NOTES
· AND ·
NEW TECHNIQUES

SOME UNUSUAL SILLIMANITE CAT'S-EYES

By E. Gübelin, M. Weibel, and C. F. Woensdregt

Brown-black sillimanite cat's-eyes from Sri Lanka present an unusually sharp band, which would make them extraordinary gems were it not for the rather unattractive body color of the stones. A study of six of these stones found that they contain 0.5 wt.% iron oxide. The principal inclusion mineral is ilmenite, which occurs in elongated, submicroscopically thin lamellae. Complex thicker lamellae consist of hercynite spinel grown together with a member of the pyroxene group. These thicker inclusions were not found in all of the specimens investigated.

Sillimanite, also known as fibrolite, is a common metamorphic mineral. Cuttable material is extremely rare but is found in the Mogok Stone Tract of Burma and in the Sri Lankan gem gravels, as transparent rounded crystals with a blue, violet-blue, or grayish green hue (Webster, 1983). Recently, deep brown to blackish sillimanite cabochons with a sharp chatoyancy have appeared on the market and are claimed to be from Sri Lanka. In transmitted light, these cat's-eyes show a characteristic violet tinge.

The Geochemical Laboratory in cooperation with the Solid State Physics Laboratory (Swiss Federal Institute of Technology, Zürich, Switzerland) has undertaken an electron-microscopic study of the new sillimanite cat's-eyes and the oriented inclusions that cause their chatoyancy, with R. Wessicken as analyst. For this study, six sillimanite cat's-eyes, all purportedly from Sri Lanka, were acquired. They ranged in size up to 10 ct. The largest cabochon (figure 1) was cut parallel to the base and the lower half sacrificed to thin-section study and the ion etching necessary for subsequent electron diffraction.

This article summarizes the results of the electron microscope study of the inclusions causing the chatoyancy, as well as the gemological characteristics of this unusual material.

EXPERIMENTAL METHODS

Chatoyancy, like asterism, is caused by the scattering of light on numerous fibrous inclusions aligned in one or more directions in the host crystal; proper cutting *en cabochon* is required to reveal the phenomenon. For good chatoyancy or asterism, the elongated inclusions must be thin compared to the wavelengths of light (Weibel, 1985). Such minute crystal individuals are not accessible to ordinary microscopy and X-ray analysis. Even though the inclusions may show up in a thin section viewed with a polarizing microscope, the images that appear are not real, but rather are produced by the scattering of light.

Two electron-microscopic techniques are particularly useful for the identification of ultrafine inclusions in gemstones:

1. A scanning electron microscope (SEM) fitted with an energy-dispersive X-ray microanalyzer

ABOUT THE AUTHORS

Dr. Gübelin, a prominent gemologist and author, is from Meggen, Switzerland; Dr. Weibel is professor of geochemistry at the Swiss Federal Institute of Technology, Zürich, Switzerland, and has just published a new book on gemstones; and Dr. Woensdregt is senior lecturer in crystallography at the Institute of Earth Sciences, State University of Utrecht, the Netherlands.

Figure 1. One of the sillimanite cat's-eyes from Sri Lanka that was studied by the authors. The relatively flat cabochon measures 13 mm and weighs 5.24 ct (although the stone originally weighed 10 ct, the base was cut off for the analyses). Note the bifurcated light band produced by irregularities in the orientation of the fibrous inclusions.

enables the surface of a polished stone to be viewed and a chemical analysis to be made of areas as small as 1 μm.

2. A transmission electron microscope combined with an energy-dispersive X-ray microanalyzer serves as a high-resolution analyzer down to about 300 nm. The transmission electron microscope produces not only an image, but also a diffraction pattern, of the crystal lattice of an ultrafine inclusion. A thin slice of the gemstone must be etched by ion-beam thinning to reduce its thickness to less than 100 nm. Thus, a chip of the gemstone under consideration must be sacrificed for the analysis (Wenk, 1976).

For this study, both these techniques were applied. With the SEM alone (method 1), the oriented inclusions in the sillimanite cat's-eye could not be identified with certainty but required a more extensive investigation drawing on electron diffraction (method 2). The reason is that the matrix around a very small inclusion also tends to be excited by the electron beam, so the spectrogram obtained is a mixture of the compositions of the inclusion and the matrix. The analysis of diffraction patterns makes use of X-ray crystallography, which can distinguish the inclusion from the host. The details of the procedure followed and the intergrowth relations between the host and the inclusion will be published in a forthcoming paper intended for a crystallographic journal.

CHEMISTRY AND STRUCTURE

The largest sillimanite cat's-eye was analyzed for iron with the SEM. Between 0.5 and 0.6 wt.% Fe_2O_3 was found in the matrix. Since the chemical formula for sillimanite is Al_2SiO_5, trivalent iron presumably substitutes for aluminum. Elongated lamellar inclusions are aligned strictly parallel to the c-axis of the sillimanite, which has a very perfect cleavage parallel to the c- and a-axes, that is the crystal plane (010). The cutter of a sillimanite cat's-eye usually chooses the cleavage plane of the stone to coincide with the base of the cabochon, but any orientation of the cabochon base parallel to the c-axis of the sillimanite would produce an optimum light band over the center of the stone.

GEMOLOGICAL PROPERTIES

The common optical properties of these sillimanite cat's-eyes concur very well with those of other sillimanites from Sri Lanka. The determinations were made by standard gemological procedures, and the following properties were found:

Refractive indices: $\alpha = 1.660$, $\beta = 1.662$, $\gamma = 1.680$

Birefringence: + 0.020, 2V = 30°

Pleochroism: α = pale yellow, β = clove-brown, γ = gray-brown

Absorption: very faint shadows at 410, 441, and 462 nm

Density: 3.257 g/cm³ (average of four hydrostatic measurements)

ORIENTED INCLUSIONS

If a thin section of a sillimanite cat's-eye is viewed through an ordinary light microscope, most of the oriented fibers show up as scattering images (figure 2), since they are thinner than the wavelengths of visible light (Weibel, 1985). In a more sophisticated study with the electron microscope, we found two varieties of fibrous inclusions, both of which measure up to a millimeter in length. First, there are relatively thick crystal lamellae (figure 3), which have a rectangular cross-section of 1 to 10 μm and consist of intergrowths of hercynite

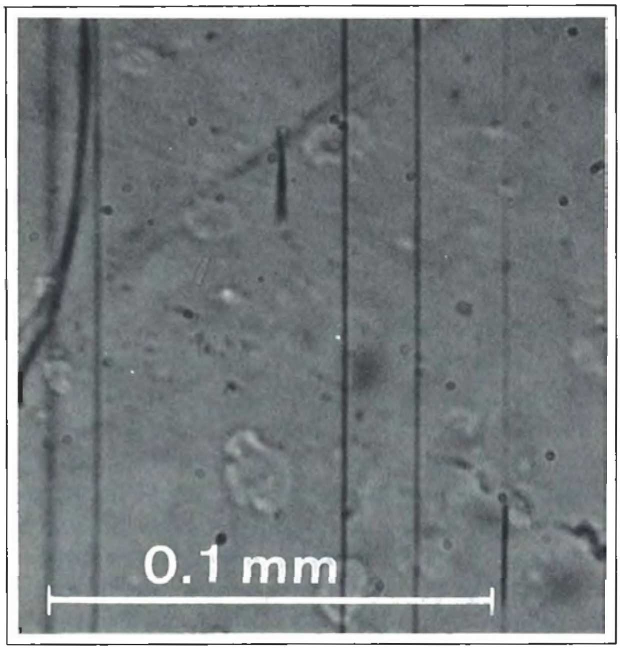

Figure 2. A photomicrograph of an optical thin section of a sillimanite cat's-eye that was cut parallel to the base of the cabochon, approximately parallel to the (010) plane of the crystal. The lamellae are intergrowths of a pyroxene and hercynite spinel. The much thinner ilmenite lamellae are not resolved.

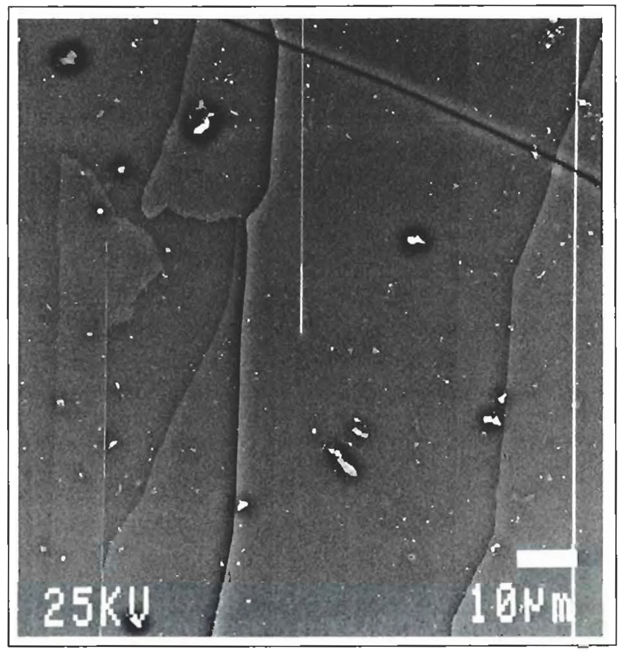

Figure 3. A scanning electron micrograph taken from a cleavage plane of a sillimanite cat's-eye. As in the photomicrograph shown in figure 2, the lamellae seen here are intergrowths of a pyroxene and hercynite spinel. The much thinner ilmenite lamellae are not resolved.

spinel and probably a pyroxene. The spinel was identified by energy-dispersive X-ray microanalysis and electron diffraction, whereas the nature of the pyroxene has not yet been established.

Since these thicker fibers do not occur in all of the sillimanite cat's-eyes included in our investigation, the chatoyancy must be caused by a second type of elongated structure. Electron diffraction showed that a more essential quantity of needles is composed of the mineral ilmenite. The ilmenite occurs as thinner lamellae, 0.05 to 0.5 μm across, with a rectangular cross-section that is probably imposed by the sillimanite structure. It is a most striking fact that in both systems of needles, the elongation contravenes the common crystal habit expected from the crystal structure of the included mineral.

Ilmenite as oriented inclusions is responsible not only for the chatoyancy and blackish appearance of the sillimanite cat's-eyes, but also for the chatoyancy of some rare aquamarine and chrysoberyl cat's-eyes (unpublished analyses of the authors). Most chrysoberyl cat's-eye, however, owes its chatoyancy to oriented rutile silk (unpublished analyses of the authors).

CONCLUSION

The characterization of a cat's-eye mineral requires the exact identification of the inclusions that cause the optical phenomenon. Moreover, the study of cat's-eyes reveals intriguing insights into the intergrowth of mineral phases, some of which appear to develop asymmetrically under strain. Thus, even a cubic crystal may display extreme elongation.

Apart from this, both chatoyancy and asterism (which can be described as double or triple chatoyancy) give a cabochon-cut stone an individual appeal highly appreciated by professional as well as amateur gemologists and gem collectors. An eminent scientific and aesthetic value is inherent in this strange group of rare gems.

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