DIAGNOSTIC FEATURES AND HEAT TREATMENT OF KASHMIR SAPPHIRES

By Rolf Schwieger

The locality origin of natural-color blue sapphires from Kashmir can, in many cases, be positively identified. However, the field of origin determination is a very complex one—especially with the now-common practice of heat treatment. Today, only by combining different gemological tests with years of practical experience, can a conclusive determination of the origin of a sapphire be made. For all practical purposes, examination of inclusions in conjunction with optical spectrophotometry remain the most important tests.

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Among fine blue sapphires, it is generally recognized that those from Kashmir (figure 1) are most highly prized. As a result, in certain segments of the gem market, a major concern is to establish the provenance of any particular blue sapphire.

Recent record-setting prices paid at auction for some of these exceptional stones have further raised public awareness of Kashmir sapphires and reinforced the desire on the part of many gemologists to be able to identify the provenance of such stones. For example, in October 1989, at Sotheby's New York, a Kashmir sapphire and diamond necklace by Van Cleef & Arpels sold for US$3,520,000, at the time a world record for any necklace sold at auction (figure 2). In May of 1990, at Christie's Geneva, another Kashmir sapphire and diamond necklace by Van Cleef & Arpels sold for US$1,100,000.

Because the mine origin of a stone is so rarely documented by reliable witnesses, gemologists have been forced to seek other methods of locality determination. For some time now, research involving highly sophisticated methods and instrumentation has been carried out on Kashmir sapphires (e.g., Hänni, 1990). Most practicing gemologists, however, cannot routinely gain access to a spectrophotometer or a means of chemical analysis such as the scanning electron microscope with energy-dispersive system (SEM-EDS) or energy-dispersive X-ray fluorescence (EDXRF). For them, the microscope remains the most important source of information.

Thus, based on a review of the literature and the author's personal examination of several hundred known Kashmir sapphires, this article will concentrate on inclusions and other microscopic features of Kashmir sapphires that can be helpful in making a locality determination. Other methods of identification are also discussed, especially the potentially critical role of spectrophotometry. The article concludes with the results of experimentation in—and the identification of—heat treatment of sapphires from Kashmir.

Figure 1. Fine Kashmir sapphires are among the most sought-after of gemstones. Yet determination of the locality of origin of any gemstone is difficult, and of Kashmir sapphires is particularly complex. On the basis of a variety of factors, which are the focus of this article, the author and others determined that the large stone in this magnificent sapphire and diamond bracelet by Cartier is from the famous Kashmir mines. At 65 ct, it is one of the largest known faceted Kashmir sapphires in the world. Photo by Michael Oldford.

HISTORY

A landslide that took place around 1881 in a small glacial cirque above the village of Sumjam, on the southwest slopes of the Zanskar range in the Himalaya Mountains, exposed gem-quality blue corundum crystals embedded in altered pegmatites (Atkinson and Kothavala, 1983). In 1884, in his book *Precious Stones and Gems,* Edwin W. Streeter became one of the first to mention the Kashmir mines. He tells the story of how the maharajah of Kashmir heard of the discovery and took immediate possession of the site by sending his own guards to the original mine, situated at a height of 4,500 m (14,800 ft.), near the level of perpetual snow. In the first years of exploitation, some superb sapphires were found there, as well as in placer deposits on the valley floor. In 1904, Bauer (p. 289) reported that "some [of the rough sapphires from Kashmir] are of considerable size, weighing 100 or even 300 carats." More recent finds, however, have been less spectacular; today, most of the stones on the market are small, and only rarely does one see faceted gem-quality stones over 20 ct (figure 3). By 1926, new mines had been opened within 200 m of the original deposit. However, mining operations have always been extremely

Figure 2. This Van Cleef & Arpels necklace of predominantly Kashmir sapphires (ranging from 10.96 to 36.00 ct) and diamonds was auctioned in 1989 by Sotheby's in New York for US$3,520,000. Photo by Michael Oldford; courtesy of Sotheby's.

difficult and limited by the weather to no more than three months per year. Mining has long been complicated, too, by political instability in the area. Two wars have already been fought between India and Pakistan for control of the Kashmir region since the discovery of sapphires there and, as this article is being written, the area is yet again in dispute.

Further information, and a detailed chronology of the Kashmir deposits, can be found in Atkinson and Kothavala (1983). Due largely to the difficult mining conditions, the low yield of gem-quality material, and, recently, the political upheaval in the area, no mining has occurred within the last 10 years. A new mining operation was planned for the summer of 1990, but it was not undertaken because of the political situation.

REVIEW OF DIAGNOSTIC FEATURES

Since blue sapphire shows little variability from locality to locality in its essential physical and optical properties, most of the basic characteristics of Kashmir sapphires are also found in sapphires from other regions. As a result, researchers have been forced to look for subtle distinguishing features for locality determination, a search that has been complicated by the shortage of Kashmir sapphires of reliably documented provenance—a shortage due partly to the relatively brief history of their mining (only slightly over 100 years) and partly to the lack of reliable witnesses who can attest to the origin of any particular stone. Nevertheless, some research work is available for assessment.

Perhaps the most obvious features of the gem-quality Kashmir sapphires are their intense blue color and their turbid, or "velvety," appearance (Streeter, 1884; Smith, 1912; Bauer, 1932; Halford-Watkins, 1935); unlike sapphires from most other localities, the blue color of Kashmir sapphires tends to improve under incandescent light. These features undoubtedly led to the rapid rise of sapphires from Kashmir to their legendary status. However, the variable presence of these characteristics in Kashmir sapphires, as well as their appearance—though rarely—in sapphires from other localities, makes them less than reliable as determinants of locality.

Most of the studies on diagnostic features of Kashmir sapphires have focused on microscopic characteristics (Gübelin, 1948, 1953; Phukan, 1966; Schubnel, 1972; Gübelin, 1973, 1985; Gübelin and Koivula, 1986; Hänni, 1990). Perhaps the most obvious microscopic feature is a sharp, well-defined color zonation that occurs in virtually all Kashmir sapphires (Phukan, 1966; Atkinson and Kothavala, 1983; Gübelin, 1985; Gübelin and Koivula, 1986; Hänni, 1990). In fact, as early as 1904, Bauer noted that even within low-quality and milky gray material, some of the "single crystals often show a difference of color in different portions; thus the center of a crystal may be of fine blue color, and the two ends colorless." Usually, the zonation consists of alternating blue and near-white, or "milky," layers that contribute to the reduced transparency ("velvetiness") of the stones. Although color zonation has been observed in sapphires from other localities (e.g., Pailin and Sri Lanka), the zoning seen in sapphires from Kashmir is usually distinctive. The milky layers are thought to contain microscopic and sub-microscopic particles that may be exsolutions of rutile (see Halford-Watkins, 1935; Gübelin and Koivula, 1986; Hänni, 1990), but these inclusions have not yet been positively identified because they are so small.

Also contributing to the Tyndall effect of light scattering throughout these stones are clouds, lines, and strings of slightly larger but still very fine, dust-like inclusions, probably exsolutions of rutile (Gübelin and Koivula, 1986; Hänni, 1990), but positive identification of these inclusions, too, remains to be made. However, the cumulative Tyndall scattering effect produced by these features can be considered as indicative of Kashmir origin (Gübelin and Koivula, 1986, p. 342). "Flags" or healed fissures are commonly mentioned in connection with Kashmir sapphires (Phukan, 1966; Schubnel, 1972; Gübelin and Koivula, 1986; Hänni, 1990), while twin lamellae have been seen, if rarely (Hänni, 1990).

Solid inclusions that have been reported in Kashmir sapphires include zircon (euhedral, with or without fracture halos, and sometimes described as "corroded"), tourmaline (rarely euhedral), and pargasite (prismatic or as long, fine needles) crystals (Phukan, 1966; Schubnel, 1972; Gübelin and Koivula, 1986; Hänni, 1990). Zircon has also been observed in blue sapphires from other localities, including Australia, Burma, Montana, Sri Lanka, Pailin (Cambodia), and Tanzania (Schubnel, 1972; Gübelin, 1973; Gübelin and Koivula, 1986). However, tourmaline and pargasite are considered diagnostic of Kashmir origin, and have not been seen in blue sapphires from other localities (Schubnel, 1972; Gübelin, 1973; Gübelin and Koivula, 1986; Hänni, 1990).

Strongly corroded colorless crystals have been identified as plagioclase, and in one case a colorless crystal with stress fissures was determined to be allanite (Hänni, 1990). The allanite crystal was identified using energy-dispersive analysis on an SEM, and this type of analysis also led Hänni to identify cubic black crystals as uraninite. However, plagioclase has been observed in sapphires from Pailin and Thailand, and uraninite has been seen in sapphires from Sri Lanka (Gübelin and Koivula, 1986), so their presence cannot be considered diagnostic of Kashmir origin. On the other hand, it appears that allanite, like tourmaline and pargasite, has as yet been seen only in sapphires from Kashmir and can thus be regarded, when present, as proof of locality. Unfortunately, these crystalline inclusions only rarely occur in Kashmir sapphires.

Figure 3. Most of the Kashmir sapphires seen in the gem market today are fairly small, but a few larger stones can still be found. The unusually fine stones in this collection range from 3 to over 30 ct. Photo by Michael Oldford.

Trace-element analysis by nondestructive energy-dispersive X-ray fluorescence (EDXRF) spectrometry (Stern and Hänni, 1982) has also been explored by Karl Vogler with considerable success as a method that contributes to identifying the provenance of sapphires. Graphs that relate the ratios Fe:Cr and Ti:Ga appear to provide the best solution (K. Vogler, pers. comm., 1990). His research indicates that sapphires from Kashmir can be distinguished by EDXRF from those of Pailin (Cambodia), Thailand, Australia, and Nigeria and, in some cases, from those of Burma (now Myanmar). Sri Lankan sapphires are more difficult to separate, as they have iron and chromium contents similar to those of Kashmirs, although gallium can occasionally be a useful indicator. However, further research is needed before conclusions can be drawn about the reliability of this method for these important distinctions.

Optical spectrophotometry has been used primarily to study the causes of color in blue sapphires (Schmetzer and Bank, 1981), but, as with rubies (Bosshart, 1982; Schmetzer, 1985), it has also been suggested that this method can provide means to determine the locality origin for Kashmir sapphires (Hänni, 1990).

MATERIALS AND METHODS

Over a 10-year period, the author has had the opportunity to examine more than 500 gem-quality sapphires reportedly from Kashmir (i.e., with at least one certificate of origin from a major gem laboratory*), from which a file of over 3,000 photomicrographs was developed. In addition, during a visit to Kashmir in September 1989, the author obtained six non-gem-quality Kashmir sapphire crystals (figure 4) from the old stock of Jammu & Kashmir Minerals (the state-owned company that controls the Kashmir mines). Similar non-gem-quality Kashmir sapphire rough from old stocks of other Indian dealers was also examined for this study.

Photomicrography was performed with a Leitz Orthoplan mineralogic microscope, using oblique illumination as provided by a powerful (200-watt) Schott fiber-optic light. Optical spectra were ob-

**Editor's Note: Although GIA recognizes the value of studies to determine locality of origin of a gem material, the GIA Gem Trade Laboratory, Inc., has a long-standing policy of not indicating locality of origin on any identification report it issues.*

Figure 4. These six non-gem-quality samples, two of which were obtained by the author in Kashmir from the old stock of Jammu & Kashmir Minerals, were among the faceted and rough samples examined for this study. They range from 2 to 6 ct. Photo by Michael Oldford.

Figure 5. Most of the specimens examined showed the sharp blue and milky or whitish zoning that appears to be characteristic of sapphires from Kashmir. Photomicrograph © Rolf Schwieger; magnified 25×.

tained with a Beckman DU-70 spectrophotometer and a microbeam condenser. Where possible, chemical analyses of inclusions were performed on a scanning electron microscope with an energy-dispersive system (Philips SEM 515 with a Tracor EDS). Heat treatment was performed in Bangkok on a 29-ct faceted commercial-quality specimen.

OBSERVATIONS

Microscopic Features. The characteristic sharp-bordered blue (sometimes with colorless layers) and whitish (milky) color zoning of Kashmir sapphires was readily apparent in most of the specimens examined for this study (figure 5). This zoning was present in almost all of the stones, but in some cases it was difficult to see. In some of the stones, even at relatively low (40×) magnification,

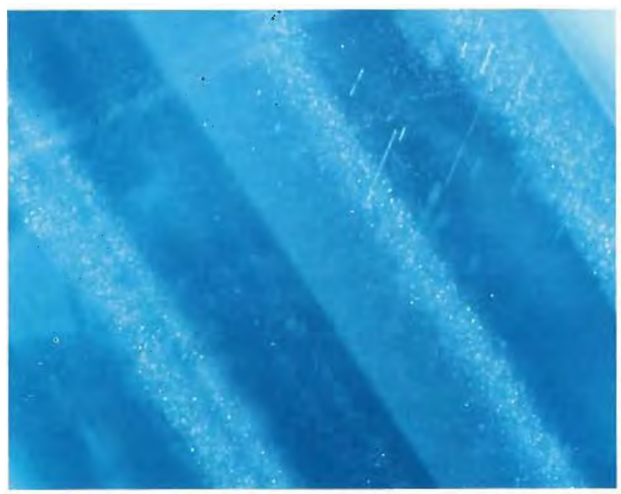


Figure 6. Even at 40× magnification, with the strong illumination provided by a powerful fiber-optic light source, the tiny particles that contribute to the haziness of the milky layers can be seen in some Kashmir sapphires. Photomicrograph © Rolf Schwieger.

extremely fine features could be seen in the milky layers (figure 6).

Using a strong fiber-optic light source in conjunction with magnification, the author also observed the clouds and lines of somewhat larger but still very fine, dust-like inclusions (figure 7) that are commonly present in Kashmir sapphires and also contribute to the "velvety" appearance of reduced transparency. These inclusions often resemble snowflakes (figure 8). Sometimes they take the form of fine, short needles (figure 9). As stated

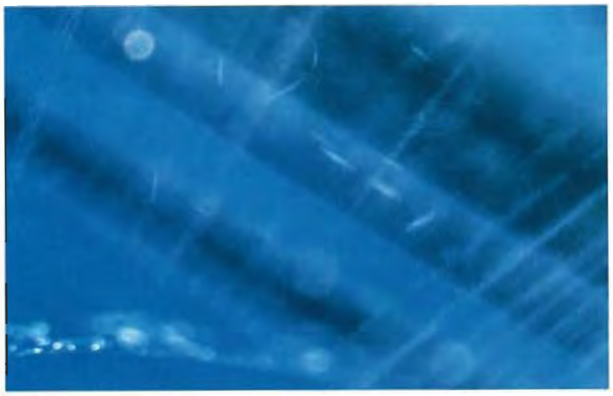


Figure 7. Clouds and lines of fine, dust-like inclusions (exsolutions of rutile?) were commonly present throughout the Kashmir sapphires examined. Photomicrograph © Rolf Schwieger; magnified 40×.

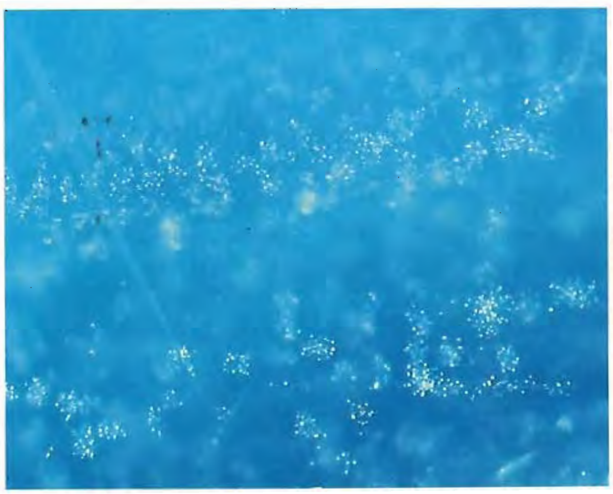


Figure 8. The clusters of dust-like inclusions often resemble snowflakes. This type of formation has not been seen in sapphires from other localities. Photomicrograph © Rolf Schwieger; magnified 40×.

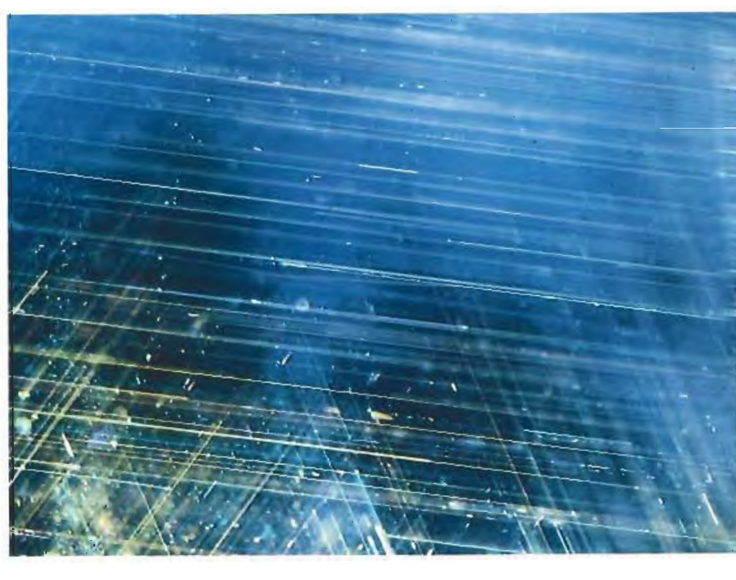
earlier, the exact nature of these inclusions (like those in the milky layers) has not yet been determined. However, their orientation — intersecting at 60° angles and aligned with the hexagonal symmetry of the host corundum (again, see figure 9) — strongly suggests that they are exsolutions of rutile. The "snowflake" formations have not been seen in sapphire from other localities.

The form and distribution of these particles suggests a geologic growth condition for Kashmir sapphires in which the variations in pressure and

Figure 9. In some instances, the dust-like particles appear to be fine, short needles. They intersect at 60° angles and are aligned with the hexagonal symmetry of the sapphire. This orientation suggests that they are probably exsolutions of rutile. Photomicrograph © Rolf Schwieger; magnified 25×.

temperature did not allow complete formation of typical rutile needles, such as those commonly found in Sri Lankan and Burmese sapphires (figure 10; K. Vogler, pers. comm., 1990; H. Hänni, pers. comm., 1990).

Figure 10. The appearance of the dust-like inclusions observed in Kashmir sapphires is very different from the well-formed rutile needles commonly seen in unheated sapphires from Sri Lanka (as shown here) and Burma. Photomicrograph © Rolf Schwieger; magnified 25×.



Although crystal inclusions in Kashmir sapphires appear to be rare when normal magnification is used, high magnification (50× or more) revealed mineral inclusions in about 60%–70% of the specimens examined. In as many as half of these instances, magnification of 100× or more was required to determine the morphology of the inclusions. Positive mineralogic identification of such inclusions usually depends on their exposure at the polished surface of a cut gem. However, since these stones are too valuable to be sacrificed to scientific investigation, this could not be done in most instances. Further research using a Raman laserprobe, which allows analysis of subsurface inclusions (Fritsch and Rossman, 1990), is needed. Schubnel (1977) was the first to identify (by SEM-EDS) pargasite as an inclusion in Kashmir sapphire, and his findings have since been confirmed by Hänni (1990) and this study (also using SEM-EDS). These needle-like inclusions (figure 11) sometimes cut across an entire stone, and were seen in about 10% of the specimens.

About 5% of the study stones were found to contain long, prismatic, colorless crystals such as those shown in figure 12. Although they could not be conclusively identified by the methods available, their morphology suggests that they are also pargasite. In the author's experience, this type of inclusion has not been seen in sapphires from other localities.

Tourmaline as an associated mineral of Kashmir sapphires has been described by several researchers (e.g., Bauer, 1904; Smith, 1912; Halford-Watkins, 1935; Brown, 1956; Atkinson and Kothavala, 1983; Gübelin and Koivula, 1986; Hänni,

Figure 11. Long, thin, needle-like crystals of pargasite were observed in about 10% of the stones examined for this study. Pargasite has not been reported in sapphires from other localities. Photomicrograph © Rolf Schwieger; magnified 40×.

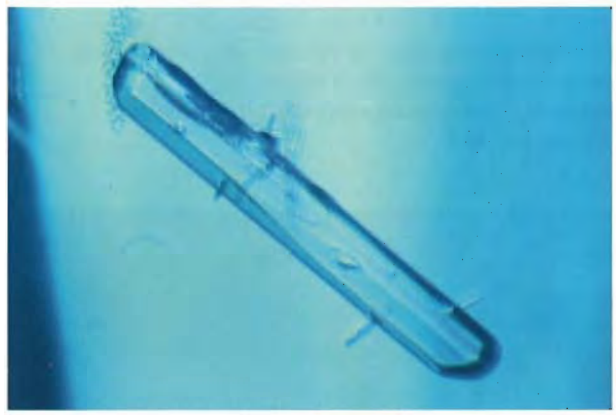


Figure 12. This type of long, prismatic, colorless crystal was also observed in a number of the sample Kashmir sapphires. While these crystals could not be identified with available methods, their morphology suggests that they, too, are pargasite. Photomicrograph © Rolf Schwieger; magnified 100×.

Figure 13. Although tourmaline commonly occurs in association with sapphires from Kashmir, it was only rarely observed as an inclusion in the sample stones (as shown here). However, tourmaline has not been reported in sapphires from other localities. Photomicrograph © Rolf Schwieger; magnified 40×.

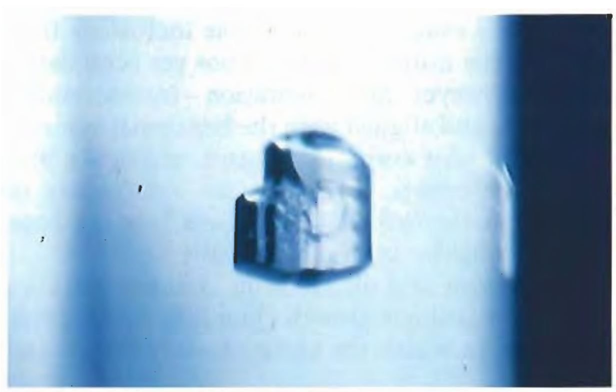


Figure 14. The Kashmir samples examined commonly contained small, slightly corroded crystals with indentations that match earlier descriptions of zircon. The smaller, black, cube-like crystals shown here on a zircon-like crystal in a Kashmir sapphire appear to be uraninite. Photomicrograph © Rolf Schwieger; magnified 200×.

Figure 15. More than half of the Kashmir sapphires studied were found to contain strongly corroded crystals of what appear to be plagioclase. Photomicrograph © Rolf Schwieger; magnified 63×.

1990), and can be found quite often as brown, greenish brown, or green crystals attached to Kashmir sapphire rough. Nevertheless, tourmaline is an infrequent inclusion in Kashmir sapphires (observed in only 5% of the study samples) and is rarely euhedral when it does occur (figure 13).

Commonly observed in the Kashmir samples examined were slightly corroded small crystals with indentations (figure 14) that match previous descriptions for zircon. Although, as noted above, zircon has been seen in sapphires from other localities, this particular form seems to be indicative of Kashmir sapphires.

Strongly corroded colorless crystals (figure 15) were, like zircon, observed in approximately 50% of the sample stones; these were similar to those identified by Hänni as plagioclase. In this form, they also appear to be indicative of Kashmir sapphire. Even more common (seen in 60% of the test samples) were cubes of opaque black prismatic crystals with tails (figure 16) or tension halos that match the reports of Phukan (1966); Hänni identified similar crystals as uraninite (see also figure 14). Allanite was seen in only 1%–2% of the samples in this study (figure 17).

Figure 16. Very common in the samples studied were cubes of opaque black crystals, often with tails (as here) or tension halos, that have been identified as uraninite. Photomicrograph © Rolf Schwieger; magnified 200×.

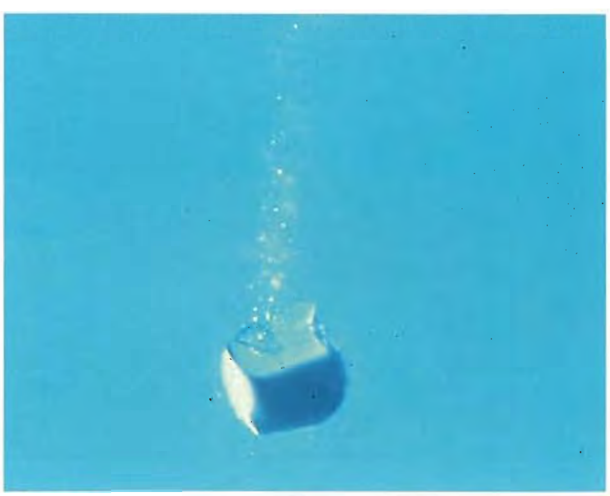


Figure 17. This group of euhedral crystals observed in a very few of the Kashmir sapphires studied matches the description given for allanite, which has not been identified in sapphires from other localities. Photomicrograph © Rolf Schwieger; magnified 40×.

Figure 18. Fingerprint-like secondary healing planes were common in the Kashmir stones examined, but have also been found in sapphires from other localities. Photomicrograph © Rolf Schwieger; magnified 40×.

"Feathers," or fingerprint-like secondary healing planes (figure 18), were also common in the Kashmir samples examined. Similar inclusions are found in sapphires from a variety of localities (see, e.g., Gübelin and Koivula, 1986).

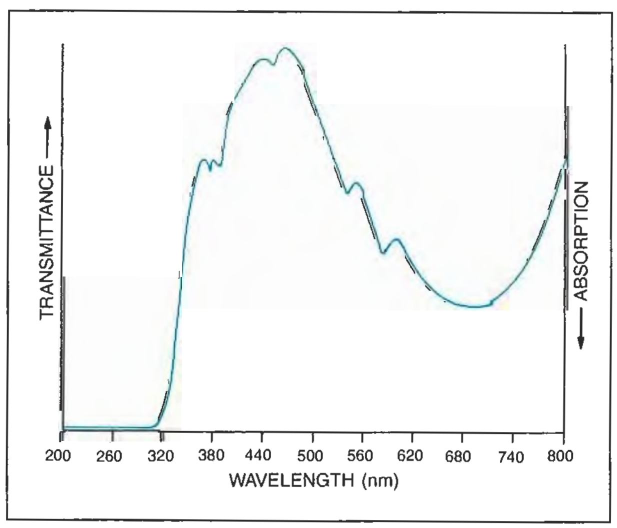
On the basis of this study and of prior reports in the literature, the following inclusions appear to be characteristic of, and most useful for origin determination of, Kashmir sapphires:

1. Color zoning as described
2. Clouds or lines of "snowflake" formations composed of dust-like particles, probably exsolutions of rutile
3. Pargasite
4. Tourmaline
5. Allanite
6. Zircons with indentations
7. Strongly corroded plagioclase

Although the color zoning may be confused with that seen in sapphires from Pailin and some heat-treated Sri Lankan sapphires, the four types of inclusions that follow on this list (in particular, the dust-like particles in a "snowflake" formation) have not been seen in sapphires from any other locality by this author or by others, as reported in the literature. The last two are, in these particular forms, at least indicative of Kashmir origin (euhedral plagioclase has been observed in sapphires from Pailin and Australia [Schubnel, 1977; Gübelin and Koivula, 1986]). At least one of these features was seen in each of the six pieces of sapphire rough obtained by the author in Kashmir. However, because of the possibility of overlap with other localities and the absence of diagnostic mineral inclusions in some stones, it is usually the combination of inclusions with optical spectra that allows the safest determination of Kashmir origin.

Spectrophotometry. From among the Kashmir sapphires studied, as well as from sapphires known to come from Cambodia (Pailin), Thailand, Vietnam, Nigeria, Australia, Burma, Sri Lanka, Montana, Brazil, and China, more than 400 optical spectra were obtained in the range 200 to 800 nm. With regard to unheated sapphires, clear differences can be noted between those of basaltic origins (Pailin, Thailand, Vietnam, Nigeria, Australia, Brazil, and China) and those of nonbasaltic origins (Kashmir, Burma, Sri Lanka, and Montana). The absorption maximum of nonbasaltic sapphires in the range of 550–800 nm is generally centered at 580 nm for the ordinary ray (o) and at 690 nm for the extraordin-

Figure 19. In most instances, the spectra of unheated Kashmir sapphires (here, the 29-ct stone that was later used in the heat-treatment experiment) appear to be distinctly different from those of their unheated counterparts from other localities. Spectral analyses of the rough sapphires obtained in Kashmir showed the same key features as this faceted stone. Transmittance spectrum, extraordinary ray.



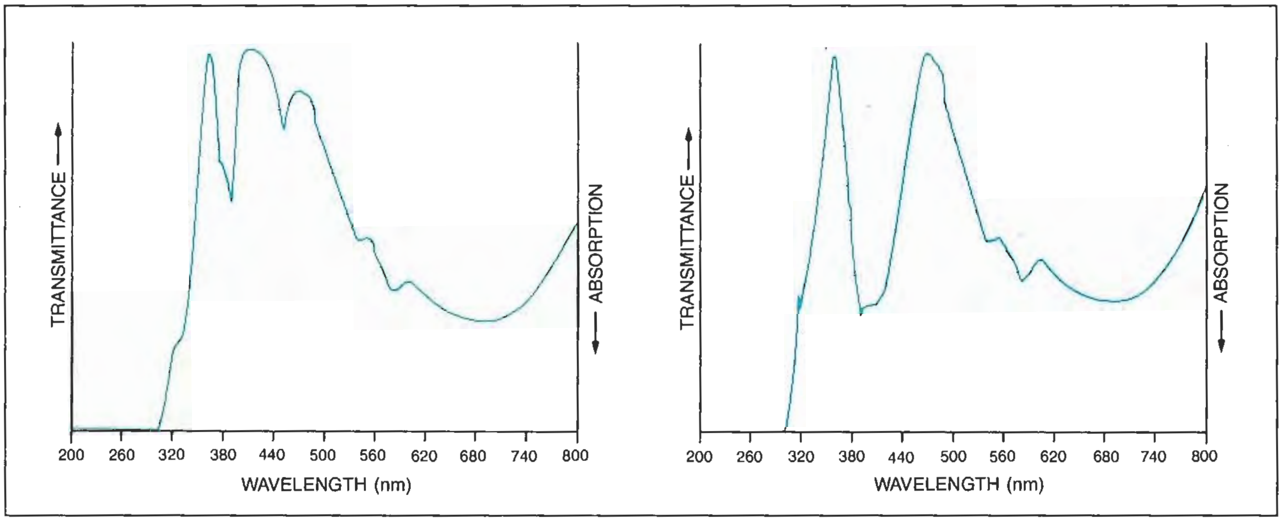


Figure 20. The spectrum shown in figure 19 for an unheated Kashmir stone is very different from those shown here for an unheated Burma sapphire (left) and Sri Lanka sapphire (right). Transmittance spectra, extraordinary ray.

ary ray (e) — caused by Fe^{2+}/Ti^{4+} pairs. In contrast, the presence of Fe^{2+}/Fe^{3+} pairs in sapphires of basaltic origin centers the absorption maximum at 800 nm.

The strength of the 450-nm system (374, 388, 450 nm) depends on the concentration of Fe^{3+}. The 450 absorption in a Kashmir sapphire is usually weak and the relative strengths of the absorption maxima at 374 and 388 are distinctive compared to those of Sri Lankan or Burmese origin. Moreover, the spectra of Kashmir sapphires (figure 19) usually reveal other features that are notably different from those of sapphires from Burma and Sri Lanka (figure 20). The absorption edge for Kashmir sapphires lies at approximately 320–340 nm, while unheated Burma and Sri Lanka sapphires usually show a "lump" at 328 nm, passing into the general absorption at about 300 nm. The absorption spectrum for a heated sapphire from any of these localities (see, e.g., figure 21) is distinctly different from that of an unheated Kashmir sapphire. This is especially important in view of the fact that some *heated* Sri Lankan sapphires superficially look like *unheated* Kashmir sapphires.

In some cases, differences are more subtle, and it is recommended that interpretation be made by an experienced specialist with files of standard comparison spectra. It is also the opinion of the author that the use of mathematically obtained parameters (Schmetzer, 1985, 1986) is not always reliable. In more than 95% of unheated Kashmir sapphires (when tested by an experienced spectroscopist), the spectra will be reliable indicators of origin. Nevertheless, in general, spectra should be used in conjunction with microscopic examination to determine conclusively the origin of a sapphire.

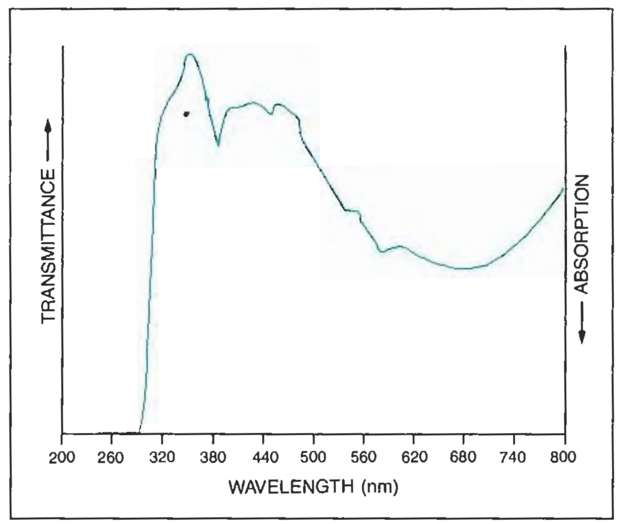


Figure 21. The author's research found that the spectrum of a heat-treated sapphire from any of the major localities (here, that of a sapphire from Sri Lanka) is significantly different from that of an unheated Kashmir sapphire. Transmittance spectrum, extraordinary ray.

HEAT TREATMENT OF KASHMIR SAPPHIRES

Heat treatment is one of the major concerns of the colored stone market, and its determination is often a serious technical problem. Although noth-

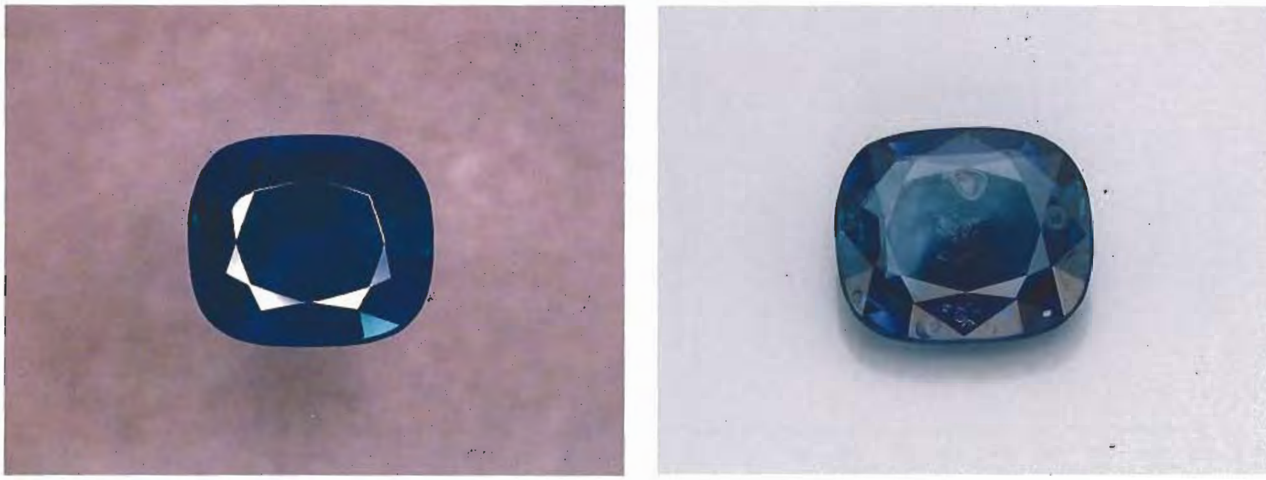


Figure 22. Before heat treatment (left), the 29-ct Kashmir sapphire was predominantly dark blue with various degrees of transparency. After treatment (right), the stone showed better transparency but also large colorless areas. Note as well the partial melting of the surface on this heat-treated stone. Photos by SSEF (left) and Michael Oldford (right).

ing has been previously reported in the literature about heat treatment of sapphires from Kashmir, it seems that, given the rarity of Kashmir stones and the unavailability of fine new material from this source, the heat treatment of existing stocks of lesser quality material is a very real probability.

The 29-ct faceted stone (with SSEF, Gübelin, and AGL certificates that state that the sapphire is of Kashmir origin) submitted for heat treatment was originally of zoned blue color ranging from mostly very dark blue to areas of light blue and with various degrees of transparency (figure 22, left). It was placed in an alumina crucible and subjected to heat treatment, with an increase in temperature of 5°C per minute until 1700°C was reached and maintained for five hours. The specimen was not coated prior to heating. The resulting stone was zoned a somewhat lighter blue with large colorless areas, and there was a general improvement in transparency (figure 22, right); partial melting of the surface was readily apparent. Repolishing, of course, would remove the telltale surface features, with a loss of no more than 3%–4% of its original weight. To remove the colorless areas, however, would require a weight loss of as much as 40%. In general, heat treatment of this stone did not result in overall improvement in appearance.

Microscopy revealed that heat treatment did produce some changes in the internal features of the stone. Color zoning was still visible, as were some of the "snowflake" formations of dust-like particles. It appears, however, that some of these dust-like inclusions were dissolved during the treatment process; we do not know whether treatment at higher temperatures and/or for a longer time would not have changed these inclusions even more. Some of the crystal inclusions were altered significantly (figure 23), which not only provided clear evidence of heat treatment but also limited their usefulness as indicators of locality origin. On the basis of this one sample, I would speculate that microscopic features (especially crystal inclusions) are usually less origin diagnostic in a heat-treated stone than in one that has not been so treated.

The spectrum of the sapphire also exhibited marked differences in absorption before (again, see figure 19) and after (figure 24) treatment, especially in the region of 360 nm. The relative strengths of absorption maxima at 374 and 388 nm (part of the 450 system) changed markedly. A shift of the absorption edge – with a weak "shoulder" at 328 nm – to a shorter wavelength below 300 nm was also apparent. Note, too, that the spectrum of the Kashmir sapphire after treatment is almost identical to that of a heat-treated Sri Lankan sapphire (again, see figure 21). Thus, spectral analysis is not useful in separating heated Kashmir sapphires from heated sapphires from Sri Lanka, which have the greatest commercial importance among treated sapphires. The fact that as many as 95% of all sapphires currently on the market may have been heat treated (see, e.g., Kammerling et al., 1990) makes this test all the more meaningful for determining not only the locality origin of, but also the absence of heat treatment in, a Kashmir sapphire.

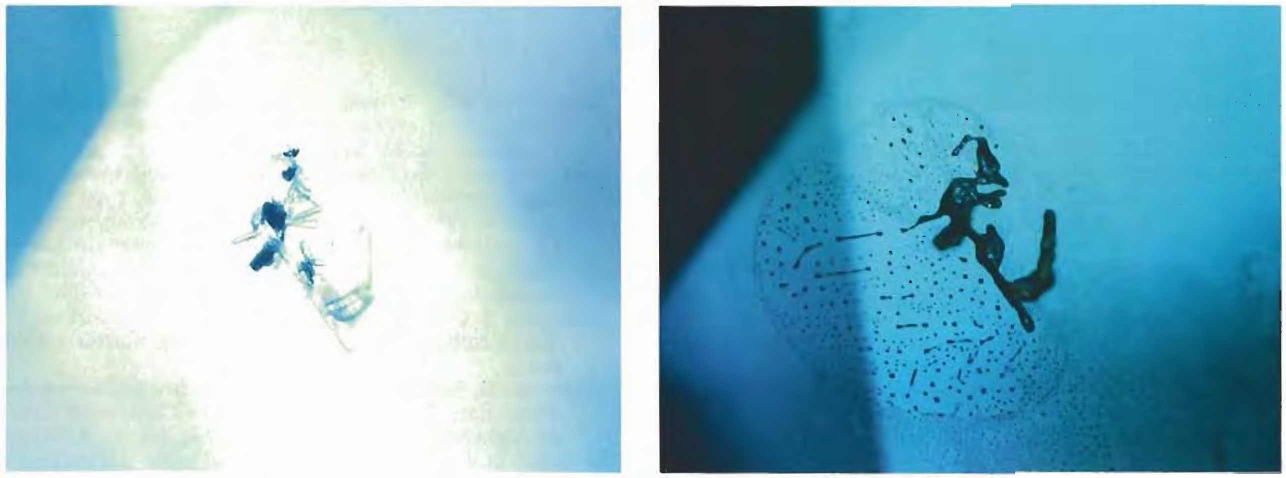


Figure 23. Heat treatment significantly altered the appearance of this group of crystals (zircon and uraninite?). They are shown here before (left) and after (right) the stone was treated. Photomicrographs © Rolf Schwieger; magnified 40×.

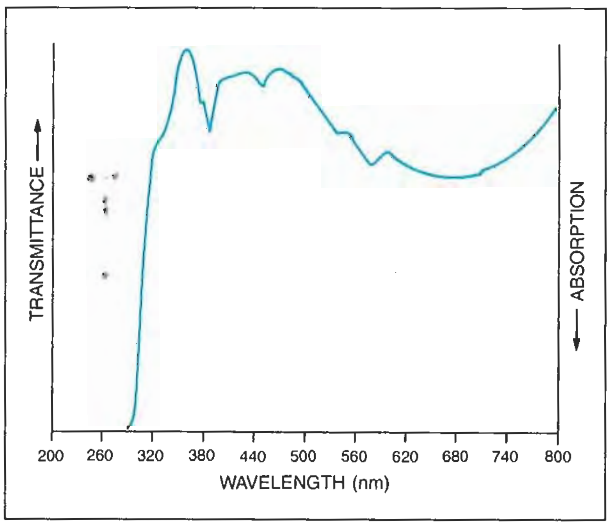


Figure 24. The spectrum of this 29-ct heat-treated Kashmir sapphire is significantly different from that of the unheated stone (see figure 19) and almost identical to those of heat-treated Sri Lankan sapphires (see, e.g., figure 21). Transmittance spectrum, extraordinary ray.

CONCLUSION

The locality origin of natural blue sapphires from Kashmir can, in many cases, be positively identified through a combination of microscopic examination and optical spectrophotometry. The characteristic features that can be seen with a microscope (using strong fiber-optic illumination) are: (1) distinctive color zoning; (2) clouds and/or lines of dust-like particles in a "snowflake" formation; (3) pargasite crystals; (4) tourmaline crystals; (5) allanite crystals; (6) zircon crystals with indentations; and (7) strongly corroded plagioclase crystals. The crystalline inclusions are relatively rare, but the first two features are quite common. Color zoning similar to that seen in Kashmir sapphires has been observed in some sapphires from Pailin and some heat-treated sapphires from Sri Lanka. While dust-like particles have been seen in sapphires from other localities, they have not been observed to occur in the "snowflake" formations that are exclusive to Kashmir stones.

Optical spectrophotometry not only differentiates basaltic from nonbasaltic sapphires, but it also provides the means to distinguish among sapphires from different nonbasaltic localities, when studied by an experienced analyst equipped with comparison spectra. This is especially useful to distinguish natural-color Kashmir stones from similar-appearing treated-color Sri Lankan sapphires.

It is likely that some Kashmir sapphires have been subjected to heat treatment. It appears, however, that the damage to crystalline inclusions and the marked differences in optical spectra caused by exposure to high temperature make it extremely difficult to establish conclusively the locality origin of a heat-treated Kashmir sapphire.

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