Oriented inclusions in spinels from Madagascar

Dr Karl Schmetzer[1], Prof. Dr Eduard Gübelin[2], Dr Heinz-Jürgen Bernhardt[3], and Dr Lore Kiefert[4]

1. Taubenweg 16, D-85238 Petershausen, Germany,
2. Haldenstr. 4, CH-6002 Luzern, Switzerland,
3. Institut für Mineralogie, Ruhr-Universität, D-44780 Bochum, Germany,
4. SSEF Swiss Gemmological Institute, CH-4001 Basel, Switzerland

ABSTRACT: Orientated inclusions in bluish-grey gem spinels from Madagascar were determined by a combination of qualitative and quantitative electron microprobe analysis with laser Raman microspectroscopy as enstatite, $MgSiO_3$. A possible origin of the spinels from the sapphire and spinel-bearing deposits of Andranondambo and Ilakaka, southern Madagascar, is briefly discussed.

Introduction

Oriented needle-like inclusions in cubic host minerals are responsible for the six-rayed and/or four-rayed stars in asteriated spinels and garnets (see e.g. Kumaratilake, 1998). This inclusion pattern is frequently observed in spinels and especially in garnets from different localities. Lamellar inclusions in cubic gem minerals, on the other hand, are quite rare. As an example, the determination of högbomite lamellae that are oriented parallel to octahedral {111} faces of Tanzanian spinels has been described by Schmetzer and Berger (1992).

In Madagascar, large quantities of gem-quality spinels are now recovered from the gem gravels around Ilakaka (Hänni, 1999; Schmetzer, 1999, 2000), but spinel was also mentioned from the skarn-related sapphire deposit of Andranondambo in southern Madagascar (Kiefert *et al.*, 1996; Gübelin and Peretti, 1997).

Gemmology of the spinels

The lamellar and needle-like inclusions in gem-quality spinels to be described in this paper were observed in a parcel of six light bluish-grey faceted samples ranging from 0.15 to 0.50 ct. The owner of this parcel indicated that these spinels originate from an unknown locality in southern Madagascar and were faceted in their country of origin. He also indicated that this parcel had been purchased about four years ago on a local gemstone market.

Gemmological properties of the samples are normal for natural gem spinels, and the absorption spectra in the visible and ultraviolet range are typical for spinels containing iron.

Several sets of lamellar inclusions were observed by microscopic examination in three of the samples. In one specific orientation of the hosts, an equilateral triangular network of three sets of birefringent lamellae was observed (*Figure 1*).

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Inclusions in spinel from Madagascar

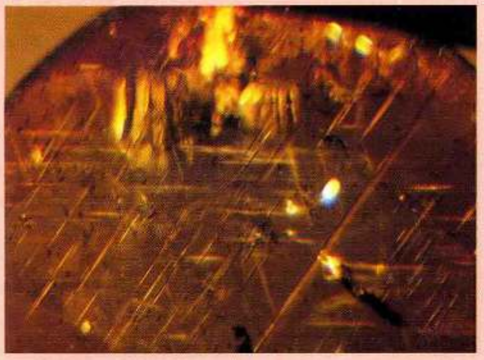

Figure 1: Three sets of birefringent lamellae that form an equilateral triangular pattern are observed in a view parallel to one of the three-fold axes of the host. Immersion, crossed polarizers, magnified 80x. Photomicrograph by K. Schmetzer.

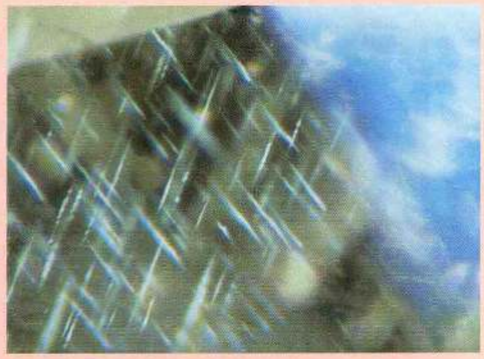

Figure 2: Two sets of birefringent lamellae that are inclined to each other are observed in a view parallel to one of the three-fold axes of the host. Dark field, fibre optic illumination, magnified 65x. Photomicrograph by E. Gübelin.

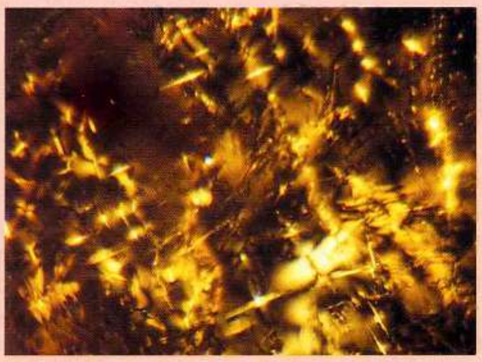

Figure 3: Birefringent crystals with various shapes are oriented parallel to specific planes within the host. Immersion, crossed polarizers, magnified 70x. Photomicrograph by K. Schmetzer.

Figure 4: Oriented lozenge-shaped or needle-like crystals, some with a distinct jagged outline. Dark field, fibre optic illumination, magnified 100x. Photomicrograph by E. Gübelin.

Occasionally, lamellae that are inclined about 60° to each other were observed only in two of these three orientations (*Figure 2*). In another direction of view, two sets of lamellae were found that formed a rectangular inclusion network. These microscopic observations indicate that the lamellae are oriented parallel to the dodecahedral {110} faces of the host spinels. The observation of a triangular pattern of three or two sets of parallel lamellae that are inclined to each other is consistent with a view of the samples parallel to one of the three-fold <111> axes, and the observation of a rectangular pattern of two sets of parallel lamellae is consistent with a view parallel to one of the four-fold <100> axes of the cubic spinels.

The remaining three samples showed an inclusion pattern, which can be described as 'incomplete lamellae'. Again, inclusions are oriented parallel to distinct planes. Some of these inclusions are small fragments of a lamella with irregular or jagged boundaries, others were developed as lozenge-shaped or needle-like crystals, but with all elongated axes of the birefringent inclusions orientated parallel to specific crystallographic directions within the spinel hosts (*Figures 3 and 4*).

Three of the six samples mentioned (designated A, B and C) revealing a dense pattern of lamellar to needle-like inclusions were selected for further examination. For the determination of inclusions in these three spinel host crystals, electron microprobe analysis and laser Raman microspectroscopy were applied. We tried to analyse inclusions that were exposed on the tables of the spinels, sometimes after having repolished these faces to avoid contamination in small cavities. One of the samples (spinel B) was cut into slices and after repolishing the surfaces, the inclusions exposed were examined by both techniques. All procedures were rather time consuming, and because the inclusions are close to 1 µm across - the diameter of the electron or laser beams - it was extremely difficult to find inclusions that gave conclusive results.

By microprobe analysis of samples A and C we were unable to separate the signals of the inclusions from the characteristic Mg-Al X-ray pattern of the host spinel. For all inclusions of this type examined, we only observed one additional characteristic X-ray line of Si (together with the lines of Mg and Al). This result indicates that the inclusions are magnesium-, aluminium- or magnesium-aluminium-silicates.

On slices of sample B we observed some 'larger' inclusions with thicknesses up to 5 µm, which allowed us to perform quantitative microprobe analysis of the crystals. We found that these birefringent minerals were magnesium silicates with smaller percentages of iron and aluminium (*Table I*). The quantitative data indicate that the inclusions are enstatites $MgSiO_3$.

These results were confirmed by Raman analysis. In all samples, a strong fluorescence of the host spinels interfered with the Raman spectra of the inclusions.

Table I: Chemical properties of enstatite inclusions in spinel

Wt%	*Crystal 1*	*Crystal 2*
	Mean of 4 anals.	*Mean of 2 anals.*
SiO_2	58.30	58.56
Al_2O_3	2.54	2.61
MgO	38.11	38.34
FeO	1.26	1.22
CaO	0.06	0.08
Total	100.27	100.81
Cations based on 6 oxygens		
Mg	1.904	1.905
Fe	0.035	0.034
Ca	0.002	0.003
Al	0.100	0.103
Si	1.954	1.953
Total	3.997	3.997

Nevertheless, we obtained Raman lines typical for enstatite from several inclusions of samples B and C.

In summary, we were able to perform qualitative chemical analysis of inclusions of samples A and C and we even obtained quantitative chemical data of two crystals in sample B. Significant Raman spectra were measured for inclusions in samples B and C. All data indicate that the orientated inclusions in the spinel were enstatite.

The literature was searched for data relating to the co-existence of spinel and enstatite but none were found which described an exsolution of enstatite in spinel or an oriented intergrowth of both minerals. Determination of the mode of origin of the enstatite lamellae must await further experimental data.

Source of the spinels

Spinel occurs within the rocks of the sapphire- and spinel-bearing skarn area of southern Madagascar, but enstatite was not

Figure 5: Lamella in purple spinel from Ilakaka, Madagascar, consisting of polycrystalline rutile. Immersion, crossed polarizers, magnified 50x. Photomicrograph by K. Schmetzer.

reported from these mineral assemblages (Rakotondrazafy *et al.*, 1996; Kiefert *et al.*, 1996; Schwarz *et al.*, 1996; Gübelin and Peretti, 1997; see also Pezzotta, 1999).

The spinel samples examined were purchased at least two years before the new Ilakaka deposit in southern Madagascar was discovered and intensely exploited. In about 120 blue, bluish-green, violet, purple or pink spinels from Ilakaka recently examined by one of the authors (see Schmetzer, 2000), only one rough sample with a lamellar inclusion was found. After faceting of this dark purple spinel, the lamella was exposed on the surface of one smaller facet (*Figure 5*) determined by the Raman technique to be rutile. A careful microscopic examination showed that the lamella consists of numerous small rutile crystals.

Consequently, there is no indication that the spinels with various forms of enstatite inclusions might come either from the Andranondambo or from the Ilakaka area in southern Madagascar and the exact location of the samples remains unclear.

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