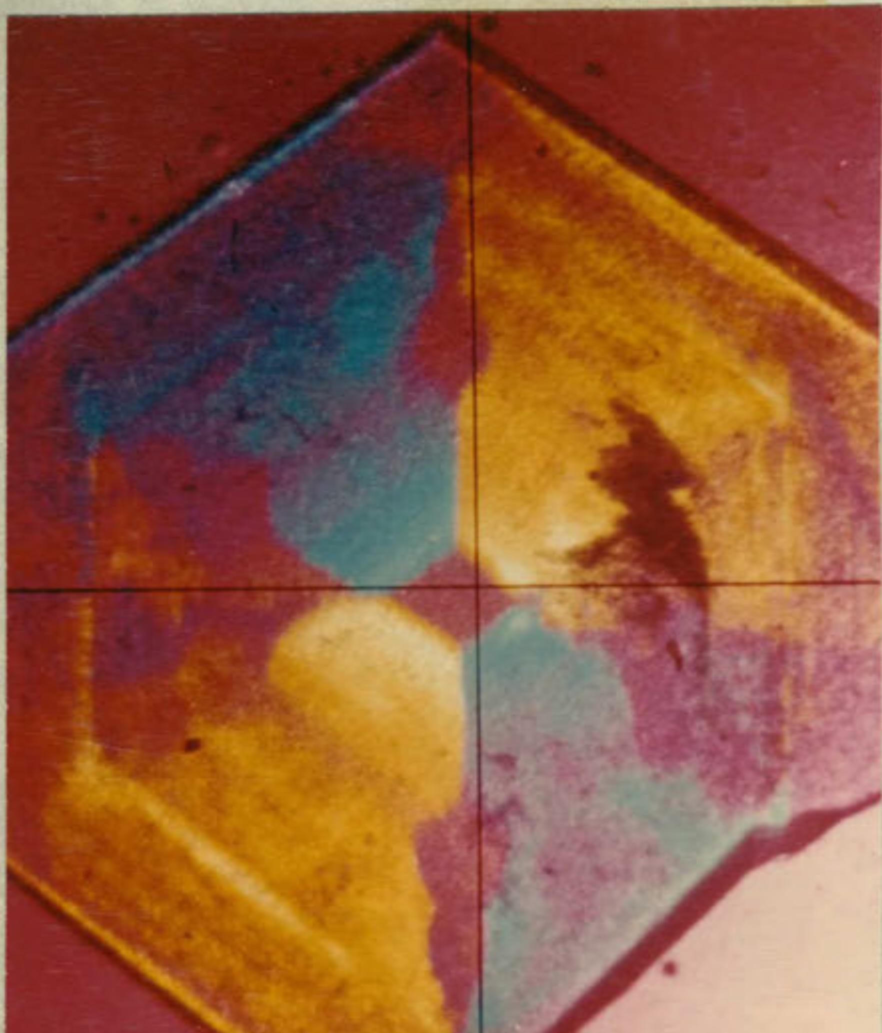
Anisotropism in Garnets

Arthur B. Merkle

ANISOTROPISM IN GARNETS - MERKLE



Garnet VI. C. Anisotropic crystal, view parallel two-fold axis, before heating, X-nicols, first order red plate, 26X.

ANISOTROPISM IN GARNETS

By

Arthur B. Merkle

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Geology

The University of New Mexico

1961

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 26, 1961
Date

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Chairman

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ABSTRACT

Six anisotropic garnets are studied by optical, thermal, and X-ray diffraction methods in an attempt to determine the cause of anisotropism. The garnets are all ugrandites with compositions ranging from chromian grossularite to nearly pure andradite, the composition having been estimated from indices of refraction and unit cell dimensions. In all cases the birefringence is 0.004 or less. Both positive and negative uniaxial and biaxial figures are sometimes observed. Heating of the garnets at 900°C for periods of 96 to 264 hours reduced the anisotropism in five of the six garnets studied; this observation is in agreement with previously reported studies. Precession and powder X-ray diffraction photographs show no detectable change from unheated to heated samples. Precession photographs of several sectors of a single anisotropic garnet yield identical patterns with isometric Ia3d symmetry, suggesting that anisotropism is not caused by twinning. I feel the cause of anisotropism in garnets is due to a combination of strain and rate of crystal growth in the metamorphic environment. A technical garnet bibliography of over 300 papers, written from 1900 to 1960 is presented; papers on anisotropic garnets written before 1900 are also included.

ABSTRACT

Six anisotropic garnets are studied by optical, thermal, and X-ray diffraction methods in an attempt to determine the cause of anisotropism. The garnets are all ugrandites with compositions ranging from chromian grossularite to nearly pure andradite; the composition having been estimated from indices of refraction and unit cell dimensions. In all cases the birefringence is 0.004 or less. Both positive and negative uniaxial and biaxial figures are sometimes observed. Heating of the garnets at 900°C for periods of 96 to 264 hours reduced the anisotropism in five of the six garnets studied; this observation is in agreement with previously reported studies. Precession and powder X-ray diffraction photographs show no detectable change from unheated to heated samples. Precession photographs of several sections of a single anisotropic garnet yield identical patterns with isometric Ia3d symmetry, suggesting that anisotropism is not caused by twinning. I feel the cause of anisotropism in garnets is due to a combination of strain and rate of crystal growth in the metamorphic environment. A technical garnet bibliography of over [illegible] papers, written from 1900 to 1960 is presented; papers on anisotropic garnets written before 1900 are also included.

INTRODUCTION

The Garnet Group

The term garnet is derived from the Latin granatus, meaning grainlike. This mineral crystallizes in the hexoctahedral class of the isometric system and forms a group of isomorphous silicates whose general formula is $R_3^{+2} R_2^{+3} (SiO_4)_3$. Winchell (1933, p. 174) has divided the garnet group into two species with the following names and compositions:

Specie	Type	Composition
Pyralspite	Pyrope	$Mg_3Al_2(SiO_4)_3$
	Almandite	$Fe_3Al_2(SiO_4)_3$
	Spessartite	$Mn_3Al_2(SiO_4)_3$
Ugrandite	Uvarovite	$Ca_3Cr_2(SiO_4)_3$
	Grossularite	$Ca_3Al_2(SiO_4)_3$
	Andradite	$Ca_3Fe_2(SiO_4)_3$

According to Dana (1932, p. 591-592) the two common habits of garnet are dodecahedral and trapezohedral. Their hardness ranges from 6.5 to 7.5; the specific gravity varies from 3.15 to 4.3.

Menzer (1928, p. 300-304) described the structure of garnet as follows: space group Ia3d; eight formulas to the unit cell.

Lattice Parameters

Ion	Position	Parameters
R^{+3}	16	(0,0,0)
Si^{+4}	24	(1/4,3/8,0)
R^{+2}	24	(1/4,1/8,0)
O^{-2}	96	(x,y,z)

In aluminum garnets the oxygen parameters are, $x=0.04\pm.01$, $y=0.055\pm.01$, and $z=0.64\pm.015$; in calcium-iron and calcium-chrome garnets the oxygen parameters are, $x=0.035\pm.01$, $y=0.04\pm.01$ and $z=0.655\pm.015$.

Dana (1932, p. 591) describes the structure of garnet as follows, SiO_4 tetrahedra are independent of each other; R^{+3} atoms lie in the center of a group of six oxygen atoms, and R^{+2} atoms in the center of a group of eight oxygen atoms.

Substitution in garnets may occur freely within each species,but is limited to about 20% between the two species.

Garnets are normally isotropic. Some, however, show optical anisotropism. Winchell (1933, p. 180) states anisotropism is usually restricted to ugrandite, but is sometimes seen in spessartite.

Purpose, Scope, and Method

The three main purposes of this thesis are:

1. The description of anisotropism in garnets.
2. A study of the effect of heat on anisotropic garnets.
3. A study of the cause of anisotropism in garnets.

Experimental work of three types, optical, thermal, and X-ray, was done between November 1959 and March 1961.

Anisotropic garnets from California, Canada, New Mexico, and Tasmania were studied. A literature search was made, and a selected bibliography of all technical garnet papers from 1900 to 1960 prepared; papers dated prior to 1900 were included only if they pertained directly to anisotropism in garnets.

Acknowledgments

The author wishes to express appreciation to Dr. Abraham Rosenzweig, of the University of New Mexico Geology Department, for suggesting the problem and guiding the research. The author wishes to thank Dr. V. C. Kelley, Dr. W. E. Elston, Mr. W. W. Pinch, and Mr. W. R. Seager for supplying garnet samples used in this study. The author also wishes to thank Dr. J. P. Fitzsimmons for translating Russian literature. Special thanks to the reference staff of the University of New Mexico library

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Previous Work

Since anisotropism was first observed in garnets, many attempts have been made to define its cause. In these attempts two methods of study have been used, optical and X-ray diffraction. Previous studies indicate two main causes of garnet anisotropism:

1. Twinning of elements with a lower symmetry.
2. Stress and pressure caused by isomorphous substitution during formation of the garnet.

The following statements are those of the authors; their terminology is used in all cases.

The first optical study of anisotropic garnets was carried out by Mallard in 1876. His studies led him to believe anisotropism was caused by twinning of individuals with a lower symmetry.

Klein (1898) studied various garnets from Vilui, Siberia and decided they were composed of twinned monoclinic or triclinic individuals showing vicinal forms. He also found anisotropism was not dependent on composi-

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Kirganov (1941) said anisotropism in garnets is caused by the presence of intergrown twin laminae.

Corin (1943) stated anisotropic garnets are caused by leucite-type polysynthetic twinning.

Lehmann (1888) said anisotropic garnets are a "mechanical mixture" of two or more chemically different garnet types. The different thermal coefficients of expansion of these types cause stress within the crystal, that varies with crystallographic direction. Homogeneous crystals have similar coefficients of expansion in all directions, whereas in mixed crystals the coefficients of expansion vary with the crystallographic directions. This could be the cause of anisotropism in garnets.

Brauns (1891) stated that optical observations show anisotropism in garnets caused by an isomorphous substitution of two or more chemically different garnet types. This substitution creates internal stress and tension causing anisotropism. The amount of anisotropism is varied by a variation of stress with crystallographic direction. This is analagous to phenomena seen in sylvite and flourite.

Rinne (1925) was the first person to study anisotropic garnets by the use of X-ray diffraction (the Laue and powder methods). His experiments showed anisotropic garnets are caused by variations in the electron paths due to a slight shifting of the atomic nucleus. This shifting was probably caused by stress and pressure due to twinning and isomorphous substitution within the crystal.

Starkov (1950) described three distinct types of optical anomalies in garnets:

1. Crystals consisting of concentric anisotropic zones, forming true hexagons with sectoral extinction (Starkov fig. 2, p. 284). More commonly the hexagonal figure is not displayed due to the fact that the crystals are cut in different orientations. The number of the birefringent zones and their

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Stone (1929) was the first person to study anisotropic garnets by the use of X-ray diffraction (the Laue and powder methods). His experiments showed anisotropic garnets are caused by variations in the lattice, which due to a slight shifting of the atoms positions. This shifting was probably caused by stress and thus was due to twinning and isomorphous substitution within the crystal.

Starkov (1950) described three distinct types of optical anomalies in garnets:

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thickness are variable. All bands extinguish parallel to the 110 trace of the crystal. This extinction appears in six regular sectors corresponding to the faces of a hexagon.

2. Crystals are characterized by a system of bands in each sector, generally trending at an angle near 60° to the trace of the (110) face for the given sector and parallel to the trace of the (110) face in one of the adjoining sectors. These bands are uniform in width and situated in a triangle between the central core and the peripheral part of the crystal (Starkov fig. 4, p. 285).

3. Crystals with birefringent bands arranged perpendicular to the trace of the (110) face. These bands do not have sharp boundaries and are generally found near the edge of the crystal. In cross section, these bands form a "rectangular lattice with the concentric layers."_/

Starkov felt these features were caused by isomorphous replacement of Fe^{+2} by Ca^{+2}. The difference in the ionic

_/ The expression in quotation is a direct translation from the Russian. Starkov provides no illustration of this garnet type, and consequently the description of this anisotropism remains ambiguous.

radii of these two ions will cause a distortion "of the electron shell surrounding ions of andradite" thus creating internal stress. Impurities in the crystallizing solution were systematically arranged in layered overgrowths. These also could cause anisotropism.

Merwin (in Wright, C. W., 1915, p. 108) performed the first thermal experiments with anisotropic garnets. He observed that they became isotropic when heated to 800° for a few hours.

Soloviev and Nikogosyan (1938) found that anisotropic garnets lost their birefringence within the temperature range 750°-850°C and a heating time of 72-168 hours.

Kozu (1940) observed that anisotropic zones in garnets decreased in intensity with increased temperature.

Yoder and Keith (1951) working with artificially prepared garnets, found a complete solid solution between spessartite and yttrogarnet

$$Mn_3Al_2(SiO_4)_3 \longrightarrow Y_3Al_2(AlO_4)_3$$

Yttrogarnet has been shown to be isometric. However, at 1970°C±50° a solid state transition occurs between yttrogarnet and yttroalumite. X-ray studies by Donnay show yttroalumite to be tetragonal with a primitive lattice.

Keith and Roy (1954) presented further evidence substantiating the experiments of Yoder and Keith.

EXPERIMENTAL WORK

Procedures

The purpose of the experimental work of this thesis is three-fold:

1. Identification of the garnet type.
2. Relation of the crystallographic properties to anisotropism.
3. Relation of the thermal behavior to anisotropism.

The garnets studied in this thesis were unoriented garnet masses (garnets I, II, and III), small single crystals (garnets IV and V), and orientated thin sections of large single crystals (garnet VI).

All garnets were heated in an electric furnace, under oxidizing conditions and atmospheric pressure, to temperatures of 900°C for intervals ranging from 96 to 264 hours. The results of this work are presented in table 2.

The index of refraction of the garnets was determined by the immersion method on crushed fragments. Optic signs and figures were obtained with the polarizing microscope. The 2V was approximated by the curvature of the isogyres. In each garnet studied the birefringence is approximated as 0.004 or less. The universal stage was not used in any of the optical observations.

X-ray powder photographs were taken of garnets I, II, III, and IV; Buerger precession photographs were taken of

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All garnets were heated in an electric furnace, under oxidizing conditions and atmospheric pressure, at temperatures of 900°C for intervals ranging from 24 to 200 hours. The results of this work are presented in table 2.

The index of refraction of the garnets was determined by the immersion method on crushed fragments. Optic signs and figures were obtained with the polarizing microscope. The 2V was approximated by the curvature of the isogyres. On each garnet studied the birefringence is approximated at 0.001 or less. The universal stage was not used in any of the optical observations.

X-ray powder photographs were taken of garnets I, II, III, and IV; precession photographs were taken of garnets IV, V, and VI. Filtered molybdenum and copper radiations were used. The unit cell dimensions and the symmetry of these garnets weredetermined from the reflections present on these photographs. The unique space group Ia3d was selected because the systematic extinctions of this group impose conditions that are fulfilled by the garnets studied. That is, reflections of the type hkl are present only if h+k+l is even; hhl reflections are present only when l is even; furthermore, for hhl, 2h+l is a multiple of four, and hk0 reflections are present only when both h and k are even.

The crystals of garnet VI were large enough to isolate various portions of the crystal in the X-ray beam, permitting an examination of the orientation of various crystal segments in order to detect twinning. In general, the procedure is as follows: the crystal is centered in the X-ray beam and lined up on a symmetry axis. A precession photograph is then taken. The crystal is then shifted, so the X-ray beam strikes the outer edge of a portion of the crystal. Another precession photograph is taken. This procedure is repeated at regular intervals around the crystals edge. If detectable twinning is present it will be seen as a change in the orientation of the diffraction pattern. No detectable twinning was observed in garnet VI.

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The crystals of garnet VI were moved through [illegible] various portions of the crystal in the X-ray beam, permitting an examination of the orientation of various crystal segments in order to detect twinning. In general, the procedure is as follows: the crystal is mounted in the X-ray beam and lined up on a symmetry axis. A precession photograph is then taken. The crystal is translated, so the X-ray beam strikes the outer edge of a portion of the crystal. Another precession photograph is taken. This procedure is repeated at regular intervals around the crystals edge. If lamellar twinning is present it will be seen as a change in the orientation of the diffraction pattern. No observable twinning was observed in garnet VI.

Garnets seen in plates I. B, I. D, and II. C are not the same areas seen in plates I. A, I. C, and II. B; these areas are of adjacent thin sections in the rock sample.

Composition of the Garnets

The composition of the garnets studied has been determined from triangular diagrams plotted by Sriramadas (1957, p. 294-298). These diagrams relate unit cell dimension and index of refraction to composition. The compositions of these garnets are shown in table 1.

Anisotropism of the Garnets

Garnet I.

Location:

One and a quarter miles north of Darwin, near the Thompson Mine, Darwin mining district, Inyo County, California.

Megascopic description:

The garnet occurs as a yellowish-green mass in a tactite.

Optical properties:

The thin-section color of the garnets is light yellowish-gray. The masses are made up of zoned dodecahedra. Numerous inclusions are present. The crystals are composed of anisotropic and isotropic zones (Pl. I. A). Wavy

Garnets seen in Plates [illegible] are not the same [illegible] these [illegible] of [illegible] sample.

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Table 1.--Garnet composition

Garnet number Location	Unit cell dimension	Index of refraction	Composition (after Sriramadas, 1957)
I Darwin, California	11.9Å	1.830±.005	53% Andradite 34% Grossularite 16% Others
II Silverhill Mine, New Mexico	12.0Å	1.865±.005	83% Andradite 12% Grossularite 5% Others
III Unknown	12.0Å	1.870±.005	85% Andradite 7% Grossularite 8% Others
IV Iron King Mine, New Mexico	12.0Å	1.880±.005	90% Andradite 2% Grossularite 8% Others
V Tasmania	12.0Å	1.875±.005	88% Andradite 5% Grossularite 7% Others
VI Orford, Canada	11.8Å	1.730±.005	90% Grossularite 10% Others (probably uvarovite in part)

extinction is seen in some crystals. Faint uniaxial and biaxial figures are seen. The optic sign varies from (+) to (-). The optical anomalies resemble Starkov's type 1.

Garnet II.

Location:

Southeast of the Silver Hill mine, NW$\frac{1}{4}$ sec. 3, T. 25 S., R. 21 W., Hidalgo County, New Mexico.

Megascopic description:

The rock is a solid mass of green, brown, and red garnet. Some euhedral crystals are present. These crystals show zoning which can be distinguished by color differences.

Optical properties:

The thin-section color is a yellowish-green. The garnets are massive, anhedral, and cloudy with numerous inclusions. Wavy extinction is present. The optic sign and optic figure are not determinable. Anisotropism is present in the entire mass (Pl. I. C).

Garnet III.

Location:

Unknown.

Megascopic description:

Garnet crystals occur in a calcite mass with chalcopyrite, malachite, and magnetite. The garnet is green-brown and zoned.

Optical properties:

Thin-section color of the garnets is greenish-brown. The garnet is massive with some euhedral crystals. Zoning present in the garnets parallels dodecahedral faces (Pl. II. A). Some wavy extinction is observed. These garnets are mostly isotropic; anisotropism is seen in zones of varied widths, which outline dodecahedral faces (Pl. II. B). The anisotropism resembles Starkov's type 1; uniaxial and biaxial figures are observed.

Garnet IV.

Location:

Iron King mine, Jarilla Mountains, sec. 34, T. 21 S., R. 8 E., Otero County, New Mexico.

Megascopic description:

Euhedral, yellowish-brown garnets occur in a granular marble with specular hematite. These garnets are zoned and are both dodecahedral and trapezohedral in habit.

Optical properties:

The crystal studied is a yellowish-brown dodecahedron 0.5 mm in size. The crystal is anisotropic and contains some inclusions. Anisotropism varies with crystallographic direction. Due to the small size of the crystal, optic figures and signs are not observed.

Garnet V.

Location:

Tasmania (precise locality and mode of occurrence not known).

Megascopic description:

The crystals are greenish dodecahedrons. Their size ranges from 0.5 mm to 1.0 mm; the crystals are intergrown with some inclusions.

Optical properties:

The crystal studied is a greenish dodecahedron 0.7 mm in size. Anisotropism seen in the crystal varies with crystallographic direction. Because of the crystal size, optic figures and signs are not observed.

Garnet VI.

Location:

Orford, Sherbrooke County, Quebec, Canada.

Megascopic description:

Emerald green garnet crystals occur in a soft white talc.

Optical properties:

Three dodecahedral garnet crystals were studied. Their color in thin section is greenish; their size is about 3.5 mm. Three orientated thin sections were made.

A. perpendicular to a three-fold axis; B. perpendicular to a four-fold axis; and C. perpendicular to a two-fold axis.

Crystal A. Anisotropism in this crystal is a combination of Starkov's type 1, and type 3 (Pl. III. A and B). Anisotropic zone boundaries are not sharp. The crystal shows biaxial negative optic figures. A 2V of 60° is estimated from the curvature of the isogyres.

Crystal B. This crystal is mainly isotropic with some small anisotropic bands (Pl. III. C and D). The anisotropism is similar to Starkov's type 1. Faint traces of similarly orientated biaxial (-) figures are observed.

Crystal C. Thin isotropic sections are observed. The central part of the crystal is biaxial (-); 2V is about 60°. Six triangular areas are arranged about the central portion. These sectors are uniaxial; their optic signs alternate (+) and (-). This crystal is shown on Plate IV. The anisotropism is a combination of Starkov's type 1 and type 3.

Symmetry of Anisotropic Garnets

Based on procedures stated in the beginning of the experimental work section, the symmetry of the six anisotropic garnets is found to be Ia3d. There are no observable deviations from this. No detectable twinning is seen in garnets IV, V, and VI. X-ray patterns of garnets IV, V, and VI are in no way altered with heat.

Thermal Treatment and Results

The six garnets studied have been heated in an electric furnace, under oxidizing conditions and atmospheric pressure, to a temperature of 900°C for intervals ranging from 96 to 264 hours. Optical and X-ray properties remain constant after heating. Only the amount of anisotropism in the garnets is changed. Where possible to observe, as in garnet VI, the optics of the anisotropic zones are in no way altered with heat. X-ray patterns are also unaltered. Results of this treatment are shown in table 2.

CONCLUSIONS

Thermal treatment of five of the six garnet samples show either a reduction in or a destruction of the anisotropism of the garnets. In these five cases the samples were heated to 900°C for intervals ranging from 96 to 264 hours. The sixth sample (garnet I)

Summary of Anisotropic Garnets

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CONCLUSIONS

Thermal treatment of five of the six garnet samples show either a reduction in or a disappearance of the anisotropism of the samples. [illegible] samples were heated at 900° C for intervals ranging from 96 to 264 hours. [illegible] sample (garnet VI)

Table 2.--Results of thermal treatment of the garnets

Garnet number Location	Temperature attained	Hours held	Observed results
I. Darwin, California	900°C	226	Thin section color changed from light-yellow-gray to yellow-brown. Heat had no observable effect on anisotropism (Pl. I. B).
II. Silver Hill mine, New Mexico	900°C	226	Thin section color changed from yellowish-green to brown-yellow. Faint traces of anisotropism remain in the mass (Pl. I. D). Heat reduced the amount of anisotropism.
III. Unknown	900°C	264	Thin section color changed from greenish-brown to brown-yellow. Thin anisotropic zones remain (Pl. II. C). Amount of anisotropism was reduced with heat.
IV. Iron King mine, New Mexico	900°C	168	Thin section color changed from yellowish-brown to red-brown. The amount of anisotropism was greatly reduced.
V. Tasmania	900°C	96	Thin section color changed from greenish to yellowish-brown. Heating reduced the anisotropism present. However, it did not produce a completely isotropic crystal.
VI. Orford, Canada	900°C	168	Thin section color changed from greenish to brown-green. Zones remaining anisotropic became yellow-green. Anisotropism is reduced in amount in each crystal (Pls. III and IV).

was heated to 700°C [illegible] for [illegible] hours with no [illegible] observable change in the anisotropic nature of the crystals (Plate I, A. 2). This thermal treatment agrees in general with all previously performed work.

Powder photographs and X-ray precession photographs show all six garnets as having isometric holohedral symmetry; the space group is Ia3d. No deviation [illegible] is observed in the garnets. These facts show the optical anomalies seen in garnets are [illegible] not related to the internal structure of the garnets.

According to Brauns [illegible] (1891) [illegible] solid isotropic substances will acquire [illegible] properties of an anisotropic crystal if [illegible] under strain. [illegible] [illegible] [illegible] anisotropism in garnets.

The strain is caused by [illegible] [illegible] that formed the garnet. [illegible] [illegible] the strain and produce an isotropic [illegible]. [illegible] heating some vestiges of anisotropism may remain due to incomplete removal of the strain.

This hypothesis is substantiated by [illegible] X-ray patterns of these garnets [illegible] by heat. X-ray precession photographs [illegible] hexoctahedral symmetry [illegible] heating with no intensity changes. This would be the case [illegible] isometric crystal. [illegible] in the [illegible] to destroy the anisotropic effect is probably in some way proportional to the amount of strain that the garnet has undergone during its formation.

With further study this could probably be developed into a tool to define the temperature and pressure of formation of a metamorphic deposit containing anisotropic garnets.

This "strain" hypothesis does not take into account the sharp boundaries and distinct crystallographically orientated zones of anisotropism in the garnets. A possible but unproven reason for these could be the rate of growth of the crystal. The faster the growth the more pronounced the anisotropic effect. These anisotropic zones are usually parallel to the outer faces of the crystal and would represent growth surfaces.

The anisotropic effect seen in garnets could be due to a combination of strain and growth rate of the crystal.

The absence of detectable twinning does not rule out the possibility that twinning is the cause of anisotropism in garnets. One needs to use other and better methods for determining the presence of twinning in garnets.

PLATE I

A. Garnet I: Anisotropic crystals, before heating, X-nicols, 80X

B. Garnet I: Anisotropic crystals, after heating for 226 hours, X-nicols, 80X

C. Garnet II: Anisotropic mass, before heating, X-nicols, 26X

D. Garnet II: Anisotropic mass, after heating for 226 hours, X-nicols, 26X

PLATE II

A. Garnet III: Anisotropic crystals, before heating, plane polarized light, 26X

B. Garnet III: Anisotropic crystals, before heating, X-nicols, 26X

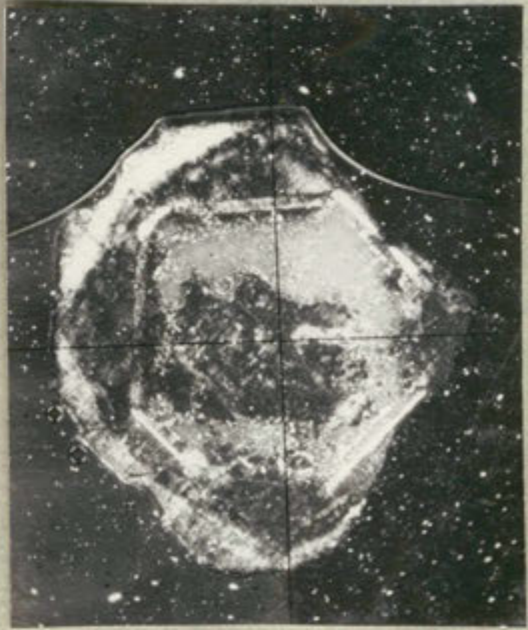
C. Garnet III: Anisotropic crystals, after heating for 264 hours, X-nicols, 26X

PLATE III

A. Garnet VI.A: Anisotropic crystal, view parallel three-fold axis, before heating, X-nicols, 26X

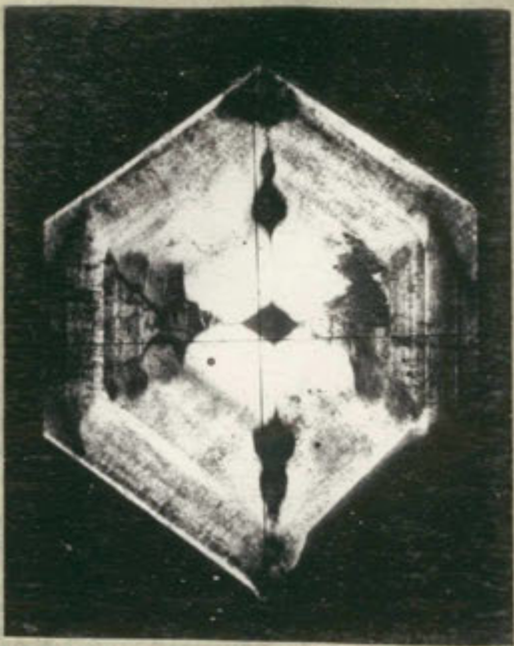
B. Garnet VI.A: Anisotropic crystal, view parallel three-fold axis, after heating for 168 hours, X-nicols, 28X

C. Garnet VI.B: Anisotropic crystal, view parallel four-fold axis, before heating, X-nicols, 26X



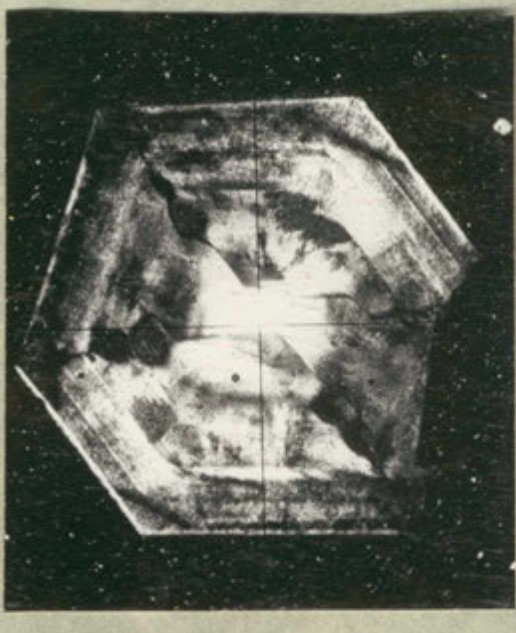
D. Garnet VI.B: Anisotropic crystal, view parallel four-fold axis, after heating for 168 hours, X-nicols, 28X

PLATE IV

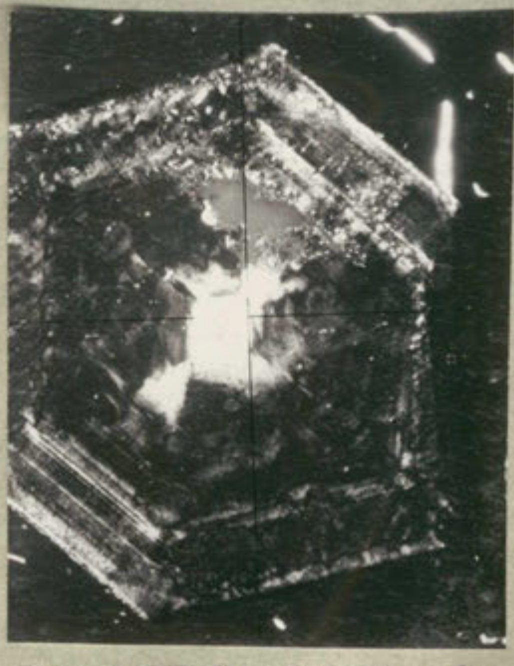


A. Garnet VI.C: Anisotropic crystal, view parallel two-fold axis, before heating, X-nicols, 26X

B. Garnet VI.C: Anisotropic crystal, view parallel two-fold axis, after heating for 144 hours, X-nicols, 28X



C. Garnet VI.C: Anisotropic crystal, view parallel two-fold axis, rotated 45° from A., before heating, X-nicols, 26X



D. Garnet VI.C: Anisotropic crystal, view parallel two-fold axis, rotated 45° from A., after heating for 144 hours, X-nicols, 28X

SELECTED BIBLIOGRAPHY

Where possible this bibliography follows the form set forth in Suggestions to Authors of the reports of the United States Geological Survey. Otherwise articles are given as found in the secondary references. The bibliography was compiled from the following sources:

1. Bibliography and Index of Geology Exclusive of North America.
2. Bibliography of North American Geology.
3. Chemical Abstracts.
4. Geologic Literature on North America.
5. Poggendorff's Biographisch-Literarisches Handworterbuch.
6. Royal Society Catalogue of Scientific Papers.

Abrahams, S. C., and Geller, S. C., 1958, Refinement of the structure of a grossularite garnet: Acta. Cryst. v. 11, p. 437-441.

Agar, W. M., and Krieger, J. C., 1932, Garnet rocks near west Redding, Connecticut: Am. Jour. Sci., v. 29, p. 68-80.

Alderman, A. R., 1935, Almandine from Botallack, Cornwall: Mineralog. Mag., v. 24, p. 42-48.

Alessi, A. J., 1938, Chloride garnets of Michigan: Mineralogist, v. 6, p. 9-10.

Amaral, S. E., 1949, Nota sobre uma granada de Ouixadá, Ceara: Mineracão e Metal., v. 14, p. 78-79.

Andreatta, Cito, 1938, Giacimenti di granato alamandine ai contatti del massiecio intrusivo di Cima d'Asta e loro paragenesi: Studi Trentini Sci. Nat., v. 19, p. 105-130 (in Italian).

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]

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[illegible]

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Angel, Franz, and Schaider, Ferdinand, 1950, Granat und Omphazit aus dem Eklogit des Gertrusk: Carinthia II, Jg. 139-140, p. 33-36 (in German).

Asano, Goro, 1950, Garnets in banded iron areas, from Manchuria: Jap. Assoc. Mineralogists, v. 34, p. 179-187 (in Japanese).

Asano, Goro, and Okada, S. C., 1940, Almandite from the Kung-Chang-Ling iron mine: Manchukuo Geol. Inst., no. 98, p. 51-56 (in Japanese).

Badalov, S. T., 1951, Vanadium-containing tourmaline and garnet: Mem. Soc. Russe. Mineral., v. 80, p. 212-213 (in Russian).

Bain, G. W., 1923, Almandite and its significance in the contact zones of the Grenville limestone: Jour. Geology, v. 31, p. 650-658.

Balk, Robert, 1944, Comments on some eastern Adirondack (New York) problems: Jour. Geology, v. 52, no. 5, p. 289-318.

Belkov, I. V., 1949, Srastanie granata s muskovitom: Doklady Akad. Nauk. SSSR, v. 64, no. 2, p. 241-243, (in Russian).

Benedicks, Carl, 1907, Yttrium-bearing manganese garnet: Bull. Geol. Inst. Univ. Upsala, v. 7, p. 271-277.

Ben-Saude, Alfredo, 1894, Beitrage zu einer Theorie der optischen Anomalien der regularen Kristalle: Lisbon (in German).

Bertaut, Felix, and Forrat, Francis, 1957, Garnet parameters: Acad. Sci. (Paris) Comptes rendus, v. 244, p. 96-99 (in French).

Betekhtin, A. G., 1946, On chrome garnets from the Nizhne-Tagilsk dunite Massif: D. S. Beluandin Jubilee Vol. Acad. Sci. SSSR, p. 68-73 (in Russian).

Bianchi, A. P., 1923, Interesting crystals of andradite in the serpentine of the Passo della Rossa: Atti. Acad. Lincei, v. 32, p. 504-508.

Billiet, V. P., and Vanderdriessche, A. D., 1937, Grenats de La région de Bastogne-Libramont: Soc. Belge. Geol., v. 47, p. 222-224 (in French).

Bobrovnik, D. P., 1950, Garnets from coal seams of the Lemberg region: Mem. Soc. Russe. Mineral., v. 80, p. 127-139 (in Russian).

Beoke, H. E., 1914, The garnet group: Zeitschr. Krist., v. 53, p. 149-157 (in German).

Borobev, V. P., 1897, The optical structure of garnet in the Eugene-Maximillian mine: Mem. Soc. Russe. Mineral. no. 1 (in Russian).

Brammall, A. C., and Bracewell, S. P., 1936, Variability of garnet in granites: Mining Mag., v. 24, p. 254-265.

Brauns, R. A., 1891, Die optischen Anomalian der Kristalle: Preisschr. Jablonowski Ges., Leipzig, 370 p. (in German).

_____ 1907, Light effect of garnet, zircon, and sapphire: Neues Jahrb. Min. Geol., no. 1, p. 13-20 (in German).

_____ (no date given), The chemical constitution of garnetiferous crystalline schists, cordierite rocks, and sanidinite from the Lake Laach Region: Neues Jahrb. Min. Geol., v. 34, p. 85-175 (in German).

Bressler, C. T., 1950, Garnet deposits near Wrangell, Southeastern Alaska: U. S. Geol. Survey Bull. 963-C, p. 81-93.

Briere, Y. A., 1920, An amphibolite with garnet, olivine, and hypersthene: Soc. Mineral. France Bull., v. 43, p. 300-303 (in French).

Brindley, J. C., 1954, The garnetiferous beds of the Leinster granite aureole and their small scale structures: Sci. Proc. Roy. Dublin Soc., v. 26, p. 245-262.

Brock, R. W., 1915, A British Columbia example of the contact metamorphism of a granite to a garnet: Roy. Soc. Can. Trans., v. 9, p. 175-180.

Brown, I. A., 1929, A garnet-bearing dike near Mornya, New South Wales: Linnean Soc. N. S. Wales 54, pt. 3, p. 176-184.

Brun, Albert, 1930, Optical constants of almandite, sphalerite, and zircon: Bull. Soc. Franc. Mineral, v. 53, p. 35-46 (in French).

Buddington, A. F., 1950, Composition and genesis of pyroxene and garnet related to Adirondack anorthosite and anorthosite-marble contact zones: Am. Mineralogist, v. 35, nos. 9-10, p. 659-670.

Buddington, A. F., and Whitcomb, Lawrence, 1941, Geology of the Willsboro quadrangle (New York): N. Y. State Mus. Bull. 325, 137 p.

Buttgenbach, H. P., 1922, The garnets of Bastogne and Salm-Chateau: Ann. Soc. Geol. Belg. 45, p. 249-260 (in French).

_____ 1930, Crystals of gold, titanite, and garnet: Acad. royale Belgique Bull. cl. sci., v. 16, p. 874-880.

Carithers, L. W., and Guard, A. K., 1945, Geology and ore deposits of the Sultan Basin, Snohomish County, Washington: Washington Div. Mines and Geology Bull., v. 36, 90 p.

Carozzi, Enrico, 1926, A chromiferous spessartite from St. Barthelmy, Valle d 'Aosta: Atti Accad. Lincei, (6) 3, p. 230-232 (in Italian).

Carpanese, T., 1932, Garnet, vesuvianite, ilmenite, and titanite from Monte Roseo di Verra (Monte Rosa Group). Atti Accad. Lincei 15, p. 591-595 (in Italian).

Charlu, T. G. K., 1951, A note on the development of large garnets in Sutherland migmatites: Geol. Mag. v. 88, no. 3, p. 185-191.

Christophe-Michel-Levy, Mireille, 1956, Reproduction artificielle des grenats calciques; grossulaire et andradite: Soc. Franc. Miner., B. t. 79, no. 1-3, p. 124-128 (in French).

Coetzee, C. B., 1941, An anorthite-epidote-garnet hornfels from Namaqualand, South Africa: Mineralog. Mag. 26, p. 134-139.

Colasso, Teresa, 1937, I minerali dei filoni pegmatitici di Olgiasca: Soc. Ital., Sci. Nat. Milano, Atti v. 76, f. 4, p. 403-418 (in Italian).

Colomba, Luigi, (no date), Iron chromium garnet from Praborna (S. Marcel): 1 st. Min. Univ. Torino. Atti Accad. Lincei, 19, II, p. 146-150 (in Italian).

Conant, L. C., 1935, The New Hampshire garnet deposits: Econ. Geology, v. 30, no. 4, p. 387-399.

Conforto, B. S., 1947, Origin of garnets and zirconia in magnatite sand: Ricerca sci., 17, p. 1609-1610.

Connah, F. E., 1913, The garnet rocks of Chillagoe, Queensland: Queensland Roy. Soc. Proc., 22, p. 31-34.

Corin, Francois, 1938, A propos des grenats de la region de la zone de paliseul: Soc. Belge Geologie, B. t. 48, f. 2, p. 451-473 (in French).

_____ 1943, New observations concerning the anisotropy of the garnets of Ardenne: Ann. Soc. Belge Geologie, Bull. 66, p. 143-148 (in French).

Cornu, F. J., 1906, Analysis of garnet from the granulite of Etzmannsdorf, lower Austria: Min. Pet. Mitt., v. 25, p. 355-356.

Corstorphine, G. S., (no date given), The occurrence in Kimberlite of garnet-pyroxene nodules carrying diamonds: Geol. Soc. South Africa Trans. and Proc., v. 10, p. 65-68.

Dana, E. S., 1932, A textbook of mineralogy: New York, John Wiley and Sons, 851 p.

De Beaupuis, F. S., 1922, Garnet from the island of Quessant: Soc. Mineral. France Bull., v. 45, p. 5-7 (in French).

Donnay, J. D. H., and Faessler, Carl, 1941, Trisoctahedral garnet from the Black Lake Region, Quebec: Toronto Univ. Studies, Geol. Ser. 46, p. 19-24.

Doughty, D. C., and White, E. A. D., 1960, Imperfections in yttrium iron garnet crystals: Acta Cryst., v. 13, pt. 10, p. 761-762.

Dunn, J. A., 1932, Reaction minerals in a garnet-cordierite-gneiss from Mogok, Burma: India Geol. Survey Rcs., 65, p. 445-456.

Colomba, Luigi, (no date), Iron chromium garnet from Praborna (S. Marcel): I st. Min. Univ. Torino. Atti Accad. Lincei, 19, II, p. 146-150 (in Italian).

Conant, L. C., 1935, The New Hampshire garnet deposits: Econ. Geology, v. 30, no. 4, p. 357-359.

Conforto, B. S., 1947, Origin of garnets and zircons in magnetite sand: Ricerca sci., 17, p. 1609-1610.

Connah, F. E., 1913, The garnet rocks of Chillagoe, Queensland: Queensland Roy. Soc. Proc., 22, p. 31-34.

Corin, Francois, 1938, A propos des grenats de la region de la zone de pelissant: Soc. Belge Geologie, P. t. 48, f. 2, p. 451-473 (in French).

______ 1943, New observations concerning the anisotropy of the garnets of Ardennes: Ann. Soc. Belge Geologie, Bull. 66, p. 143-148 (in French).

Cornu, F. J., 1906, Analysis of garnet from the granulite of Etzmannsdorf, lower Austria: Min. Pet. Mitt., v. 25, p. 355-355.

Corstorphine, G. S., (no date given), The occurrence in kimberlite of garnet-pyroxene nodules carrying diamonds: Geol. Soc. South Africa Trans. and Proc., v. 10, p. 65-68.

Dana, E. S., 1932, A textbook of mineralogy: New York, John Wiley and Sons, 851 p.

De Beaupuis, P. S., 1922, Garnet from the island of Quessant: Soc. Mineral. France Bull., v. 45, p. 5-7 (in French).

Donnay, J. D. H., and Fasssler, Carl, 1941, Trisoctahedral garnet from the Black Lake Region, Quebec: Toronto Univ. Studies, Geol. Ser. 46, p. 19-24.

Doughty, D. C., and White, E. A. D., 1960, Imperfections in yttrium iron garnet crystals: Acta Cryst., v. 13, pt. 10, p. 761-762.

Dunn, J. A., 1932, Reaction minerals in a garnet-cordierite-gneiss from Mogok, Burma: India Geol. Survey Rec., 65, p. 445-456.

Durrell, Cordell, 1943, Geology of the Sierra Nevada northeast of Visalia, Tulare County, California: California Jour. Mines and Geology, v. 39, no. 2, p. 153-168.

Eakle, A. S., 1917, Minerals associated with the crystalline limestone at Crestmore, Riverside County, California: Univ. Cal. Bull. Dept. Geol., v. 10, p. 327-360.

Eckel, E. B., 1932, Garnet as an amygdule mineral: Am. Mineralogist, v. 17, no. 11, p. 522-529.

Edwards, A. B., 1936, On the occurrence of almandine garnets in some Devonian igneous rocks of Victoria: Roy. Soc. Victoria, Pr. N. S., v. 49, pt. 1, p. 40-50.

Eitel, W. C., 1921, The polynary miscibility of garnet minerals: Zeitschr. Krist. 56, p. 526-531 (in German).

Endell, K. R., 1913, Garnet-amphibolite and eclogite from Tromso and Tromsdaltind: Centr. Min. Geol., p. 129-133 (in German).

Eskola, Pentti, 1921, The eclogites of Norway: Videnskapssels kapets Skrifter 1, no. 8, p. 118.

Fedorow, E, von, 1897, Der Granat von den Turjinsk'schen Gruben: Zeitschr. Krist., v. 27, p. 276-290 (in German).

Fermor, L. L., 1934, Note on the manganese-lime series of garnets: India Geol. Survey Recs., v. 68, pt. 3, p. 337-343.

_____ 1938, Garnets and their role in nature: Indian Assoc. Cultivation Sci., Special pub. no. 6, pi-iii, 1-105.

_____ 1938, Khoharite, a new garnet, and the nomenclature of garnets: India Geol. Survey Recs. 73, p. 145-156.

_____ 1952, A new chrome garnet: Geol. Mag. 89, p. 145-147.

Fleischer, Michael, 1937, The relation between chemical composition and physical properties in the garnet group: Am. Mineralogist, v. 22, no. 6, p. 751-759.

Folinsbee, R. E., 1941, The chemical composition of garnet associated with cordierite: Am. Mineralogist, v. 26, no. 1, p. 50-53.

Ford, W. E., 1915, A study of the relations existing between the chemical, optical, and other physical properties of the members of the garnet group: Am. Jour. Sci., v. 40, p. 33-49.

Fowler-Billings, Katherine, and Page, L. R., 1942, The geology of the Cardigan and Rumney quadrangles, New Hampshire: Concord, New Hampshire plan. comm., 31 p.

Fowler-Lunn, K. S., and Kingsley, Louise, 1937, Geology of the Cardigan quadrangle, New Hampshire: Geol. Soc. America Bull., v. 48, no. 10, p. 1363-1386.

Franco, R. R., 1945, Granada almandina em Pernambuco: Mineracão e Metal., v. 9, no. 53, p. 221-223.

Frankel, J. J., 1959, Uvarovite garnet and South African jade from Transvaal: Am. Mineralogist, v. 44, nos. 5 & 6, p. 565-591.

Frietsch, Rudyard, 1957, Determination of the composition of garnets without chemical analysis: Geol. Fören. Stockholm, Förh. v. 79, h. 1, no. 488, p. 43-51.

Geller, S. C., and Miller, C. E., 1959, The synthesis of uvarovite: Am. Mineralogist, v. 44, nos. 3 & 4, p. 445-446.

_____ 1959, Substitution of Fe^{+3} for Al^{+3} in synthetic spessartite: Am. Mineralogist, v. 44, nos. 5 & 6, p. 665-667.

_____ 1959, Silicate garnet-yttrium-iron garnet solid solutions: Am. Mineralogist, v. 44, no. 11-12, p. 1115-1120.

Gentile, A. L., and Roy, Rustum, 1960, Isomorphism and crystalline solubility in the garnet family: Am. Mineralogist, v. 45, nos. 5 & 6, p. 701-711.

Glasser, F. P., 1959, On the stability and synthesis of uvarovite $Ca_3Cr_2Si_3O_{12}$: Am. Mineralogist, v. 44, no. 11-12, p. 1301-1303.

Gliszczynski, S. V., 1940a, Garnet twins?: Zentr. Mineral., Geol. p. 252-253 (in German).

Gnevushev, M. A., Kalinin, A. I., Mikheev, V. I., and Smirnov, G. I., 1956, Changes in the elementary cell dimensions of garnets as a function of their chemical composition: Zapiski Vsesoyuz. Mineral. Obshchestva 85, p. 472-490 (in Russian).

Goodspeed, G. E., and Coombs, H. A., 1932, Quartz-diopside-garnet veinlets: Am. Mineralogist, 17, p. 554-560.

Gossner, B. R., 1931, Composition of garnets of the garnet group: Neues Jahrb. Min., v. 64, p. 225-233 (in German).

Gossner, B. R., and Ilg, E. C., 1932, Mineralogy of the Bavarian Forest and the chemical composition of the almandite-spessartite series and of cordierite: Centr. Mineral. Geol. p. 1-12 (in German).

Gottfried, C. D., 1930, Minerals from the Adamello Mts. (Trentino): Chem. Erde., v. 5, p. 106-112 (in German).

Green, J. N. F., 1915, The garnets and streaky rocks of the English Lake District: Mineral Mag., v. 17, p. 207-218.

Gregory, H. E., 1916, Garnet deposits on the Navajo Reservation, Arizona and Utah: Econ. Geology, v. 11, p. 223-230.

Grill, E. S., (no date given), Epidote and garnet from the Brosso Mine, Piemont: Atti. Accad. Lincei, v. 23, I, p. 535-538.

Grubenmann, U. A., (no date given), The garnet-olivine rock of the Gorduno Valley and its accompanying rocks: Vierteljahresschrift Naturf. Ges. Zurich, v. 53, p. 1-28 (in German).

Hall, A. L., 1925, On "Jade" (massive garnet) from the Bushveld in the Western Transvaal: Geol. Soc. South Africa Trans., v. 27, p. 39-55.

Harker, R. I., 1954, Further data on the petrology of the pelitic hornfelses of the Charn Chuinneafinchbea Region, Ross-Shire, with special reference to the status of almandine: Geol. Mag. v. 91, no. 6, p. 445-462.

Hartmans, N. E., and de Jong, W. F., 1940, Determination of garnets: Naturwetenensch. Tijds., v. 22, p. 237-240 (in German).

Hartshorne, N. H., and Stuart, A. R., 1950, Crystals and the polarizing microscope: London, Edward Arnold & Co., 549 p.

Hasegawa, Shuzo, 1955, Corundum and andradite from Okita, Daito-Machi, Iwate prefecture: Jap. Assoc. Mineralogists, v. 39, no. 5, p. 194-203 (in Japanese).

Heritsch, Franz, 1926-7, Chemistry of garnets: Neues Jahrb. Min. Abt. A, v. 55, p. 60-91 (in German).

Heritsch, H. D., 1933, X-ray examination of garnet from the gorge of the Lieser near Spittal (Carinthia): Zeitschr. Krist., v. 85, p. 392-403 (in German).

Herriot, A. N., 1956, Notes on an occurrence of garnet in the felsite of Tinto, Lanarkshire: Geol. Soc. Glascow, Tr. v. 22, pt. 1, p. 94-99.

Hezner, Laura, 1914, Analysis of a garnet in asbestos from Binnental: Centr. Min. Geol., p. 325 (in German).

Hietanen, Anna, 1959, Kyanite-garnet gedritite near Orofino, Idaho: Am. Mineralogist, v. 44, nos. 5 & 6, p. 539-564.

Himmel, Hans, 1938a, Ernita=garnet: Zentr. Mineral., Geol. p. 243-245 (in German).

Houston, J. R., 1955, The garnet deposit near Wrangell, Alaska: Rocks and Minerals, v. 30, nos. 11 & 12, p. 563-569.

Howard, J. W., 1933, Garnets: Jour. Chem. Education, v. 10, p. 713-716.

Howie, R. A., and Subramaniam, A. P., 1957, The paragenesis of garnet in charnockite, enderbite and related granulites: Mineralog. Mag., v. 31, no. 238, p. 565-585.

Hummel, F. A., 1950, Synthesis of uvarovite: Am. Mineralogist, v. 35, nos. 3 & 4, p. 324-325.

Icki, Y. A., 1942, Chemical analysis of garnet from Hahossu, Fushun Prefecture, Fengtien Province, Manchuria: Mem. Geol. Inst. Manchoakuo, v. 17, p. 98-100 (in Japanese).

Hartmans, M. S., and de Jong, W. F., 1940, Determination of garnets: Naturwetenschap. Tijdschr., v. 22, p. 237-240 (in German).

Hartshorne, N. H., and Stuart, A. K., 1950, Crystals and the polarizing microscope: London, Edward Arnold & Co., 529 p.

Hasegawa, Shozo, 1955, Corundum and grossularite from Oriku, Saito-Machi, Iwate prefecture: Jap. Assoc. Mineralogists, v. 39, no. 5, p. 194-205 (in Japanese).

Heritsch, Franz, 1926-7, Umwandlung of garnets: Neues Jahrb. Min. Abt. A, v. 55, p. 60-91 (in German).

Heritsch, H. D., 1933, X-ray examination of garnet from the gorge of the Isar near Schäftlarn: Zeitschr. Krist., v. 85, p. 392-403 (in German).

Herriot, A. N., 1956, Notes on an occurrence of garnet in the felsite of Tinto, Lanarkshire: Geol. Soc. Glasgow, Tr., v. 22, pt. 1, p. 94-97.

Hezner, Laura, 1914, Analysis of a garnet in asbestos from Binnental: Centr. Min. Geol., p. 195 (in German).

Hietanen, Anna, 1959, Kyanite-garnet gedrite near Orofino, Idaho: Am. Mineralogist, v. 44, nos. 5 & 6, p. 539-564.

Himmel, Hans, 1938a, Grolite-garnet: Centr. Mineral., Geol. p. 243-245 (in German).

Houston, J. R., 1955, The garnet deposit near Wrangell, Alaska: Rocks and Minerals, v. 30, nos. 11 & 12, p. 563-569.

Howard, J. W., 1933, Garnets: Jour. Chem. Education, v. 10, p. 713-716.

Howie, R. A., and Subramaniam, A. P., 1957, The paragenesis of garnet in charnockite, enderbite and related granulites: Mineralog. Mag., v. 31, no. 239, p. 565-586.

Hummel, F. A., 1950, Synthesis of uvarovite: Am. Mineralogist, v. 35, nos. 3 & 4, p. 324-325.

Ichi, Y. A., 1942, Chemical analysis of garnet from Hahonsan, Fushun Prefecture, Manchukuo: Manchuria: Mem. Geol. Inst. Manchoukuo, v. 17, p. 98-100 (in Japanese).

Ignatev, N. A., 1934, Amphibolites, garnet-gedritites and micaites from Shuertskii, Karelia: Trans. Inst. Petrog. Acad. Sci. SSSR, v. 6, p. 65-82 (in Russian).

Ingerson, Earl, and Barksdale, J. D., 1943, Iridescent garnet from the Adelaide Mining District, Nevada: Am. Mineralogist, v. 28, no. 5, p. 303-312.

Ito, T. D., 1935, Crystallographic studies on minerals: Beitr. Mineral. Japan, Neue Folge I, 259 p. (in Japanese).

Jaffe, H. W., 1951, The role of yttrium and other minor elements in the garnet group: Am. Mineralogist, v. 36, nos. 1 & 2, p. 133-155.

Jayaraman, N., 1937, Mineralogy and chemical composition of garnets from the schist complex of Nellore: Indian Acad. Sci. Proc., S, A, 148-160.

Jeremejew, W., 1882, Doppelbrechung am Granat: Zeitschr. Krist., v. 1, p. 589 (in German).

Jurkovic, Ivan, 1953, Garnet in skarn, Novo Brdo: Vestnik Zavod. Geol. Geofis. Ins. Serbia, v. 10, p. 125-134 (in Russian).

Kalinin, P. V., 1955, Garnets from the pegmatite veins of Southern Transbaikalia: Trudy Moskov. Geol. Razvedochnogo Inst. Im. S. Ordzhonikidze, v. 28, p. 39-46 (in Russian).

Keith, M. L., and Roy, Rustum, 1954, Structural relations among double oxides of trivalent elements: Am. Mineralogist, v. 39, nos. 1 & 2, p. 1-23.

Keith, M. L., and Schairer, J. F., 1952, The stability field of sapphirine in the system $MgO- Al_2O_3- SiO_2$: Jour. Geology, v. 60, no. 2, p. 181-186.

Kelley, V. C., 1938, Geology and ore deposits of the Darwin silver-lead mining district, Inyo County, California: California Journal of Mines and Geology, Report 34, of the State Mineralogist, p. 503-562.

Keyes, C. B., (no date given), Garnet contact deposits of copper and the depth at which they are formed: Econ. Geology, v. 4, p. 365-372.

Kirganov, R. N., 1941, The garnets of the Palkin mineral deposits near Sverdlovsk: Soc. Russe Miner., Mem., v. 70, Iv. 1, p. 23-45 (in Russian).

Klein, J. F. C., 1883, Optische Studien am Granat: Neues Jahrb. Min. 1, p. 87 (in German).

_____ 1894, Optische Studien am Granat, Vesuvian, und Pennin: Berlin Akad. S. Ber, p. 49 (in German).

_____ 1895, Beitrage zur Kenntnis des Granats in optischer Hinsicht: Neues. Jahrb. Min., p. 68 (in German).

_____ 1898, Optische Anomalien des Granats und neuere Versuche sie zu erklaren: Berlin Akad. S. Ber., 16 p., (in German).

Knorring, O. V., 1946, A manganese garnet enclosed in sphalerite from Kimito in southwestern Finland: Comptes Rendus Soc. Geol. Finlande, no. 138, p. 77-87.

_____ 1951, A new occurrence of uvarovite from northern Kanelina in Finland: Mineralog. Mag., v. 29, no. 213, p. 594-601.

Knorring, O. V., and Kennedy, W. O., 1958, The mineral paragenesis and metamorphic status of garnet-hornblende-pyroxene-scapolite gneiss from Ghana (Gold Coast): Mining Mag., v. 31, no. 241, p. 846-859.

Kokta, Jar, and Nemec, Fr., 1936, Granat ultrabasickych hornin od Cernina: Veda Prirodni, r. 17, c. 6-8, p. 176-180 (in Czechoslovakian).

Kolderup, N. H., and Rosenquist, I. T., 1952, Giant garnet crystals from Gjlanger, western Norway: Bergens Mus. Arb. 1950, Nat. Rekke no. 6, 11 p.

Koning, L. P. G., 1947, On cassiterite and garnet from the Kaokoveld, S. W. Africa: Koninkl. Nederlandse Akad. Wetensch. Proc., v. 50, no. 10, p. 1343-1347.

Kostov, Ivan, 1950, The morphology of garnets: Annuaire Univ. Sofia. Fac. Sci., v. 3, no. 46, p. 329-339.

Kozu, Shukusuke, and Kwano, Y., and Yagi, K., 1941, Studies on garnet from Wadatoge (II); chemical properties: Japanese Assoc. Mineralogists, J.v. 25, no. 1, p. 1-12 (in Japanese).

Kirganov, B. N., 1941, The garnets of the Tal'kin mineral deposits near Sverdlovsk: Zap. Russ. Mineral. Obshch., v. 70, Iv. 1, p. 23-45 (in Russian).

Klein, J. F. C., 1883, Optische Studien am Granat: Neues Jahrb. Min. 1, p. 87 (in German).

______ 1894, Optische Studien an Granat, Vesuvian, und Pennin: Berlin Akad. S. Ber., p. 49 (in German).

______ 1895, Beitrage zur Kenntnis des Granats in optischer Hinsicht: Neues. Jahrb. Min., p. 62 (in German).

______ 1898, Optische Anomalien des Granats und neuere Versuche sie zu erklaren: Berlin Akad. S. Ber., 16 p., (in German).

Knorring, O. V., 1946, A manganese garnet enclosed in sphalerite from Kimito in southwestern Finland: Comptes Rendus Soc. Geol. Finlande, no. 136, p. 72-77.

______ 1951, A new occurrence of uvarovite from northern Karelina in Finland: Mineralog. Mag., v. 29, no. 213, p. 594-601.

Knorring, O. V., and Kennedy, W. C., 1958, The mineral paragenesis and metamorphic status of garnet-hornblende-pyroxene-scapolite gneiss from Ghana (Gold Coast): Mining Mag., v. 31, no. 241, p. 846-859.

Kokta, Jar, and Nemec, Fr., 1956, Granat ultrabazickych hornin od Cerniny: Veda Prirodni, v. 17, c. 5-6, p. 176-180 (in Czechoslovakian).

Kolderup, N. H., and Rosenquist, I. T., 1952, Black garnet crystals from Gjlanger, western Norway: Bergens Mus. Arb. 1950, Nat. Rekke no. 6, 12 p.

Koning, L. P. G., 1947, On cassiterite and garnet from the Rooiberg, S. W. Africa: Koninkl. Nederlandse Akad. Wetensch. Proc., v. 50, no. 10, p. 1343-1347.

Kostov, Ivan, 1950, The morphology of garnets: Annuaire Univ. Sofia. Fac. Sci., v. 3, no. 45, p. 325-339.

Kozu, Shukusuke, and Kuwano, Y., and Yagi, K., 1943, Studies on garnet from Wadatoge (III): chemical properties: Japanese Assoc. Mineralogists, J.V. 25, no. 1, p. 1-12 (in Japanese).

Kozu, Shukusuke, and Kawano, Y., 1938, Spessartitic almandite from Nagakubo, Ishikawa: Japanese Assoc. Mineralogists ..., J. v. 20, no. 5, p. 210-223 (in Japanese).

_____ 1939, Chemical composition of garnet from Anamushi: Japanese Assoc. Mineralogists, J. v. 21, no. 2, p. 80-85, (in Japanese).

Kozu, Shukusuke, and Ohmori, K., 1939, Change in the refractive index and the specific gravity of garnet influenced by the andradite molecule in it: Japanese Assoc. Mineralogists, J. v. 22, no. 1, p. 37-41 (in Japanese).

_____ 1942, Garnet from Nishidohira, Ibaragi Prefecture, (Japan): Japanese Assoc. Mineralogists, J. v. 28, no. 5, p. 225-243 (in Japanese).

Kozu, Shukusuke, and others, 1940, Studies on garnet from Wandatoge (1); modes of occurrence and physical properties: Japanese Assoc. Mineralogists, J. v. 24, no. 5, p. 221-228 (in Japanese).

_____ 1940, The influence of temperature on the zonal structure of garnet: Japanese Assoc. Mineralogists, J. v. 23, no. 4, p. 178-188 (in Japanese).

_____ 1941, Studies of garnet from Kyuchorei, Manchoukuo, (II); chemical properties: Japanese Assoc. Mineralogists, J. v. 25, no. 2, p. 51-57 (in Japanese).

Kozu, Shukusuke, and Takane, K. R., 1939, Cell constant of garnet from Anamushi: Japanese Assoc. Mineralogists, J. v. 21, no. 3, p. 123-125 (in Japanese).

_____ 1939, Cell constant of spessartite-almandite from Ishikama: Japanese Assoc. Mineralogists, J. v. 21, no. 1, p. 33-35 (in Japanese).

Kozu, Shukusuke, and Takane, K. R., and Takeuti, T. V., 1939, Cell constants of andradite and of grossularite-andradite from Otaki: Japanese Assoc. Mineralogists, J. v. 21, no. 5, p. 239-244 (in Japanese).

Kozu, Shukusuke, and Takeuti, T. V., and Kizaki, Y. S., 1942, Grossularite from Fusodo and Kyudodo, Heianhokudo, Korea: Japanese Assoc. Mineralogists, J. v. 28, no. 4, p. 136-148 (in Japanese).

Kozu, Shukusuke, and Takeuti, T. V., and Ohmori, K. R., 1940, A new method for obtaining the chemical composition of garnet by computation using the physical constants: Japanese Assoc. Mineralogists, J. v. 23, no. 5, p. 203-212 (in Japanese).

_____ 1940, Cell constants of dark green and dark red garnet crystals from Naganobori, Prefecture, Yamaguti: Japanese Assoc. Mineralogists, J. v. 23, no. 4, p. 155-164 (in Japanese).

_____ 1940, The relation between chemical composition and physical properties in the garnet crystals from Ishikawa, Anamushi, and Nakatsugawa: Japanese Assoc. Mineralogists, J. v. 23, no. 2, p. 51-65 (in Japanese).

_____ 1941, Garnets from the Kaso manganese mine: Japanese Assoc. Mineralogists, J. v. 26, no. 4, p. 151-171 (in Japanese).

Kozu, Shukusuke, and Yagi, K. D., 1941, Chemical studies of garnet and its mother rock from Amataki: Japanese Assoc. Mineralogists, J. v. 26, no. 3, p. 101-121 (in Japanese).

Krieger, M. H., 1937, Geology of the Thirteenth Lake Quadrangle: New York State Mus. Bull. 308, 124 p.

Krishna Rao, J. S. R., 1953, Manganese garnets from Chipurupalle area, Vizagapatam district: Indian Acad. Sci., pr. Sec. A, v. 38, no. 1, p. 20-22.

Lacroix, A. B., 1914, Garnets of the almandite-spessartite-pyrope groups from Madagascar: Soc. Mineral. France Bull., v. 37, p. 108-112.

Ladoo, R. B., 1922, Garnet: U. S. Bur. Mines Rept. Inv., no. 2347, 16 p.

Lakshimi Narayana Rao, S. V., 1955, Garnets from the ortho-and para-gneisses of the Narsipatam area, Vizagapatam district: Geol. Min. & Met. Soc. India, Q. J. v. 27, no. 3, p. 139-141.

Lavrenko, E. I., and Laz'ko, E. M., 1954, Garnets from Archean and Proterozoic sediments of the Aldan shield: Doklady Akad. Nauk SSSR, v. 99, p. 613-616 (in Russian).

Kozu, Shukusuke, and Takeuchi, T. Y., and [illegible], T., 1940, A new method for calculating the chemical composition of garnet by computation using the physical constants: Japanese Assoc. Mineralogists, J. v. 23, no. 5, p. 203-212 (in Japanese).

____ 1940, Cell constants of dark brown and light red garnet crystals from Hagamoori, [illegible] Prefecture, Japanese Assoc. Mineralogists, J. v. 23, no. 4, p. 155-164 (in Japanese).

____ 1940, The relation between chemical composition and physical properties in the garnet crystals from Ishikawa, Amamoshi, and Kakatsugawa: Japanese Assoc. Mineralogists, J. v. 23, [illegible] 2, p. 51-59 (in Japanese).

____ 1941, Garnets from the [illegible] manganese mine: Japanese Assoc. Mineralogists, J. v. 26, no. 4, p. 151-[illegible] (in Japanese).

Kozu, Shukusuke, and Yagi, K. D., 1941, Chemical studies of garnet and its mother rock from [illegible]: Japanese Assoc. Mineralogists, J. v. 26, no. 3, p. 101-[illegible] (in Japanese).

Krieger, M. H., 1937, Geology of the Thirteenth Lake Quadrangle: New York State Mus. Bull. 308, 124 p.

Krishna Rao, J. S. R., 1953, Manganese garnets from Chipurupalle area, Vizagapatam district: Indian Acad. Sci., pr. Sec. A, v. 38, no. 1, p. [illegible].

Lacroix, A. D., 1924, Garnets of the almandite-spessartite-pyrope groups from Madagascar: Soc. Minéral. France Bull., v. 37, p. 108-112.

Ladoo, R. B., 1922, Garnet: U. S. Bur. Mines Dept. Inv., no. 2347, 16 p.

Lakshmi Narayana Rao, S. V., 1955, Garnets from the ortho-and para-gneisses of the [illegible] area, Visagapatam district: Geol. Min. [illegible] Soc. India, Q. J. v. 27, no. 3, p. 139-141.

Lavrenko, E. I., and Lasi'ko, E. M., 1952, Garnets from Archean and Proterozoic sediments of the Aldan shield: Doklady Akad. Nauk SSSR, v. 97, p. 613-616 (in Russian).

Lee, D. E., 1958, An andradite-spessartite garnet from Pajsberg, Sweden: Am. Mineralogist, v. 43, nos. 3 & 4, p. 208-215.

Lehmann, Otto, 1888-1889, Molekularphysik mit besonderer Berucksichtigung microskopischer Untersuchungen und Anleitung zu solchen, sowie einem Anhang uber mikroskopischer Analyse: Leipzig, W. Englmann (in German).

Lester, J. G., 1939, Garnet segregations in granite gneiss of De Kalb, County, Ga.: Jour. Geology, v. 47, no. 8, p. 841-847.

Levin, S. B., 1948, Petrology and genesis of Gore Mountain garnet, New York (abs.): Geol. Soc. Am. Bull., v. 59, no. 12, pt. 2, p. 1335-1336.

_____ 1949, Garnet evidence in Adirondack petrogeny (N. Y.): New York Acad. Sci. Trans., Ser. 2, v. 11, no. 5, p. 156-162.

_____ 1950, The physical analysis of polycomponent garnet (abs.): Am. Mineralogist, v. 35, nos. 3-4, p. 285-286.

_____ 1950, Genesis of some Adirondack garnet deposits: Geol. Soc. Am. Bull., v. 61, no. 6, p. 519-565.

_____ 1951, Origin of hornblende rims on Adirondack garnet (abs.): Am. Mineralogist, v. 36, nos, 3 & 4, p. 319.

Lindgren, Waldemar, 1914, The origin of the "garnet zones" and associated ore deposits: Econ. Geology, v. 9, p. 283-292.

Lindroth, G. T., 1919, The nature of the garnet in mid-Swedish ore-deposit contact-rock formations: Geol. Fören Förh., v. 41, p. 64-87.

_____ 1945, Till Vigdad Kannedom om granateus natur i de Mellansvenska Skarnjarmalmerna: Geol. Fören. Stockholm, Förh., v. 67, no. 3, p. 351-359.

Lucchi, G. de, 1940, Studi geologico-petrografici sul massiccio dell' adamello; il giacimento di contatto di Q. 2591 del M. Faunas del Frefone: R. Ist. Veneto Sci. Atti., v. 98, pt. 2, d. 1, p. 79-98 (in Italian).

Lee, D. E., 1958, An andradite-spessartite garnet from Pajsberg, Sweden: Am. Mineralogist, v. 43, nos. 3 & 4, p. 208-215.

Lehmann, Otto, 1888-1889, Molekularphysik mit besonderer Beruecksichtigung mikroskopischer Untersuchungen und Anleitung zu solchen, sowie einem Anhang; über mikroskopischer Analyse: Leipzig, W. Engelmann (in German).

Lester, J. G., 1939, Garnet segregations in granite gneiss of De Kalb County, Ga.: Jour. Geology, v. 47, no. 8, p. 841-847.

Levin, S. B., 1948, Petrology and genesis of Gore Mountain garnet, New York (abs.): Geol. Soc. Am. Bull., v. 59, no. 12, pt. 2, p. 1335-1336.

____ 1949, Garnet evidence in Adirondack petrogeny (N. Y.): New York Acad. Sci. Trans., Ser. 2, v. 11, no. 5, p. 155-162.

____ 1950, The physical analysis of polycomponent garnet (abs.): Am. Mineralogist, v. 35, nos. 3-4, p. 285-286.

____ 1950, Genesis of some Adirondack garnet deposits: Geol. Soc. Am. Bull., v. 61, no. 6, p. 519-565.

____ 1951, Origin of hornblende rims on Adirondack garnet (abs.): Am. Mineralogist, v. 36, nos. 3 & 4, p. 319.

Lindgren, Waldemar, 1914, The origin of the "garnet zones" and associated ore deposits: Econ. Geology, v. 9, p. 283-292.

Lindroth, G. T., 1919, The nature of the garnet in mid-Swedish ore-deposit contact-rock formations: Geol. Foren Förh., v. 41, p. 64-87.

____ 1945, Till Vidgad Kännedom om granaternas natur i de Mellansvenska Skarnjärnmalmerna: Geol. Fören. Stockholm, Förh., v. 67, no. 3, p. 351-357.

Lucchi, G. de, 1940, Studi geologico-petrografici nel massiccio dell' adamello; il giacimento di contatto di q. 2591 del M. Fausone del Pretoni S. Ist. Veneto Sci. Atti., v. 99, pt. 2, d. 1, p. 79-95 (in Italian).

Macdonald, R. D., 1944, Regional metamorphism in the Kenogamisis River area (Ontario): Jour. Geology, v. 52, no. 6, p. 414-423.

Machatschki, F. D., and Gartner, H. R., 1927a, Biotite-garnet amphibolite from the Koralps, Westeiermark: Centr. Mineral. Geol. p. 314-320 (in German).

Machibu, Isamu, 1942, Garnet from Kyuchorei, Manchuria; III modes of occurrence: 1. 2. J. Japanese Assoc. Mineralogists, Petrol., Econ. Geol. v. 27, p. 1-27, p. 87-106 (in Japanese).

Mackowsky, M. T., 1939, Uber die chemisch-physikalischen Zusammenhange in den Granatsystemen Grossular-Melanit and Melanit- Titanmelanit unter dem Einfluss des Eisens bzw. Titans: Chemie d. Erde (Linck) v. 12, no. 2, p. 123-157.

_____ 1939, Einige Bemerkungen zu der Analyse eines Japanischen Granats: Zentr. Miner. Abt. A, no. 8, p. 251-253 (in German).

Maier, Wilhelm, 1951, Gedrillte Asteriten im Rosenquarz und Granat: Heidelberg Beitr. Miner. Petrog., v. 2, no. 5, p. 428-431 (in German).

Mallard, E., 1876, Explination des phenomenes optiques anomaux que presentent un grand nombre de substances cristallisees: Ann. d. Min., v. 7, no. 10 (in French).

Marchenko, E. Ya., 1955, Zonal differentiation in Skarns from River Tibek (Khakass Autonomous Region): Doklady Akad. Nauk. SSSR, v. 104, p. 619-621.

Mason, Brian, and Berggren, Thelma, 1942, A phosphate-bearing spessartite garnet from Wodgina, Western Australia: Geol. Foren. Stockholm, Forh. v. 63, h. 4, no. 427, p. 413-418.

Matiba, I. S., 1940, Studies of garnet from Kyuchoeri Manchoukuo (I) Physical constants: Japanese Assoc. Mineralogists, J. v. 24, no. 6, p. 251-270 (in Japanese).

_____ 1942, Studies of garnet from Kyuchorei, Manchuria (3); Modes of occurrence: Japanese Assoc. Mineralogists, J. v. 27, nos. 1 & 2, p. 1-27, 87-106 (in Japanese).

McConnel, Duncan, 1933, Garnets from Sierra Tlayacae Morelos, Mexico: Am. Mineralogist, v. 18, p. 25-29.

_____ 1942, Griphite, a hydro-phosphate garnetoid: Am. Mineralogist, v. 27, no. 6, p. 452-461.

_____ 1943, Isomorphism and isotypism among silicates and phosphates: Science, v. 97, p. 98-99.

_____ 1948, Garnets, their properties, occurrences and utilization (abs.): Colorado-Wyoming Acad. Sci. Jour., v. 3, no. 5, p. 35.

Meixner, Heinz, 1938, Kraubather Lagerstätten studien III; Uwarowit von Kraubath - eine Fehlbestimmung und Fundortsverwechselung und Zirkon von Kraubath: Zentr. Miner. Abt. A, no. 4, p. 115-120 (in German).

_____ 1952, "Eklogit" - Granat von der Saualpe, Kärten; eine Richtigstellung: Neues Jarb. Miner., Monatshefte no. 1, p. 1-13 (in German).

Mende, Ilse, 1941, The lattice constants of magnesium aluminum garnet: Zentr. Miner. Geol. A, no. 6, p. 137-139 (in German).

Menzer, G. R., 1926, The crystal structure of garnet: Zeitschr. Krist. 63, p. 157-158 (in German).

_____ 1928, The crystal structure of garnet: Zeitschr. Krist. v. 69, p. 300-396 (in German).

Michel-Levy, M. C., 1951, Reproduction artifielle de grenats ferro-manganesiferes; serie almandin-spessartine: Acad. sci. (Paris) Comptes rendus, v. 232, no. 21, p. 1953-1954 (in French).

Mikheev, V. I., 1957, X-ray determination of minerals: Kristallografiya, v. 2, p. 466-469.

Miller, W. J., 1912, The garnet deposits of Warren County, New York: Econ. Geology, v. 7, p. 493-501.

_____ 1914, Geology of the North Creek quadrangle, Warren County, New York: New York State Mus., Bull. 170, 90 p.

_____ 1938, Genesis of certain Adirondack garnet deposits: Am. Mineralogist, v. 23, no. 6, p. 399-408.

Milton, Charles, and Davidson, Norman, 1950, An occurrence of natrolite, andradite, and allanite in the Franklin Furnace quadrangle, New Jersey: Am. Mineralogist, v. 35, nos. 7 & 8, p. 500-507.

Miyashiro, Akiho, 1953, Calcium-poor garnet in relation to metamorphism: Geochim. et Cosmochim. Acta, v. 4, no. 4, p. 179-208.

M'lintock, W. F. P., 1916, Zeolites and associates minerals from the Tertiary lavas around Ben More, Mull: Roy. Soc. Edinburgh Trans., v. 51, pt. 1, p. 1-33.

Morimoto, Ryohei, 1944, Mode of occurrence of garnet at Nijo Volcano; microscopic observation of garnet-bearing xenoliths: Jour. Japanese Assoc. Mineralogists, Petrol., Econ. Geology, v. 32, p. 231-238 (in Japanese).

Mosebach, R. S., 1935, Über die Entstehung der Barytgänge im Jungersen Granit des Spessarts bei Aschaffenburg: "Senckenbergiana," v. 17, p. 219-223 (in German).

_____ 1938, Petrographische studieren im Kristall in dem Spessarts, 5; Pegmatite und deren mineralien: Senckenbergiana (Senckenb. Naturf. Ges.), v. 20, no. 6, p. 443-462 (in German).

_____ 1953, Mineral-synthetic and petrologic-interpretation on the example of agate, chalcedony and garnets: Chem. Erde, v. 16, p. 123-134 (in German).

Mountain, E. D., 1938, Tabular spessartine crystals in muscovite: Mineralog. Mag., v. 25, no. 162, p. 125-134.

Murdoch, Joseph, 1938, Some garnet crystals from California: Jour. Geology, v. 47, no. 2, p. 189-197.

Narayanaiyer, L. A., 1921, Occurrence of garnetiferous sillimanite gneisses, scapolite gneisses, and the associated marble beds in the Coimbatore district: Proc. 7th Indian Sci. Cong.

Neilson, J. W., 1958, Growth of magnetic garnet crystals: Jour. App. Phys. v. 29, no. 3, p. 390-391.

Nikolov, N., 1936, Chemische-mineralogische Untersuchungen einiger Granate in Bulgarien: Sofia, Univ., Ann. 32, Fac. phys.- mat., Lv. 3, p. 51-66 (in Bulgarian, German Summ.).

Nishikawa, Shoji, 1917, Crystal structure of a garnet: Tokyo Math. Phys. Soc. Proc. (2), v. 9, p. 194-197 (in Japanese).

Novjacek, Radim, (no date given), Garnet from Marchendorf near Sobotin: Mineralog. Abstracts 4, p. 516-517.

_____ 1931, Über Granate der Pegmatite aus der Tschechoslowakei: Vestnick II. tr. Kral. Ces. Spol. Nauk. Sept., 1-55.

Ohmori, K. R., 1939, Mode of occurrence in garnet in the environs of Ishikawa: Japanese Assoc. Mineralogists, J. v. 21, no. 1, p. 18-25 (in Japanese).

_____ 1941, Studies of garnet from Suisyo-Yama in the Hida Mountains: Japanese Assoc. Mineralogists, J. v. 25, no. 6, p. 249-265 (in Japanese).

_____ 1942, Studies of garnets in the andesites forming the Volcano Nijosan: Japanese Assoc. Mineralogists, J. v. 27, nos. 1 & 2, p. 27-58, 69-87 (in Japanese).

Ohmori, K. R., and Hasegawa, S. A., and Yokoyama, K. R., 1956, Samarskite and garnet from Kasuya pegmatite mine in Ishikawa Town, Fukushima Prefecture: Japanese Assoc. Mineralogists, J. v. 40, no. 1, p. 1-4 (in Japanese).

Pabst, Adolf, 1931, The garnets in the glaucophane schists of California: Am. Mineralogist, v. 16, no. 8, p. 327-333.

_____ 1938, Garnets from vesicles in rhyolite near Ely, Nevada: Am. Mineralogist, v. 23, no. 2, p. 101-103.

_____ 1943, Large and small garnets from Fort Wrangell, Alaska: Am. Mineralogist, v. 28, no. 4, p. 233-245.

_____ 1955, Manganese content of garnets from the Franciscan schists (California): Am. Mineralogist, v. 40, nos. 9 & 10, p. 919-923.

Nikolov, N., 1936, Chemische-mineralogische Untersuchungen einiger Granate in Bulgarien: Sofia, Univ., Ann. 32, Fac. phys.- math., Lv. 3, p. 51-66 (in Bulgarian, German Summ.).

Nishikawa, Shoji, 1917, Crystal structure of a garnet: Tokyo Math. Phys. Soc. Proc. (2), v. 9, p. 194-197 (in Japanese).

Novjacek, Radim, (no date given), Garnet from Herchendorf near Schotin: Mineralog. Abstracts 4, p. 516-517.

_____ 1931, Uber Granate der Pegmatite aus dem Tschechoslowakei: Vestnick II. tr. Kral. Ces. Spol. Nauk. Sept., 1-55.

Ohmori, K. H., 1939, Mode of occurrence in garnet in the environs of Ishikawa: Japanese Assoc. Mineralogists, J. v. 21, no. 1, p. 16-25 (in Japanese).

_____ 1941, Studies of garnet from Sulayo-Yama in the Hida Mountains: Japanese Assoc. Mineralogists, J. v. 25, no. 6, p. 249-265 (in Japanese).

_____ 1942, Studies of garnets in the andesites forming the Volcano Mijosan: Japanese Assoc. Mineralogists, J. v. 27, nos. 1 & 2, p. 27-58, 59-87 (in Japanese).

Ohmori, K. H., and Hasegawa, S. A., and Yokoyama, Z. R., 1956, Samarskite and garnet from Kasuya pegmatite mine in Ishikawa Town, Fukushima Prefecture: Japanese Assoc. Mineralogists, J. v. 40, no. 1, p. 1-4 (in Japanese).

Pabst, Adolf, 1931, The garnets in the glaucophane schists of California: Am. Mineralogist, v. 16, no. 8, p. 327-333.

_____ 1938, Garnets from vesicles in rhyolite near Ely, Nevada: Am. Mineralogist, v. 23, no. 2, p. 101-103.

_____ 1943, Large and small garnets from Fort Wrangell, Alaska: Am. Mineralogist, v. 28, no. 4, p. 233-245.

_____ 1955, Manganese content of garnets from the Franciscan schists (California): Am. Mineralogist, v. 40, nos. 9 & 10, p. 919-923.

Parsons, A. L., 1935, Trisoctahedral garnet from west Thetford Mines, Province of Quebec: Toronto Univ. Studies Geol. Ser. 38, p. 33-36.

Partridge, F. C., 1934, The identification of kimberlite and kimberlite minerals by spectroscopic and other methods: South Africa Geol. Soc. Trans., v. 37, p. 205-211.

Pavlovic, Stojan, 1952, Andradite-grossularite of Trepca: Sbornik Radova Srpska Akad. Nauk., no. 23, no. 4, p. 1-6.

Pearl, R. M., 1941, Spessartite in pegmatite at Mount Antero, Colorado: Am. Mineralogist, v. 26, no. 1, p. 54.

Philipsborn, H. von., 1928, Relations between index of refraction, density and chemical composition in the garnet group: Abhandl. Math.-Phys. Klasse. Sachs. Akad. Wiss., v. 40, p. 1-42.

Phillips, F. C., 1956, An introduction to crystallography: London, Longmans, Green and Co., 324 p.

Pinto, A. C., 1945, Breves notas petrologicas referentes a regido de Angonia: Lisboa, Univ., Mus. e Lab. Miner. e Geol., B. s. 4, no. 13, p. 85-97 (in Portuguese, Fr. Summ.).

Polar-Mantuani, L. A., and Klemen, R. D., 1940, Spessartite from the Pohorje Mountains (Yugoslavia): Zentr. Mineral., Geol., p. 112-127 (in German).

Poldervaart, Arie, 1953, Metamorphism of basaltic rocks-a review: Geol. Soc. America Bull., v. 64, no. 3, p. 259-273.

Povarennykh, A. S., 1952, Prehnite-garnet skarn from Chatkal'skii Rayon: Mem. Soc. Russe Mineral., v. 81, p. 55-58 (in Russian).

Preclik, K., 1924, An almandite-cordierite hornfels of unknown origin: Centr. Mineral. Geol., p. 652-664 (in German).

Radice, M. M., 1943, Una andesita granatifer a de Coquelen (Territorio del Rio Negro): La Plata Univ. Nat. Mus., notas t. 8, Geol. no. 25, p. 191-199.

Parsons, A. L., 1935, Tetrahedra [illegible] from the Thetford Mines, Province of Quebec [illegible]: Studies Geol. Ser. 38, [illegible].

Partridge, F. C., 1934, The identification of [illegible] and kimberlite minerals by [illegible] and other methods: South Africa Geol. Soc. [illegible], v. [illegible], p. 205-211.

Pavlovic, Stojan, 1952, Andradite-grossularite [illegible]: Sbornik Radova Srpska Akad. Nauka, v. [illegible], no. [illegible], p. 1-6.

Pearl, R. M., 1941, Spessartite in pegmatite at Mount Antero, Colorado: Am. Mineralogist, v. [illegible], no. [illegible], p. 54.

Philipsborn, H. von., 1928, Relations between index of refraction, density and chemical composition in the garnet group: Abhandl. Math.-Phys. Klasse [illegible] Akad. Wiss., v. 40, p. 1-42.

Phillips, F. C., 1956, An introduction to crystallography: London, Longmans, Green and Co., [illegible] p.

Pinto, A. O., 1945, Breves notas [illegible] região de Angonia: [illegible], Bol., [illegible] e Geol., B. s. 4, no. 13, p. 85-97 (in Portuguese, [illegible] Summ.).

Polar-Mantuani, L. A., and Eliasen, [illegible], 19[illegible], [illegible] from the Pohorje Mountains (Yugoslavia): Centr. Mineral., Geol., p. 112-127 (in German).

Poldervaart, Arie, 1953, Metamorphism of basaltic rocks — a review: Geol. Soc. America Bull., v. [illegible], p. 259-273.

Povarennykh, A. S., 1952, Prehnite-garnet [illegible] Chatkal'skii Rayon: Mem. Soc. Russe Mineral., v. [illegible], p. 55-58 (in Russian).

Precllk, K., 1924, An almandite-[illegible] of unknown origin: Centr. Mineral. Geol., [illegible] (in German).

Radice, M. M., 1943, Una andradite [illegible] (Territorio del Rio Negro): La Plata Univ. [illegible] Mus., notas t. 8, Geol. no. 25, p. [illegible].

Raisin, C. A., 1901, On altered rocks near Bastogne: Geol. Soc. London Quart. Jour., v. 57, p. 55-72.

Rakusz, J., 1924, Studies on the garnet from Dobschau: Centr. Mineral. Geol., p. 353-356 (in German).

Rao, B. R., 1945, Elastic constants of garnets: Indian Acad. Sci. Proc., v. 22, A, p. 194-198.

Rast, Nicholas, and Sturt, B. A., 1957, Crystallographic and geologic factors in the growth of garnets from Central Perthshire: Nature, v. 179, no. 4554, p. 215.

Reichert, Robert, 1935, Kristallographische Beobachtugen an einigen Tuffmineralien aus dem Borzsonyer-Gebirge: Foldtani Kozlony, v. 65, f. 10-12, p. 342-349 (in German).

Renard, A. L., 1882, Les roches grenatiferes et amphiboliques de la Region de Bastogne: Bull. Mus. Roy. d'Hist., v. 1 (in French).

Richard, L. M., 1911, Garnet deposits of Georgia: Mineral World, v. 34, p. 1135.

Riedel, Josef, 1952, Neue Mineral- und Gesteinsfunde im Ostronggebiet: Austria Geol. Bundesanst. Verh., v. 3, p. 159-163 (in German).

Rinne, F., 1925, Feinbauliche Erorterungen und Röntgenographische Erfahrungen uber optische Anomalien: Cbl. Min. A., p. 225-241 (in German).

Rogers, A. F., and Kerr, P. F., 1942, Optical mineralogy: McGraw-Hill Book Company, Inc., New York and London.

Rossetti, Vasco, 1946, Garnets of Oridda: Rend. Seminar. Facolta. Sci. Univ. Cagliaci, v. 16, p. 29-40.

Roy, D. M., and Roy, Rustum, 1957, The system CaO-Al_2O_3-SiO_2-H_2O VI: The grossularite-$3CaO \cdot Al_2O_3.6H_2O$ Join: Geol. Soc. Am. Bull. v. 68, p. 1788.

Sancro, Edoardo, 1935, Sopra due granati delle miniere de Cogne in Val d' Aosta: Periodico Miner., v. 6, no. 3, p. 213-220.

Satterly, Jack, 1943, Geology of the Dryden-Wabigoon area (Ontario): Ontario Dept. Mines Ann. Rpt. 1941, v. 50, pt. 2, iii, 67 p.

Raisin, C. A., 1901, On altered rocks near Bastogne: Geol. Soc. London Quart. Jour., v. 57, p. 55-72.

Rakusz, J., 1924, Studies on the garnet from Schmiedeberg: Centr. Mineral. Geol., p. 353-356 (in German).

Rao, B. R., 1945, Elastic constants of garnets: Indian Acad. Sci. Proc., v. 22, A, p. 194-198.

Rast, Nicholas, and Sturt, B. A., 1957, Crystallographic and geologic factors in the growth of garnets from Central Perthshire: Nature, v. 179, no. 4552, p. 215.

Reichert, Robert, 1935, Kristallographische Beobachtungen an einigen Turfmineralien aus dem Bergbau-Revier: Foldtani Kozlony, v. 65, f. 10-12, p. 365-370 (in German).

Renard, A. L., 1882, Les roches grenatifères et amphiboliques de la Région de Bastogne: (Bull.) Mus. Roy. d'Hist. Nat., v. I (in French).

Richard, L. M., 1911, Garnet deposits of Wrangel: Mining World, v. 34, p. 1235.

Riedel, Josef, 1952, Neue Mineral- und Gesteinsfunde im Ostrongebiet: Austria Geol. Bundesanst. Verh., v. 3, p. 159-163 (in German).

Rinne, F., 1925, Feinbauliche Erörterungen und röntgenographische Erfahrungen über optische Anomalien: Cbl. Min. A., p. 225-241 (in German).

Rogers, A. F., and Kerr, P. F., 1942, Optical mineralogy: McGraw-Hill Book Company, Inc., New York and London.

Rossetti, Vasco, 1946, Garnets of Orgosolo: Rend. Seminar. Facolta. Sci. Univ. Cagliari, v. 16, p. 39-40.

Roy, D. M., and Roy, Rustum, 1957, The system CaO-Al$_2$O$_3$-SiO$_2$-H$_2$O VI: The grossularite-3CaO·Al$_2$O$_3$·6H$_2$O join: Geol. Soc. Am. Bull. v. 68, p. 1788.

Sanero, Edoardo, 1975, Sopra due granati della cialite de Cogne in Val d' Aosta: Periodico Miner., v. 3, no. 3, p. 213-220.

Satterly, Jack, 1943, Geology of the Dryden-Wabigoon area (Ontario): Ontario Dept. Mines Ann. Rept. 1941, v. 50, pt. 2, 111, 67 p.

Satterly, Jack, 1943, Mineral occurrences in Pary Sound district (Ontario): Ontario Dept. Mines Ann. Rept., v. 51, pt. 2, 1942, iv, 86 p.

_____ 1943, Mineral occurrences in the Haliburton area (Ontario): Ontario Dept. Mines Ann. Rept., v. 52, pt. 2, iv, 106 p.

Schaacke, Ingeburg, 1949, Geometry and optics of optically anomolous crystals illustrated by melilite and garnet: Neues Jahrb. Mineral., Geol., Abhandl. 80A, p. 145-162 (in German).

Schairer, J. F., and Yagi, Kenzo, 1952, The system FeO-Al_2O_3-SiO_2: Am. Jour. Sci., Bowen Volume, pt. 2, p. 471-512.

_____ 1952, The stability relations of iron cordierite and almandine garnet (abs.): Am. Geophys. Union (Trans.), v. 33, p. 328.

Schipani, Rosa, 1953, I granati delle rocce cristalline della Calabria: Not. Miner. Siciliana e Calabrese, f. 4, p. 5-13 (in Italian, Engl. Summ.).

Schurmann, H. M. E., 1938, Granatführender Diorit aus der Sierra Nevada, Kalifornia: Neues Jarhb. Beilage, v. 74, Abt. A, no. 2, p. 225-250 (in German).

Serdyuchenko, D. P., 1955, Grossularite and andradite from the Archean complex of the Aldan Plateau: Doklady Akad. Nauk. SSSR, v. 104, p. 775-778 (in Russian).

Seridutschenko, D. V., 1933, Almandite from some deposits of N. Caucaus and the Ukraine: Mem. Soc. Russe. Min., v. 62, p. 97-101 (in Russian).

Serra, Aurello, 1910, Remarkable garnet from Fluminimaggiore (Sardinia): Acad. Sci. tis. Mat. Napoli Tendus, p. 222-224.

Shannon, E. V., and Gonyer, F. A., 1927, Almandite-spessartite garnet from Gwynns Falls, Baltimore: Washington Acad. Sci. Jour., v. 17, p. 534-536.

Sharma, N. L., 1944, Garnet: Jour. Sci. & Indus. Res., Dehli, v. 2, no. 4, p. 238-244.

Shaub, B. M., 1949, Paragenesis of the garnet and associated minerals of the Barton Mine near North Creek, New York: Am. Mineralogist, v. 34, nos. 7 & 8, p. 573-582.

Shavkova, N. N.m, 1947, O dvukh granatakh kolskogo poluostrova: Doklady Akad. Nauk. SSSR, v. 58, no. 6, p. 1143-1146 (in Russian).

Shilin, L. L., 1951, Garnets from the Shislim Mountains: Trudy Mineralog. Muzeya, Akad. Nauk. SSSR, no. 3, p. 146-149 (in Russian).

Sirovich, G. D., Analyses of garnet of the Tavolato Gully: Gazz. Chim. Ital., v. 43, I, p. 36-38.

Skinner, B. J., 1956, Physical properties of end-members of the garnet group: Am. Mineralogist, v. 41, nos. 5 & 6, p. 428-436.

Smith, F. G., 1952, Decrepitation characteristics of garnet: Am. Mineralogist, v. 37, nos. 5 & 6, p. 470-491.

Solovev, S. P., and Nikogosyan, Kh. S., 1938, Abnormal garnets of the Tyrny-Auz (Northern Caucausus) Region and their transition to the isotropic state on heating: Soc. Russe. Miner., Mem., v. 67, no. 4, p. 651-654 (in Russian).

Sobolev, V. S., and Vartanova, N. S., and Shainyuk, A. I., 1951, Problems of garnet growth in sediments: Zapiski Vsesoyuz, Mineral. Obshchestva, v. 80, p. 122-126 (in Russian).

Sriramadas, A., 1957, Diagrams for the correlation of unit cell edges and refractive index with the chemical composition of garnets: Am. Mineralogist, v. 42, nos. 3 & 4, p. 294-298.

Starkov, N. P., 1950, Optical anomalies in garnets from Gora. Saroba, Southern Ural: Mem. Soc. Russe. Mineral., v. 79, p. 283-290 (in Russian).

Stewart, F. H., 1950, Note on garnet crystals from Cairnie, Aberdeenshire: Miner. Mag., v. 29, no. 210, p. 252-253.

Stockwell, C. H., 1927, An X-ray study of the garnet group: Am. Mineralogist, v. 12, no. 9, p. 327-344.

Shaub, B. M., 1949, Paragenesis of the garnet and associated minerals of the Barton [illegible] Creek, New York: Am. Mineralogist, v. 34, nos. 7 & 8, p. 573-582.

Shavkova, N. P.?, 1947, [illegible]: Doklady Akad. Nauk SSSR, v. [illegible], p. 1143-1146 (in Russian).

Shilin, L. L., 1951, Garnets from the [illegible]: Trudy Mineralog. Muzeya, Akad. Nauk SSSR, [illegible], p. 146-149 (in Russian).

Sirovich, G. P., Analyses of garnet [illegible]: Gazz. Chim. Ital., v. 43, I, p. [illegible].

Skinner, B. J., 1956, Physical properties of end-members of the garnet group: Am. Mineralogist, v. 41, nos. 5 & 6, p. 428-436.

Smith, F. G., 1952, Decrepitation characteristics of garnet: Am. Mineralogist, v. 37, nos. [illegible], p. [illegible]-491.

Soloviev, S. P., and Nikogosyan, Kh. [illegible], [illegible], [illegible] garnets of the Tyrny-Auz (Northern [illegible]) and their transition to the isotropic state on heating: Zap. Vses. Mineral. Obshch., v. [illegible], no. [illegible], p. 651-654 (in Russian).

Sobolev, V. S., and Vartanova, [illegible], and [illegible], 1951, Problems of garnet growth in [illegible]: Vsesoyuz. Mineral. Obshchestva, v. [illegible], p. [illegible] (in Russian).

Sriramadas, A., 1957, Diagrams for the correlation of unit cell edges and refractive index with the chemical composition of garnets: Am. Mineralogist, v. 42, nos. 3 & 4, p. 294-298.

Starkov, N. P., 1950, Optical anomalies in garnets from Gora Sarova?, Southern Urals: Mem. Soc. Russe Mineral., v. 79, p. 283-290 (in Russian).

Stewart, F. H., 1950, Note on garnet [illegible] from Cairnie, Aberdeenshire: Mineral. Mag., v. 29, no. 210, p. 252-253.

Stockwell, C. H., 1927, An X-ray study of the garnet group: Am. Mineralogist, v. 12, no. 9, p. 327-344.

Stose, G. W., and Glass, J. J., 1938, Garnet crystals in cavities in metamorphosed Triassic conglomerate in New York County, Pa: Am. Mineralogist, v. 23, no. 7, p. 430-435.

Strekalova, L. A., 1914, Crystals of spessartite in the muscovite from the Montenaja Villa, Ural: Acad. Sci. Petrograd Bull., p. 1329-1337 (in Russian).

Strock, L. W., 1930, Spessartite from Avondale, Delaware County, Pennsylvania: Am. Mineralogist, v. 15, p. 40-41.

Sugiyama, Ruiji, and others, 1943, Morphological study of minerals, part I: Tokyo Sci. Mus., B. no. 10, 33 p., (in Japanese).

Sumin, N. G., 1954, Some pecularities of skarn minerals of iron-ore deposits: Trudy Mineralog. Muzeya, Akad. Nauk. SSSR, no. 6, p. 131-138 (in Russian).

Swaminathan, V. S., 1928, Mode of occurrence and chemical composition of garnet from Nellore District, Madras: 15th, Indian Sci. Cong. Proc., p. 228.

Takahashi, J. A., and Kitahara, J. J., 1951, Studies on garnet and augite placer deposits at Wa-Are, South Sakhalin: Japanese Assoc. Mineralogists, J. v. 34, nos. 5 & 6, p. 165-172, 199-204; v. 35, no. 1, p. 15-23 (in Japanese).

Takenouti, T. B., 1937, Garnet from the Hitachi Mine: Japanese Assoc. Mineralogists, J. v. 17, no. 5, p. 239-248 (in Japanese).

Takeuti, T. R., 1939, Refractive indices and specific gravities of garnet crystals found in Japan: Japanese Assoc. Mineralogists, J. v. 21, no. 5, p. 205-228; v. 22, no. 1, p. 1-25 (in Japanese).

_____ 1941, Studies of garnets and of its country rock from Amataki: Japanese Assoc. Mineralogists, J. v. 26, no. 2, p. 51-78 (in Japanese).

_____ 1942, Studies of minerals and rocks occurring in the Yagoshi Mine and its vicinity (6); Garnet: Japanese Assoc. Mineralogists, J. v. 27, no. 2, p. 106-114 (in Japanese).

Tauber, A. G., Banks, E. C., and Kedesdy, H. D., Synthesis of germanate garnets, Acta. Cryst., v. II, p. 893-894.

Thilo, Erich, 1941, Über die Isotypie zwischen Phosphaten der allgemeinen Zusammensetzung $(Me_1)_3$ $(Me_2)_2$ (PO_4) und den Silikaten der Granatgruppe: Naturwissenschaften, Berlin, v. 29, no. 16, p. 239 (in German).

Tilley, C. E., 1921, Precambrian para-gneisses of southern Eyre Peninsula, South Australia: Geol. Mag., v. 58, p. 251-259, 305-312.

_____ 1926, Garnet in pelitic contact-zones: Mineralog. Mag., v. 21, p. 47-50.

_____ 1926, Some mineralogical transformations in crystalline schists: Mineralog. Mag., v. 21, p. 34-46.

Tomba, A. M., 1952, I minerali del gruppa dell'Ortler; III, staurolite, granato e biotite di val peder: Acad. Naz. Lincei, Atti, cl. Sci., Rend. S. 8, v. 13, f. 1 & 2, p. 79-82.

Trainer, J. N., 1945, Pseudomorphism and zonal growth of garnets from Garnet Hill, California: Rocks and Minerals, v. 20, no. 8, p. 359-363.

_____ 1948, Vicinal forms on garnets: Rocks and Minerals, v. 23, no. 2, p. 105-107.

Tröger, E. S., 1959, Die Granat-Gruppe: Beziehungen zwischen Mineralchemismus und Gesteinsart: Neues Jahrbuch für Mineralogie, Abhandlungen, v. 93, no. 1, p. 1-44 (in German).

Uhlig, J. C., 1910, The garnets in volcanic rocks and bombs of the lower Rhine district: Bonn. Verh. Nat. Ver. preuss. Rhineland-Westfalens., v. 67, p. 307-403 (in German).

Van der Lingen, J. S., 1929, Garnets: South African Jour. Sci., v. 25, p. 10-15.

Vermaas, F. H. S., 1952, Manganese-iron garnet from Otjosondu, Southwest Africa: Am. Mineralogist, v. 37, nos. 11 & 12, p. 1065.

Vistelius, A. B., 1943, On the garnets from the region of the Lake Balkhash: Soc. Russe. Miner., Mem. v. 72, nos. 3 & 4, p. 167-173 (in Russian).

Tauber, A. G., Banks, E. C., and Kedesdy, H. D., Synthesis of germanate garnets, Acta. Cryst., v. 11, p. 893-894.

Thilo, Erich, 1941, Uber die Isotypie zwischen Phosphaten der allgemeinen Zusammensetzung $(Me_I)_3 (Me_{II})_2 (PO_4)$ und den Silikaten der Granatgruppe: Naturwissenschaften, Berlin, v. 29, no. 16, p. 239 (in German).

Tilley, C. E., 1921, Precambrian para-gneisses of southern Eyre Peninsula, South Australia: Geol. Mag., v. 58, p. 251-259, 305-312.

_____ 1926, Garnet in pelitic contact-zones: Mineralog. Mag., v. 21, p. 47-50.

_____ 1926, Some mineralogical transformations in crystalline schists: Mineralog. Mag., v. 21, p. 34-46.

Tomba, A. M., 1952, I minerali del gruppa dell'Ortler; III, staurolite, granato e biotite di val pedert: Accad. Naz. Lincei, Atti, cl. Sci., Rend. S. 8, v. 13, f. 1 & 2, p. 79-82.

Trainer, J. N., 1945, Pseudomorphism and zonal growth of garnets from Garnet Hill, California: Rocks and Minerals, v. 20, no. 8, p. 359-363.

_____ 1948, Vicinal forms on garnets: Rocks and Minerals, v. 23, no. 2, p. 105-107.

Tröger, E. S., 1959, Die Granat-Gruppe: Beziehungen zwischen Mineralchemismus und Gesteinsart: Neues Jahrbuch für Mineralogie, Abhandlungen, v. 93, no. 1, p. 1-44 (in German).

Uhlig, J. C., 1910, The garnets in volcanic rocks and bombs of the lower Rhine district: Bonn. Verh. Nat. Ver. preuss. Rhineland-Westfalens., v. 67, p. 307-403 (in German).

Van der Lingen, J. S., 1929, Garnets: South African Jour. Sci., v. 25, p. 10-15.

Vermaas, F. H. S., 1952, Manganese-iron garnet from Otjosondu, Southwest Africa: Am. Mineralogist, v. 37, nos. 11 & 12, p. 1065.

Vistelius, A. B., 1943, On the garnets from the region of the Lake Balkhash: Soc. Russe. Miner., Mem. v. 72, nos. 3 & 4, p. 167-173 (in Russian).

Vitaliano, C. J., 1944, Contact metamorphism at Rye Patch, Nevada: Geol. Soc. Am. Bull., v. 55, no. 8, p. 921-950.

Walcott, A. J., 1937, Asterism in garnet, spinel, quartz, and sapphire: Field Mus. Nat. History Pub. 397, Geol. Ser., v. 7, no. 3, p. 39-57.

_____ 1938, Asterism in garnet, spinel, quartz, and sapphire: Mineralogist, v. 6, no. 6, p. 3-4.

_____ 1939, Asteriated garnet: Mineralogist, v. 7, no. 5, p. 191-192, 215-217.

Weinschenk, E. S., 1896, Beiträge zur Systematisch der Granatgruppe: Zeitsch. Krist. und Mineral., v. 25, p. 365 (in German).

Wentorf, R. H., Jr., 1956, The formation of Gore Mountain (N. Y.) garnet and hornblende at high temperature and pressure: Am. Jour. Sci., v. 254, no. 7, p. 413-419.

Wiley, John, 1947, A further note on Purgatory Chasm, Massachusetts: Rocks and Minerals, v. 22, no. 3, p. 213.

Wilson, L. G., 1956, Thermal expansion of a grossularite garnet: Australian Jour. Phys., v. 9, p. 403-405.

Winchell, A. N., 1924, Petrographic studies of limestone alterations at Bingham: Am. Inst. Mining Metall. Engineers Trans., no. 1322-M, 16 p.

_____ 1933, Elements of optical mineralogy, pt. II, Descriptions of minerals: New York, John Wiley and Sons, 459 p.

Winchell, Horace, 1958, The composition and physical properties of garnet: Am. Mineralogist, v. 43, nos. 5 & 6, p. 595-599.

Woodland, A. W., 1935, Spessartite in the Cambrian manganese ore of Merionethshire: Geol. Mag., v. 72, p. 384.

Wright, C. W., 1915, Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, 110 p.

Wright, W. I., 1938, The composition and occurrence of garnets: Am. Mineralogist, v. 23, no. 7, p. 436-449.

Yagi, K. S., 1944, Petro-chemical studies on rocks from New Guinea: I garnet-biotite-migmatite from Ranshiki River, Anggi Region: Jour. Japanese Assoc. Mineralogists, petrol., -Econ. Geol., v. 32, p. 89-105 (in Japanese).

Yedlin, L. N., 1947, Garnet at Roxbury and West Redding, Connecticut: Rocks and Minerals, v. 22, no. 9, p. 824-826.

Yoder, H. S., Jr., 1950, Stability relations of grossularite: Jour. Geology, v. 58, no. 3, p. 221-253.

_____ 1955, Almandite garnet stability range (abs.): Am. Mineralogist, v. 40, nos. 3 & 4, p. 342.

Yoder, H. S., Jr., and Keith, M. L., 1951, Complete substitution of aluminum for silicon- The system $3MnO.Al_2O_3.3SiO_2-Y_2O_3.5Al_2O_3$: Am. Mineralogist, v. 36, nos. 7 & 8, p. 519-533.

Yoshimura, Toyotumi, 1936, On the garnet from Mitsu-ishi, Hitaka Province: Japanese Assoc. Mineralogists ..., J. v. 14, no. 6, p. 257-265; v. 15, no. 1, p. 26-40 (in Japanese).

Zedlitz, Otto, 1933, Andradite rich in titanium: Zentr. Min. Geol., 1933 A, p. 225-239 (in German).

_____ 1935, Titaniferous calcium-iron garnets: II: Zentr. Mineral., Geol. 1935 A, p. 68-78 (in German).

Zombory, Laszlo, 1935, Daten zur chemischen Zusammensetzung der Granate von vaskö- Dognacska: (Ung. Akad. Wiss.), v. 52, p. 170-187 (in Hungarian).

Zorkovsky, Belo, 1956, The chemical character of the garnet from the andesite of Vel'ky Saris: Geol. Sbornik (Bratislava), v. 7, p. 321-331 (in Russian).