# Star garnets and star garnet cat's-eyes from Ambatondrazaka, Madagascar

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***ABSTRACT:*** Mineralogical and gemmological properties of star garnets from Ambatondrazaka, Madagascar, are given. All samples examined are intermediate members of the almandine-spessartine series with an appreciable pyrope component. Asterism is caused by a dense network of rutile needles that are orientated parallel to the three-fold axes of the cubic garnet hosts. In addition to the white four-rayed stars, reddish-brown cat's-eyes are present in two garnet cabochons. This additional light band is caused by orientated sillimanite lamellae. The formation of different four- and six-rayed stars in garnets is discussed.



## Introduction

Asteriated garnets are known from India, Sri Lanka, and Tanzania, as well as from Idaho and North Carolina, U.S.A. Samples have been described as almandine or intermediate pyrope-almandine garnets (rhodolite), rarely also as grossular or spessartine. Cabochons with four-rayed stars (*Figure 1a, b*) are commonly observed, and garnets with both four- and six-rayed stars (*Figure 2a, b*) have also been mentioned (Rouse, 1986; Zeitner, 1986; Rohrbach, 1986; Arem, 1987; Kammerling and Koivula, 1990; Barot *et al.*, 1995; Kumaratilake, 1997; Hamer, 1998). Extraordinarily large samples are known from India (*Figure 1b*).

Asterism in garnets is caused by orientated needle-like inclusions, which are most commonly designated as rutile or rutile silk. The most frequently observed orientation of these tiny needles is parallel to the edges of the dodecahedron, i.e. parallel to the four three-fold axes <111> of the cubic system. With that particular orientation, twelve four-rayed stars can be observed on samples cut as complete spheres (Holland, 1896; Brauns, 1907; Goldschmidt and Brauns, 1911; Maier,

***Figure 1a:*** *Asteriated garnet cabochon from India, revealing a white four-rayed star. It measures 24.2 x 21.5 mm, and weighs 69 ct. Photograph by M. Glas.*

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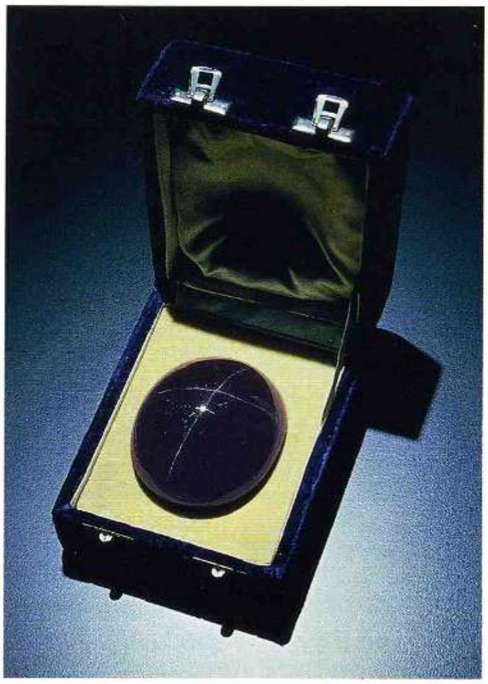


*Figure 1b: Asteriated garnet cabochon from India, revealing a white four-rayed star. It measures 95 x 82 mm and weighs 1.147 kg (5737 ct). Collection of the Precious Stones Museum, Antwerp, Belgium; photograph by P. Entremont.*



1943; Mellis, 1966; Strunz, 1968; Barot *et al.*, 1995; Kumaratilake, 1998). Chatoyancy is rarely mentioned in garnets. It is observed in 'normal' four-rayed star garnets which are misorientated (Fryer *et al.*, 1985) or in samples that show a four-rayed star with two arms of the star being extremely weak (Fryer *et al.*, 1988).

Asteriated garnets have been offered in local markets in Madagascar since about 1997. The rough materials for these cabochons or sometimes complete garnet spheres originate from a place about 25 km north-east of the town of Ambatondrazaka which is located south of Lake Alaotra, about 160 km north-east of the capital Antananarivo. The aim of this paper is to present a mineralogical and gemmological description of these garnets, including those showing chatoyancy. These garnets from Ambatondrazaka have been determined as almandines with high spessartine components and differ from another type of asteriated garnet, a more transparent pyrope-almandine from the Ilakaka mining area in

***Figure 2a:** Asteriated garnet cabochon from India, revealing a white six-rayed star. It measures 27.1 x 21.0 mm, and weighs 132 ct; collection K. Fischer, Starnberg. Photograph by M. Glas.*

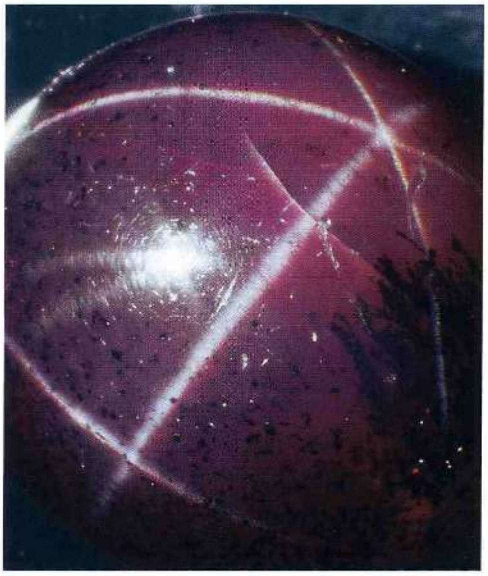


***Figure 2b:** Oval cabochon of almandine garnet weighing 28.88 ct and showing a four-rayed and a six-rayed star. Source: India. Photograph by E.A. Jobbins.*

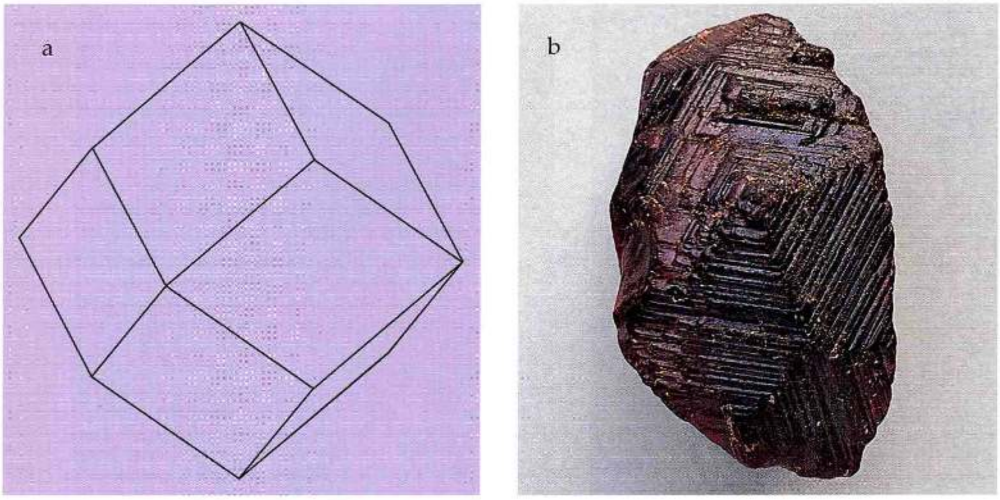



***Figure 3:*** *Normally observed habit of garnet crystals from Ambatondrazaka, Madagascar, showing only the dodecahedron crystal form {110}:*

*a) Idealized drawing (clinographic projection)*

*b) Fragment of a crystal showing three dodecahedral {110} faces; striations parallel to the edges <111> of the dodecahedron are also seen. Size of the sample is about 31 x 15 mm. Photograph by M. Glas.*

southern Madagascar (Schmetzer and Bernhardt, 2002).

## Geology of the occurrence

The region east and south-east of Lake Alaotra is one of the numerous pegmatite areas of Madagascar and is well known as a source of cyclic twins of chrysoberyl (Pezzotta, 1999). Rough garnet crystals up to 25 cm in diameter are recovered from one of these pegmatites which also contains K-feldspar, quartz, muscovite, and schorl (Pezzotta, 2001). The work in the pegmatite has been abandoned because of a landslide that covered the pits of local miners.

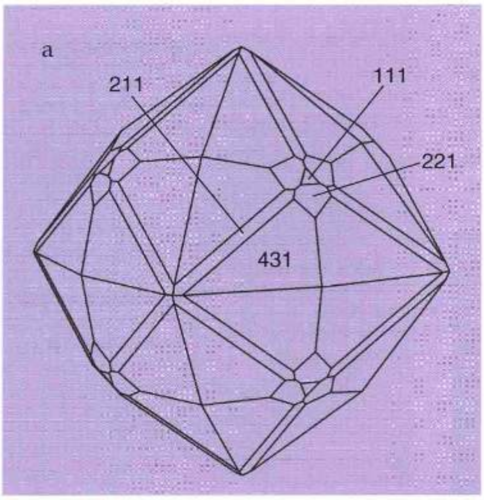
## Visual appearance of rough garnet crystals and gemmological properties

The rough material available for the present study consisted of about 50 irregular fragments of garnet crystals measuring up to 8 cm in their longest dimension. In some samples, faces of the dodecahedron {110} were developed which show distinct striations parallel to <111>, i.e. parallel to the edges of the dodecahedral faces (*Figure 3*). Two crystals are strongly distorted with trigonal habit and both are elongated along one of the cubic three-fold axes (*Figure 4*). The dominant faces are the trapezohedron {211} in combination with the hexoctahedron {431}. Smaller trisoctahedral {221} and octahedral {111} faces are also present.

All samples are non-transparent and only lightly translucent with a reddish to purplish-brown colour. Refractive indices of the samples are above the limit of normal gemmological refractometers. Specific gravities of the samples lie in the range of 4.21 to 4.26.

## Asterism and chatoyancy

For the present study, 40 cabochon-cut garnets up to 50 ct in weight and 15 samples cut as complete spheres were available. Samples cut as cabochons revealed distinct asterism forming sharp four-rayed white stars (*Figure 5*). According to the orientation of the surfaces of an individual cabochon, up to three of these four-rayed stars may be present (*Figure 6*). Garnet crystals cut as



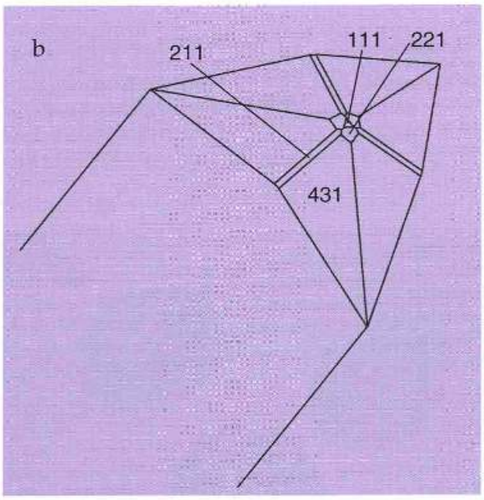





***Figure 4:** Trigonally distorted garnet crystal from Ambatondrazaka, Madagascar:*

*a) Idealized drawing (clinographic projection) of an undistorted cubic crystal showing the trapezohedron {211} in combination with the hexoctahedron {431} as dominant crystal forms; subordinate faces are the trisoctahedron {221} and the octahedron {111}.*

*b) Idealized drawing (clinographic projection) of a trigonally distorted crystal, the sample is elongated parallel to one of the three-fold axes <111> of the cubic garnet crystal (faces designated as in (a) above.*

*c) Photo of the trigonally distorted crystal drawn in (b) above, rotated compared with the idealized drawing.*

*Size of the sample is about 24 x 15 mm; photograph by M. Glas.*

complete spheres (*Figure 7a, b*) showed 12 four-rayed stars on their surfaces, the centres of which were observed in a direction parallel to the six cubic two-fold axes <110>, i.e. in a view perpendicular to one of the twelve dodecahedral {110} faces.

One exceptionally large garnet sphere (*Figure 8a, b, c*) measuring 67.8 mm in diameter weighs 676 grams (3380 ct after recutting and repolishing in Germany). This sphere also revealed sharp four-rayed asterism in directions parallel to all of the cubic two-fold axes and is regarded as one of the largest

*Figure 5:* Asteriated garnet cabochon from Ambatondrazaka, Madagascar, revealing a white four-rayed star. It measures 19.5 x 15.4 mm and weighs 34 ct. Photograph by M. Glas.

*Figure 6:* Asteriated garnet cabochons from Ambatondrazaka, Madagascar, revealing white four-rayed stars. The light bands of the four-rayed stars appear at different angles according to the orientation of the two-fold axis of the garnet in relation to base and dome of the cabochon. The cabochon in the centre is cut with a base perpendicular to a three-fold axis and shows the light bands of three four-rayed stars. Sizes of the samples are 19.5 x 15.4 mm to 11.1 x 8.9 mm, and weights vary from 34 ct to 5 ct. Photograph by M. Glas.

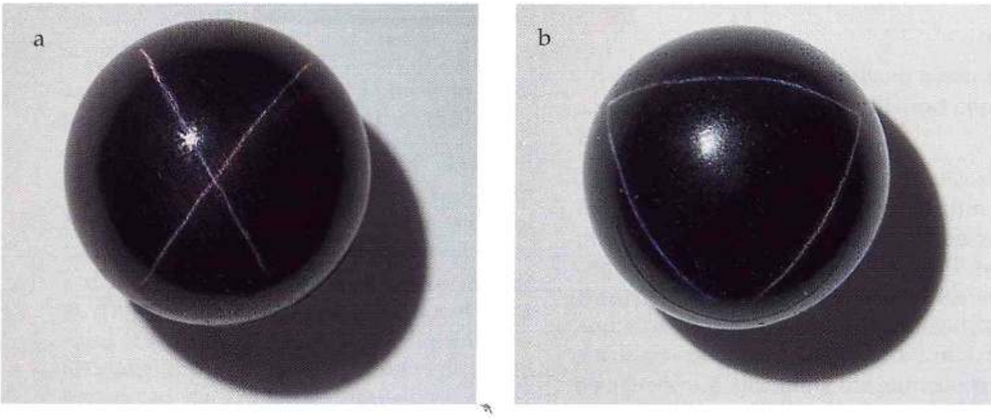



*Figure 7:* Garnet from Ambatondrazaka, Madagascar, cut as a complete sphere: a) In a view parallel to one of the two-fold axes a four-rayed star is observed. b) In a view parallel to one of the three-fold axes, the light bands of three four-rayed stars are observed. The diameter of the sphere is 13.0 mm, weight 18 ct. Photographs by M. Glas.


*Figure 8: Garnet from Ambatondrazaka, Madagascar, cut as a complete sphere:*

*a) In a view parallel to one of the two-fold axes a four-rayed star is observed.*

*b) In a view parallel to one of the three-fold axes, the light bands of three four-rayed stars are observed.*

*c) In a view inclined to one of the two-fold axes a four-rayed star is observed.*

*The diameter of the sphere is 67.8 mm, weight 676 grams (3380 ct). Photographs by M. Glas.*



asteriated garnet spheres known to date (see e.g. Brauns, 1907; Sinkankas, 1959).

In addition to the commonly observed asterism of the material from Ambatondrazaka, two of the garnet cabochons weighing 32.74 and 19.76 ct show a distinct reddish brown cat's-eye (*Figure 9*). The orientation of this additional light band is oblique to the different light bands forming the commonly observed white four-rayed stars of these samples.

## Chemical composition

Microprobe analyses of three samples are given in *Table I*. These data represent average concentrations measured in scans of 20 point analyses each across the plane bases of the samples. In these scans, no distinct chemical zoning was observed.

The garnets are members of the almandine-spessartine series with almandine components of 70-73 mol.% and high spessartine components in the range of 18-21 mol.%. Appreciable pyrope percentages between 7 and 9 mol.% were also determined, and a small grossular component of 1-2 mol.% was also present. Calculating the garnet composition for 12 oxygens and for both iron valencies, iron in the trivalent state is always present in small amounts (between 0.035 and 0.045 $Fe^{3+}$ atoms per formula unit). These data indicate a small component of about 1-2 mol.% of andradite in the garnet samples.

*Table I:* Composition of almandine-spessartine garnets from Ambatondrazaka, Madagascar; electron microprobe analyses.

| Sample (wt%)* | 1 | 2 | 3 |
|---|---|---|---|
| MgO | 2.17 | 1.90 | 2.00 |
| CaO | 0.60 | 0.36 | 0.47 |
| MnO | 8.02 | 8.60 | 8.96 |
| FeO** | 32.48 | 32.50 | 31.71 |
| $V_2O_3$ | 0.01 | 0.01 | 0.02 |
| $Cr_2O_3$ | 0.02 | 0.01 | 0.01 |
| $Al_2O_3$ | 20.90 | 20.87 | 20.93 |
| $SiO_2$ | 36.50 | 36.28 | 36.32 |
| $TiO_2$ | 0.14 | 0.06 | 0.04 |
| Total | 100.84 | 100.59 | 100.46 |
| Cations based on 12 O | | | |
| Mg | 0.263 | 0.231 | 0.243 |
| Ca | 0.052 | 0.032 | 0.041 |
| Mn | 0.551 | 0.594 | 0.618 |
| Fe | 2.202 | 2.215 | 2.161 |
| V | 0.001 | 0.001 | 0.001 |
| Cr | 0.002 | 0.001 | 0.001 |
| Al | 1.997 | 2.005 | 2.009 |
| Si | 2.959 | 2.957 | 2.959 |
| Ti | 0.008 | 0.004 | 0.003 |
| Mol. % end-members | | | |
| Pyrope | 8.57 | 7.51 | 7.94 |
| Grossular | 1.69 | 1.03 | 1.33 |
| Spessartine | 17.96 | 19.34 | 20.18 |
| Almandine | 71.78 | 72.12 | 70.55 |

* *Each composition reported is an average of 20 analyses.*
** *Total iron is given as FeO.*

***Figure 9:*** *Asteriated garnet cabochon from Ambatondrazaka, Madagascar, revealing a white four-rayed star and a reddish-brown cat's-eye. It measures 19.2 x 17.2 mm, and weighs 33 ct. Photograph by M. Glas.*

## Microscopic properties observed in thin sections and determination of acicular inclusions

For the examination of needle-like inclusions in the slightly translucent samples, and especially for the evaluation of the causes of asterism and chatoyancy, we prepared four polished thin sections of rough fragments of garnet crystals. These sections were not cut parallel to specific faces or according to specific crystallographic orientations.

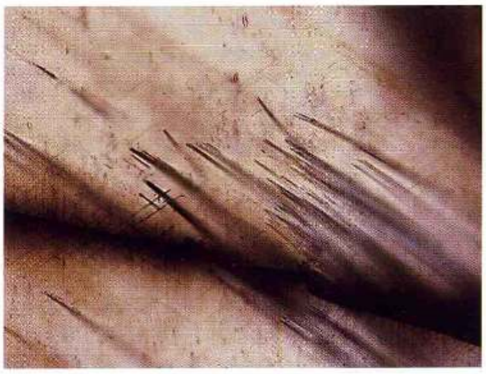


***Figure 10:*** *Dense network of rutile needles in an orientation parallel to two edges of the dodecahedron. Thin section, width of the sample about 0.45 mm.*

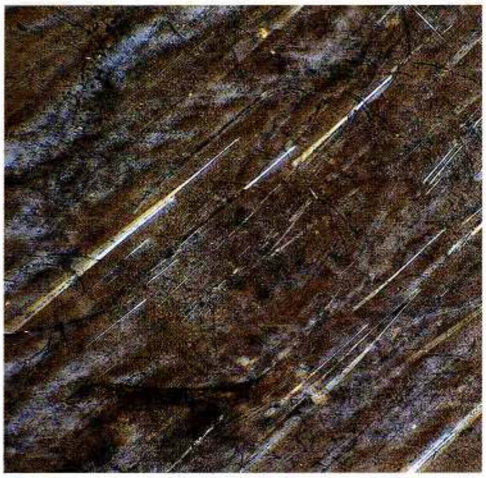


***Figure 11:*** *Lamellar inclusions of birefringent sillimanite crystals in garnet from Ambatondrazaka, Madagascar. Thin section, crossed polarizers, width of the sample about 1.75 mm. Photograph by O. Medenbach.*



All samples showed a network of fine needle-like inclusions (*Figure 10*). In one of the four thin sections, the needles are somewhat thicker than in the other three and were large enough to be analysed by electron microprobe. Only titanium was found as a major component of these needles, and this is consistent with the results from micro Raman spectroscopy, which indicated the needles to be rutile.

In all four thin sections a variable concentration of a second type of microscopic lamellar inclusion was also observed (*Figure 11*). These birefringent lamellae are orientated in one direction which in every instance, differed from the orientation of the rutile needles. Occasionally, the lamellae are slightly inclined or bent. In one of the four thin sections that revealed a relatively high concentration of this second type of acicular inclusion, several lamellae could be measured quantitatively by electron microprobe. The analyses gave the exact composition of $Al_2SiO_5$ with iron contents in the range of 1.5 to 1.7 wt.% $Fe_2O_3$. Additional examination of these lamellae by micro Raman spectroscopy indicated that they are sillimanite.

## Formation of asterism in garnets

In specific orientations of garnet hosts, asteriated samples typically show six and/or four-rayed stars formed by dense networks of needle-like inclusions. In both cases the stars are formed by bands of light which are orientated perpendicular to the needle axes. In the first case, a four-rayed star is observed in each direction of view perpendicular to a dodecahedral face. In the second case, a six-rayed star is observed in each direction of view perpendicular to an octahedral face. In a view perpendicular to a cube, the arms of six-rayed stars intersect and thus form a four-rayed star (Maier, 1943; Strunz, 1968; Kumaratilake, 1998).

In samples which show only four-rayed stars, the stars are formed by needles which are orientated parallel to <111>, i.e. parallel to the edges of the dodecahedron (*Figure 12a*). In a view perpendicular to a dodecahedral face, a rhomb with angles of 70° and 110° is seen, the edges of which are parallel to two <111> directions. The light bands causing asterism are oriented perpendicular to these edges. Consequently, four-rayed stars are observable in each view perpendicular to one of the twelve {110} faces. The stereographic projection (*Figure 12b*) shows the four light bands and their intersection points. On the surface of garnet crystals that are cut as complete spheres (*Figure 12c*), the centres of the stars are located at the positions of the two-fold axes <110>, that are perpendicular to the dodecahedral faces {110}. Turning a sphere through a certain angle $\alpha$ causes the light bands to move through an angle of $2\alpha$. Consequently, the spherical triangles of light bands observable on the surface of a garnet sphere are double the size of the spherical triangles drawn in *Figure 12c*.

In samples which show both four and six-rayed stars, the stars are formed by needles that are oriented parallel to <110>, i.e. parallel to the edges of the octahedron (*Figure 13a*). In a view perpendicular to an octahedral face, a triangle with three equal 60° angles is seen that is formed by three <110> directions, i.e. by three sets of needles. The light bands

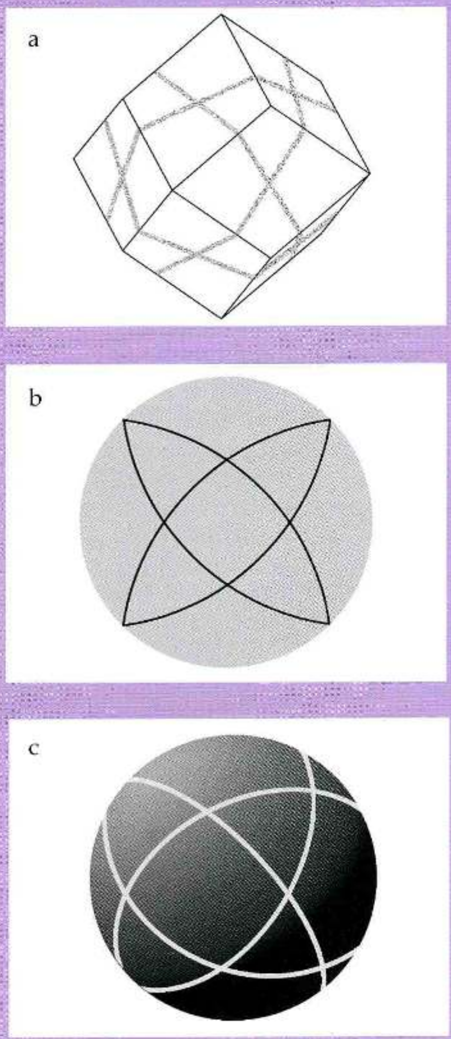
## Four-rayed stars

***Figure 12:*** *With an orientation of needle-like inclusions parallel to the edges of the dodecahedron, i.e. parallel to the four three-fold axes of garnet, four-rayed stars are formed in directions perpendicular to the dodecahedral faces; the arms of the stars are perpendicular to the long axes of the inclusions.*

*a) Clinographic projection of a cubic crystal with dodecahedral faces {110}, the theoretical positions of light bands perpendicular to the edges of the {110} faces are also shown.*

*b) The stereographic projection shows four intersection points of four light bands on the upper part of the projection sphere, four additional intersection points are found at the equatorial line of the sphere and another four intersection points are located on the lower half of the sphere (not shown).*

*c) Three dimensional view of a garnet sphere with four-rayed asterism caused by four light bands perpendicular to the cubic three-fold axes (orientation according to (a) above); the four light bands intersect at the dodecahedral faces. In a view of a sphere in different orientations, only two or three of these intersection points are seen (Figures 6, 7, 8). In a view parallel to one of the two-fold axes (Figures 7a, 8a) two intersecting light bands are observed. With a fixed orientation of the sphere, all intersection points are observable with an incident light rotated around the surface of the sphere.*





causing asterism are orientated perpendicular to these edges. Consequently, six-rayed stars are observable in each view perpendicular to one of the eight {111} faces. In a view perpendicular to a cube {100}, two sets of needles intersect at right angles. Consequently, six four-rayed stars with their centres at the position of the cubic four-fold axes <100> are seen. The stereographic projection (*Figure 13b*) shows the six light bands and their intersection points. On the surfaces of garnet crystals that are cut as complete spheres (*Figure 13c*), eight six-rayed stars are observable with the centres of the stars at the position of the cubic three-fold axes <111>, that are perpendicular to the octahedral faces {111}. In addition, six four-rayed stars are observable with the centres of the stars at the position of the cubic four-fold axes <100>.

## Six- and four-rayed stars

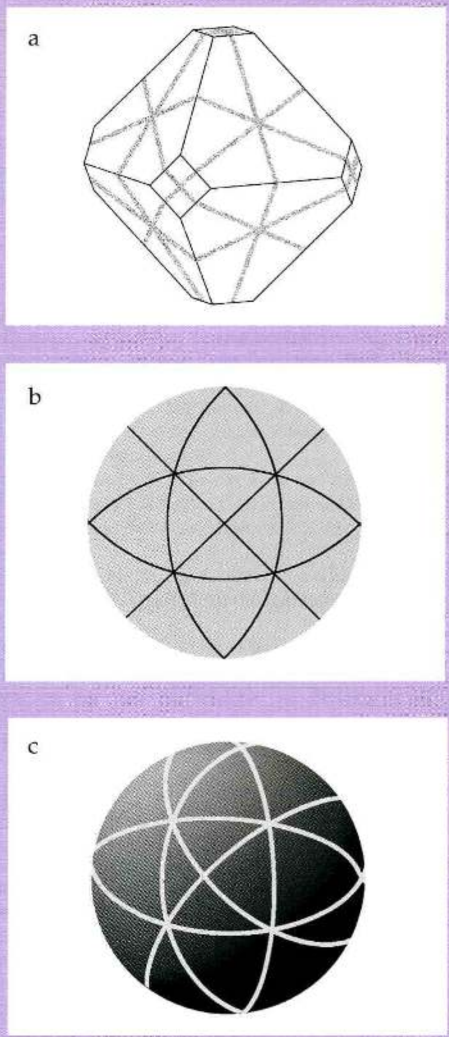



***Figure 13:*** *With an orientation of needle-like inclusions parallel to the edges of the octahedron, i.e. parallel to the six two-fold axes of garnet, six-rayed stars are visible in directions perpendicular to the octahedral faces. Viewed in directions perpendicular to cube faces, four-rayed stars are formed by intersecting arms of six-rayed stars. The arms of both types of star are perpendicular to the long axes of the inclusions.*

*a) Clinographic projection of a cubic crystal with octahedral faces {111} and cube faces {100}, the theoretical positions of light bands perpendicular to the edges of the {111} faces are also shown.*

*b) The stereographic projection shows four intersection points of three light bands on the upper part of the projection sphere; four identical intersection points are located on the lower half of the sphere (not shown); four additional intersection points of two light bands are found at the equatorial line of the sphere, one intersection point is located in the upper pole of the sphere and another one in the lower pole of the sphere (not shown).*

*c) Three-dimensional view of a garnet sphere with six- and four-rayed asterism caused by six light bands perpendicular to the cubic two-fold axes (orientation according to a) above); the six bands that intersect at the octahedral and at the cube faces form six- and four-rayed stars (see also the detailed explanation of Figure 12).*



As well as the two types of star-forming needles parallel to <111> and parallel to <110> mentioned above, a third type of orientated needles in garnets is also described in the literature (Holland, 1896; Mellis, 1966; Strunz, 1968). These needles are found parallel to the cubic four-fold axes <100>, i.e. perpendicular to the cubic planes of garnets from India and Madagascar. Until now, star garnets with this particular orientation of needles have not been described, probably because the needles in this orientation do not form a dense silk-like network that is necessary for the formation of asterism.

## Conclusions

Asteriated garnets from Ambatondrazaka near Lake Alaotra, Madagascar, are almandines with high spessartine and somewhat lower pyrope contents. The ordinary asterism of the samples is caused by orientated rutile needles forming white four-rayed stars. Additional chatoyancy is due to orientated lamellae of sillimanite. To our knowledge, this is the first report of garnet cat's-eyes that show a certain type of acicular inclusion in one single orientation only. The formation of different six- and/or four-rayed stars in garnets is explained by the intersection of light bands that are formed perpendicular to dense networks of acicular inclusions.

## References


Arem, J.E., 1987. *Color Encyclopedia of Gemstones.* 2nd edn. Van Nostrand Reinhold Company, New York, 248pp

Barot, N.R., Graziani, G., Gübelin, E., and Rettighieri, M., 1995. Cat's-eye and asteriated gemstones from East Africa. *Journal of Gemmology*, **24** (8), 569-80

Brauns, R., 1997. Lichtschein bei Granat, Zirkon und Sapphir, *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, **1907** (I. Band), 13-20

Fryer, C.W., Crowningshield, R., Hurwitt, K.N. and Kane, R.E., 1985. Gem Trade Lab notes. Garnet: almandite, exhibiting both chatoyancy and asterism. *Gems & Gemology*, **21** (1), 44

Fryer, C.W., Crowningshield, R., Hurwitt, K.N., and Kane, R.E., 1988. Star (or cat's-eye?) almandite garnet. *Gems & Gemology*, **24** (2), 112

Goldschmidt, V., and Brauns, R., 1911. Über Lichtkreise und Lichtknoten an Kristallkugeln. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, **31**. Beilage-Band, 220-42

Hamer, M., 1998. Almost heaven. *Lapidary Journal*, **52** (9), 69-72

Holland, T.H., 1896. On the acicular inclusions in Indian garnets. *Records of the Geological Survey of India*, **29**, 16-19

Kammerling, R.C., and Koivula, J.I., 1990. Star rhodolite garnet from Tanzania. *Journal of Gemmology*, **25** (1), 16-18

Kumaratilake, W.L.D.R.A., 1997. Gems of Sri Lanka: a list of cat's-eyes and stars. *Journal of Gemmology*, **25** (7), 474-82

Kumaratilake, W.L.D.R.A., 1998. Spinel and garnet star networks: an interesting asterism in gems from Sri Lanka. *Journal of Gemmology*, **26** (1), 24-8

Maier, W., 1943. Experimenteller Asterismus. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, **78** (3), 283-380

Mellis, O., 1966. Die nadeligen Einschlüsse in Pyralspitgranaten. 44. Jahrestagung, *Deutsche Mineralogische Gesellschaft*, München 1966, Referate, 2 pp

Pezzotta, F., 1999. Madagascar. Das Paradies der Mineralien und Edelsteine. *In:* Glas, M. (Ed.), *extraLapis*, 17, Christian Weise Verlag, München, 98 pp

Pezzotta, F., 2001. Pers. comm.

Rohrbach, R.P., 1986. Stars and stripes forever. *Lapidary Journal*, **40** (7), 20-30

Rouse, J.D., 1986. *Garnet.* Butterworths, London, 134 pp

Schmetzer, K., and Bernhardt, H.-J., 2002. Star Garnets from Ilakaka, Madagascar. *Australian Gemmologist* (in press)

Sinkankas, J., 1959. *Gemstones of North America.* Van Nostrand Reinhold Company, New York, 285-6

Strunz, H., 1968. *Atomare Struktur, Eigenschaften und Klassifikation der Edelsteine.* In: Mackowsky, M-T. (Ed.) Edelsteine. Aufschluß, 18. Sonderheft, 68- 102

Zeitner, J.C., 1986. Phenomenal gems. *Lapidary Journal*, **40** (7), 32-6