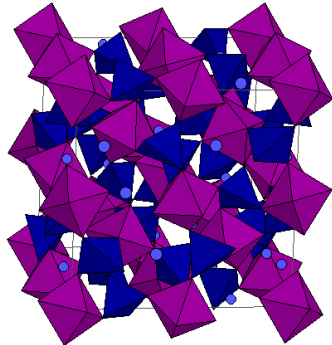


Mineral Cup Project

[1] Mineral Basics

Mineral name:	Garnet
Mineral formula:	$X_3Y_2(SiO_4)_3$
Polymorphs:	-
Mineral group:	Garnet
Silicate structural group:	Isolated (Nesosilicates)
Solid solution, yes or no:	Yes
End member names:	Pyrope, Almandine, Spessartite, Uvarovite, Grossular, Andradite
End member formulas / substitutions:	Pyrope: $Mg_3Al_2(SiO_4)_3$ Almandine: $Fe_3Al_2(SiO_4)_3$ Spessartite: $Mn_3Al_2(SiO_4)_3$ Uvarovite: $Ca_3Cr_2(SiO_4)_3$ Grossular: $Ca_3Al_2(SiO_4)_3$ Andradite: $Ca_3Fe_2(SiO_4)_3$
Cation crystal lattice sites present:	X-site is 8 coordinated, Y-site is 6-coordinated, Z-site is 4-coordinated
Model of atomic structure:	
<i>Image credit</i>	University of Colorado Boulder: Mineral Structure Data
Number of formula units in unit cell:	8 formula units
Crystal system:	Isometric
Crystal class (point group) name:	Hexoctahedral
Hermann-Mauguin symbol of the point grp:	$4/m\bar{3}2/m$
Symmetry elements of the point group:	3 4-fold rotation axes, 4 3-fold rotot inversion axes, 6 2-fold rotation axes, 9 mirror planes, and a center of symmetry

3D block visualization of crystal form:

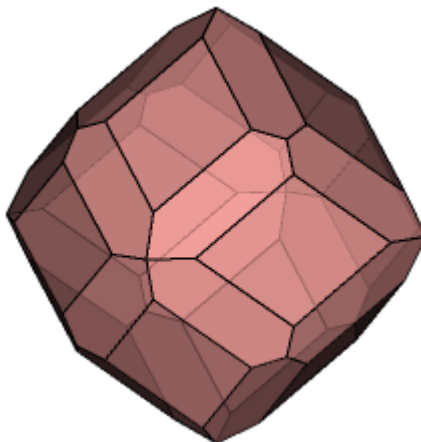


Image credit

Mindat.org

Image of the mineral exhibiting this form:



Image credit

Mindat.org

Color:

Various

Luster:

Vitreous

Streak:

White

Cleavage and/or fracture:

None / conchoidal

Habit and/or state of aggregation:

Rhombic dodecahedron, dodecahedral, or cubic habit

Hardness

6.5 – 7.5

Specific gravity:

3.1 - 4.3

Twinning:

Occurs (frequently) in andradite and grossular garnets, not as common in other endmembers.



Other special properties in hand sample:

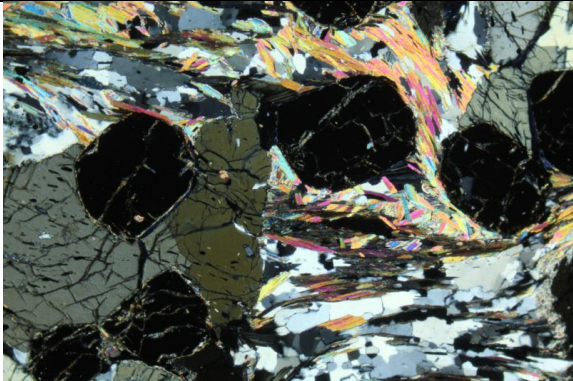

Garnets can be opaque or translucent to transparent and can also be found as individual crystals or clumps of inter-grown crystals.


Most obvious/diagnostic property:

Dodecahedron habit

Image of the mineral showing this property:

	
<i>Image credit</i>	Cochise College
Occurrence - rock type(s):	<p>Most commonly found in metamorphic rocks but can be found in igneous and sedimentary rocks as well sometimes.</p> <p>Igneous rocks: granite and basalt Sedimentary rocks: shale, sandstone Metamorphic rocks: mica schist, gneiss</p>
Common mineral associations:	<p>Most commonly found in metamorphic rocks.</p> <p>In metamorphic rocks: typically, mica, also staurolite, kyanite, and sillimanite In igneous rocks: quartz, feldspars In sedimentary rocks: quartz</p>
Alteration products:	Serpentine, Talc, Chlorite
Opaque or transparent:	It can be both opaque or transparent in-hand samples.
Relief:	High relief
Pleochroism:	None
Common shapes in cross section:	Hexagonal
Image of mineral in plane polarized light:	
<i>Image credit</i>	Alex Strekeisen
Isotropic or anisotropic:	Isotropic
Birefringence:	None
Interference color in 30-μm-thick section:	-
Sign of elongation:	-

Type and/or angle of extinction:	-
Uniaxial or biaxial:	-
Optic sign:	-
2V angle:	-
Image of mineral in cross polarized light:	
<i>Image credit</i>	Alex Strekeisen
Other special properties in thin section:	<p>The distinct edges, super pale colors PPL, and extinction are the most diagnostic characteristics of garnet in thin sections. It also oftentimes contains inclusions of other minerals, including biotite, quartz, and other metamorphic minerals.</p>
Societal use of the mineral:	<p>Historically, garnet was believed to have healing powers. It was given to warriors to ward off plague and used during medieval times to heal depression. It was seen as a sign of strength and nobility. A red garnet, called carbuncle was believed to be one of the four precious stones that God gave to King Solomon.</p> <p>Today, garnet is still used in jewelry and is also commonly used in abrasives such as skid-resistant road aggregate, paints, and concrete filler.</p>
Image of the mineral showing this use:	<p>Historical:</p> 

	<p>Today:</p> 
<p><i>Image credit</i></p>	<p>Historical: Gemological Institute of America Today: GMA Garnet Group</p>

How does one identify this mineral in hand sample and thin section?

In hand samples, garnet can be somewhat tricky to identify. Its most diagnostic aspect is its crystal habit, which can be challenging to see in very small crystal samples. However, garnet's dodecahedron (or sometimes cubic or rhombic dodecahedron) habit can be evident in some examples. Depending on the type of garnet, its color can vary. Often, garnet is characterized by its standard deep red color, specifically for the pyrope end member. Still, many types of garnet and even many pyrope samples are not red. It exhibits a vitreous luster and white streak, typical of most other silicates. Similarly, it has a mid-range hardness of around 7. If habit cannot be decided or needs to be confirmed, one should then determine the cleavage and fracture of the sample. Garnet has no cleavage, but it has a conchoidal fracture, meaning it will break into smooth, curved surfaces. Garnet can be found in almost all types of rocks, but some are far more common than others and can help identify the mineral. Garnet is most commonly found in metamorphic rocks such as mica schist and gneiss, alongside mica, staurolite, kyanite, and sillimanite. While garnet is one of the most common minerals on earth, making it sometimes challenging to distinguish amongst other minerals, the listed characteristics can diagnose it.

To identify garnet in a thin section, one would start in PPL. The first thing to notice is the garnet's high relief and hexagonal cross sections. Combined with its very pale colors or sometimes translucency in PPL, these characteristics are diagnostic. Garnet can have irregular fractures that may also be viewed. After determining the minerals' color, relief, and cross-section shape, one would switch to XPL. The most noticeable aspect of garnet in XPL is that it is an isotropic mineral, meaning it is opaque in XPL. Garnet often has inclusions that can be easier to see in XPL since they will not be opaque. The inclusions are usually of other metamorphic minerals, including biotite and quartz. Again, garnet is commonly found in metamorphic rocks and thin sections with other metamorphic minerals such as quartz, feldspars, and mica. Through determining these characteristics, garnet can be identified in thin sections.

Mineral Cup Project

[2] Mineral Research

"Garnet" encompasses a group of minerals categorized as silicates, including pyrope, almandine, spessartine, and grossular. The general garnet formula is $X_3Y_2(SiO_4)_3$ and is visually known for its vibrant colors and dodecahedral crystal habit. In addition, the most common form of garnet is isometric and is optically isotropic. It is one of the earth's most commonly occurring minerals and has proven helpful for determining and investigating geological processes (Cesare 1). Three scientific articles will be reviewed and summarized in the following paragraphs to deliberate recent research conducted about garnet and to determine a gap or possible direction for further research around the mineral. All articles focus on how garnet changes and develop under metamorphism and pose the idea that garnet's crystallographic structure and composition can be used as dating tools for areas with high levels of metamorphism activity.

Cesare et al. (2019) challenge the idea that "common" garnet is isometric. They hypothesized that not all common garnet specimens are isometric. They tested their hypothesis and found that a tetragonal crystal structure is more common than previously thought, specifically in low-temperature, high-pressure metamorphosed basalts and low-grade metamorphosed mudstones. They used garnet samples from high-pressure, low-temperature metamorphosed basalt (blueschist) from subduction zones, and greenschist-facies metamorphosed mudstones (phyllites) from mountain ranges. They used a "multi-technique approach including optical microstructural analysis, BSEM, EMPA, EBSD, FTIR, TEM, and single-crystal XRD to test the hypothesis. Overall, their evidence leads to the thought that garnet does not initially grow cubic; instead, the cubic system results from metamorphism processes. Citing what was previously known as rare characteristics of common garnet, including birefringence that has previously been cited as an internal strain within the cubic structure. Most evidently, non-isometric crystal systems appear in common garnet formed at low temperatures (<450°C) and with low magnesium compositions. In conclusion, common garnet in said low-temperature regional metamorphic rock formations grow as tetragonal. There may be strange, local environmental processes forming non-cubic garnet in their specific sample locations. The discovery that garnets form in non-cubic structures at low temperatures is an important geological conclusion and must be vetted by many more scientific studies that create a much larger sample size.

Wotzlaw et al. (2022) analyzed the evolution of phonolite magmas from the Pompei and Pollena eruptions. Using garnet uranium-thorium petrochronology (the connection of time to rock-forming processes), they determined that as volcano ages, the pre-eruption residence times become increasingly shorter. First, Wotzlaw et al. (2022) determined a process using laser ablation and coupled plasma mass spectrometry that allows the use of in situ U-Th disequilibrium dating of Ca-rich garnet phenocrysts to specify time scales and conditions for phonolite magma storage. Using textural and geochemical characterization of the sampled crystals, they assess the timescales and dynamics of magma storage and provide a petrochronology framework. One theory that garnet can be in magma for a shorter residence time is for garnet to crystallize later, existing in the magma for less time before the eruption. The authors disagree with the theory because of the wide stability range of garnet compositions in the magma samples. There is no

reason why the garnet would crystallize later since the conditions (temperature and pressure) are suitable for crystallization. Wotzlaw et al. (2022) determine through this logic that the short timescales of garnet crystallization are related to volcanic events, such as the duration of magma storage beneath the volcano before the eruption. They concluded that the garnet core samples crystallized from a more evolved melt than the white phonolite pumice glass sampled from the same volcano. Essentially, different magmas crystallize at different times, creating a relationship between the garnet rims and their host pumices that constrains the extent of magma mixing after garnet crystallization. The analysis of the Pompei and Pollena eruptions can be applied to other volcanic eruptions to develop further a petrochronology framework for garnet formed in volcanic eruptions.

Viete et al. (2018) connect to the Cesare et al. (2019) analysis of changes to garnet during high-pressure, low-temperature metamorphism during subduction. Viete et al. (2018) hypothesize that the relation of permeability to metamorphism and dehydration reactions causes incomplete crystal formations. Using samples from the Franciscan Complex, California, they found evidence of rhythmic incomplete continuous reactions within samples from subduction zones. Large earthquakes fracture the rock, forming cracks that make the rock more permeable. When water can flow out of rock easily, cracks, especially small ones, fill up with debris, mineral cement, and newly crystallized grains. The new material decreases the permeability of the rock prior to the earthquake, theoretically returning the relevant pore fluid pressure. Viete et al. (2018) use electron probe microanalysis to determine the pore fluid pressure for the samples at various magnitude and time scales. To develop a time scale regarding the pore fluid pressure of garnet in relevance to earthquake cycles, they determined what was consistent with the viewed garnet that had undergone natural metamorphism, including earthquake cycles.

Cesare et al. (2019) and Viete et al. (2018) both argue that the form in which garnet is most commonly seen is not its original form but that many years of samples undergoing metamorphism create what is viewed as common garnet by geologists today. Wotzlaw et al. (2022) use the idea that garnet changes with metamorphic processes to determine a relative scale to use when dating volcanic ages. The future of research surrounding garnet is the solidification of how exactly the metamorphic process develops garnet in different areas. Important research questions for future studies include: Does garnet forming at low temperatures grow in a tetragonal crystallographic structure? What is the consistency of changes geological events such as volcanic eruptions and earthquakes make to the structure and composition of garnet? A high volume of samples must be examined to create applicable scales for all garnet samples. Through the methods that the analyzed articles used, including electron probe microanalysis and optical analysis, more data needs to be collected prior to analyzing and developing a relevant time scale for garnet. Developing a baseline of geologic processes garnet undergoes within subduction zones is essential to determining what a base sample of garnet could be and how garnet can develop under different geologic processes. Then, the true power of using garnet to date geological processes can be used to provide specific time scales since garnet is a widely common mineral.

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