A contribution to the distinguishing characteristics of sapphire from Kashmir

Dr H. A. Hänni, FGA

Mineralogical Institute, University of Basel, Switzerland

Abstract

This investigation was undertaken to contribute to the knowledge of sapphire from Kashmir, and over 50 cut stones were studied. Comparison of the observed inclusions with those described in other publications, identified in part using the scanning electron microscope SEM/EDS, confirmed the results of earlier findings (tourmaline, pargasite and zircon inclusions). In addition, some internal characteristics are newly described: plagioclase, uraninite, allanite and rutile (?) occurring in various forms, healed fissures and zoned growth. Spectral properties are presented. The significance of origin reports is discussed.

Introduction

Sapphire, the blue variety of corundum, is produced from numerous deposits distributed worldwide. The term **Kashmir Sapphire** is used to denote the origin of a stone from a specific location, and should not be regarded as a term describing either quality or colour. Some of the earlier worked deposits are no longer in production, their supply being either exhausted or no longer economically viable. This would also seem to be the case of the sapphire deposits of Kashmir.

Sapphire deposits can be classified into a number of types, on the basis of their genesis or geological setting (Deer *et al.*, 1980; Kiefert, 1987). Basaltic occurrences of the mineral (e.g. in Australia, Malawi, Thailand, Cambodia, etc.), often producing too dark, greenish-blue stones, do not host the most coveted blue corundum. Sapphires from pegmatitic dykes and metamorphic deposits are often too light or exhibit mixed colours, and are not generally considered to be of particular value (Montana, Tanzania, Sri Lanka). Nevertheless, the production of rough material with excellent colour from the latter type of deposits is considerable. These sapphires may attain top class quality after cutting (such as some from Burma, Sri Lanka, Kashmir).

Historical review

According to a number of authors (Mallet, 1882; La Touche, 1890), sapphire was discovered in 1881 at Soomjam in the district of Padar (Jammu and Kashmir Province) in India. The deposits, which occur at an altitude of about 4400m, were intermittently mined at several localities (Old Mine, New Mine, Valley). The production included some large crystals and a large quantity of medium-sized and smaller crystals. The colour and transparency of the stones varied considerably (Middlemiss, 1931; Roy, 1949), and mining figures for some years clearly show that the operation was often unprofitable. Due to the low yield and often inferior quality of the sapphire, mining was frequently interrupted and management changed on many occasions. A recent article describing all aspects of the deposit can be found in Atkinson and Kothavala, 1985. In his book on corundum, Hughes (in press) also presents a comprehensive list of literature on sapphire from Kashmir.

Origin of study material

The following study was carried out on cut sapphires submitted to the Swiss Foundation for the Research of Gemstones (SSEF) Laboratory in Zürich (Figure 1). Rough corundum of gem quality from Soomjam was not available to the author, and such material is at present not being mined. Study of inferior grade material (of which much is available), is of limited significance when information on transparent gem quality is required. The author received cloudy material together with host rock from Soomjam from two independent and reliable sources. The samples from both sources appeared identical and corresponded with information given in the original literature (Mallet, 1882; La Touche, 1890; Bauer, 1896). Corundum, which occurs in lenses and pockets, is hosted by a rock often described as kaolin. A sample of this fine-grained 'plumasitic' rock was examined and contains feldspar, sheet silicates and also black tourmaline, as described by La Touche (1890). The sample material studied was supplemented by a transparent sapphire crystal provided by a museum.

Earlier descriptions and photomicrographs of diagnostic inclusions (Phukan, 1966; Schubnel, 1972; Gübelin and Koivula, 1986) are scarce, but

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individual characteristics have been identically described. In the sapphires studied here, new inclusions were identified in addition to the classical diagnostic Kashmir inclusions (pargasite, tourmaline, milky lines with short traverse streaks, see Gübelin and Koivula, 1986). As far as possible, these new inclusions were mineralogically identified by Scanning Electron Microscope with Energy Dispersive System (SEM/EDS).

Absorption spectra exhibit a characteristic course, different from other sapphire curves. Thus, a second diagnostic criterion in addition to the inclusions is available for origin determination. Spectral behaviour, inclusion paragenesis and trace element content has been discussed with colleagues experienced in sapphire identification.

The new internal characteristics revealed in this paper have been used for the determination of origin, as they have consistently been shown to be typical of sapphire from Kashmir. The presence of all mineral inclusions identified so far in Kashmir sapphire can be satisfactorily explained by the geological setting at Soomjam. This paper reveals and discusses the additional characteristics.

The determination of origin by characteristics typical of the locality must be carried out in comparison with the properties of all other occurrences of sapphire. Some properties may be characteristic but not diagnostic for a definite population, since they are also found in stones from other localities. Thus, a fundamentally safe assignment of each stone to a specific locality does not always exist. Further discussion of the certainty of determining origin is presented in Hänni, 1988[a].

Habit and colour of Kashmir sapphire

The crystals normally display a simple pyramidal form with small basal planes (Goldschmidt, 1918). They are either totally or partially transparent, and the frosted to coarse surfaces are covered with a white crust (Bauer, 1896; Middlemiss, 1931), see Figure 2. The small, semi-translucent crystals of a grey colour and with a coarse surface are often still encountered as rough stone material today. They appear to have been found in large amounts and are suitable to a degree for heat treatment ('Kashmir-Geuda', Figure 2). Grey crystals of this kind have been described by Middlemiss (1931).

A particularly marked characteristic of much Kashmir sapphire is the velvety blue colour, due to slightly reduced transparency of the stones. It is the result of a cumulation of effets:

- turbidity due to microscopic and submicroscopic features of an unknown nature (Tyndall Effect on segregations of rutile (?) dust particles). Figure 3.
- scattering of light on microscopically small flat inclusions of an unknown nature (films of rutile or fluid inclusions?), which are distributed both homogeneously and oriented in rows throughout the stone. (Figure 4).
- zonal growth as sequences of transparent (blue or colourless) and turbid white lamellae with sharp borders (Figure 5).
- lamellar or block-like textures of different crystallographic planes with slightly varying refractive indices which tend to disturb the light path.

Absorption spectra

The blue colour of Kashmir sapphire can be explained by iron and titanium contents (Schmetzer and Bank, 1981). The absorption spectra exhibit the characteristic maxima caused by Fe^{2+}/Ti^{4+} pairs, and Fe^{3+}. Occasionally, light red portions occur in larger, bi-coloured crystals or as light pink crystals. Likewise, the occurrence of light rubies has been noted (Middlemiss, 1931). In fact, small quantities of chromium have been occasionally observed in Kashmir sapphire, identifiable by the emission line at 693nm in the absorption spectrum or by energy-dispersive X-ray fluorescence spectroscopy (Stern and Hänni, 1982). The blue colour of sapphire is the result of the relative absorption of all colours but blue (transmission from ca. 420-470nm). The spectral part from red, yellow and green is absorbed by a broad band centred at 580nm for the ordinary ray (*o*) and at 690nm for this extraordinary (*e*) ray. Fe^{2+}/Ti^{4+} pairs are responsible for this absorption behaviour. Absorption in the UV and VIS is also caused by Fe^{3+} eventually present, with absorption maxima at 374, 388 and 450nm. The presence of Fe^{2+}/Fe^{3+} pairs, mainly in green and greenish sapphire, results in an absorption maximum at 700 (*e* vibration) and 600nm (*o* vibration) affecting the colour. Even small amounts of Cr^{3+} in sapphire lead to an absorption at 600nm and the fluorescence line at 693nm. More information can be found in Bosshart (1981) and Schmetzer and Bank (1981).

The intensities of the absorption lines of Kashmir sapphire at 374, 388 and 450nm are similar to those for sapphire from Sri Lanka (weak) and weaker than those for sapphire from Burma (fairly strong). The maximum transmissions for the *e* vibration lie characteristically at 350, 420 and 470nm. The absorption curve edge starts to rise at below 370nm, usually passing into the general absorption at 320-330nm. A low Cr^{3+}-content results in a small band at 410nm (*e* vibration). Thus, the most important portion of the absorption curves of sapphire for determination of origin lies between 500 and 280nm.

Fig. 1. Three cut Kashmir sapphires (6-14ct) showing different degrees of transparency and colour saturation.

Fig. 2. Corundum crystal of low quality from Soomjam, and a slice of parent rock containing black tourmaline. The milky crystals are used for heat-treatment (so-called 'Kashmir Geuda'), blue pieces at right after treatment. Width of photo ca. 10cm.

Inclusions described in literature

Descriptions and illustrations of internal characteristics in sapphire from Kashmir are relatively rare compared to those from other deposits. On the basis of optical study, Phukan (1966) described the following characteristic features:–

P1 – oriented rutile needles, partly decomposed
P2 – fine dust, scattered between rutile needles or concentrated in cloudy patches of extremely fine particles
P3 – zircon, with or without 'winged' fracture haloes
P4 – opaque black prismatic crystals, surrounded by liquid feathers
P5 – liquid feathers, partly with tiny drops arranged in rows
P6 – healing feathers with grid-like patterns
P7 – flat liquid films or fluid-filled cavities

Schubnel (1972) considered the characteristic inclusions (the first two of which were identified using the electron microprobe) to consist of:–

S1 – tourmaline, greenish and possessing irregular forms
S2 – pargasite, fine light green needles up to 6mm in length
S3 – partly corroded colourless crystals (his Figure 26b, p.166)
S4 – flat fluid films.

According to Gübelin and Koivula (1986), the following inclusions are typical of Kashmir sapphire:–

G1 – zoned texture and cloudy haziness
G2 – randomly-scattered brush-stroke-like inclusions and nebulous clouds
G3 – wispy pennant-like inclusions attached to strings
G4 – corroded (profiled) zircon crystals
G5 – pargasitic hornblende
G6 – tourmaline
G7 – 'flags' of sealed fluid remnants.

Confirmation of known and new inclusion types

Modern gem microscopy profits over the old monocular microscopy through the availability of improved illumination and binocular observation. Only the use of powerful oblique illumination (e.g. by fibre optics) against a dark background will reveal certain types of inclusions, for example cloudiness, fine dust tracks and very fine rutile needles. In the past, such features could not be recognized, and thus cannot be expected to be reported in earlier literature.

After observation of an inclusion, the next step is its identification. A definite identification requires knowledge of its chemical composition and its crystal structure. One is usually restricted in the possibilities of analysing inclusions in gemstones (as either they do not reach the surface, or they are fluids, or because the crystals are corroded, not idiomorphic, etc.). In addition, there is also the pressure of time when analysing very precious gems. In this paper, the following abbreviations are used to indicate the method of identification:

LM Optical light microscopy
SEM Scanning electron microscopy with energy-dispersive system
EMP Electron microprobe analysis
XRD X-ray diffraction analysis

Structural features

The methods recommended by Schmetzer (1986) for the optical measurement of crystallographic growth and colour zoning were used by Kiefert (1987) for the study of zoning in sapphire. Due to the lack of suitable material, they could not be applied in the case of the Kashmir sapphire. The evaluation of crystallographic features on a large number of Kashmir sapphires supplied valuable evidence for the determination of origin (Peretti, Schmetzer, 1989). Narrow twin lamellae parallel to the rhombohedron face rarely occur in Kashmir sapphire (Figure 7).

Healed fissures

They presumably originated during various phases of crystallization of the corundum. The patterns of these original fissure planes can be very diverse and in varying stages of healing (see Roedder in Gübelin and Koivula, 1986, p.84). Feathers and veils consisting of minute cavities and negative crystals can exhibit various forms, although they are formed of a mainly simple, lobular fissure plane. Occasionally, this can be bent or folded, but seldom overlapping. Depending on the stage of healing of the original fissure, the veils can exhibit various patterns (Figures 8-12):–

- covered with isometric voids to short tubes, graded in size from outside to inside, occasionally in a sort of fishbone pattern (Figure 8): of type P5.
- covered with connecting canals, but also with extensively dissolved networks (Figure 9).
- containing flat cavities or negative crystals, which often possess trigonal step patterns and sometimes black, opaque platelets (graphite ?) as partial fillings. (Figure 10).
- flat negative crystals with minute satellites, presumably formed by bursting of the main cavity and healing of the fissure plane (Figure 11).
- very incompletely healed fissures with a frost pattern (Figure 12).

The small cavities, flat negative crystals or interlinked canals are suspected of containing fluid inclusions.

Fig. 3. Turbidity induced by dust particles (rutile?) occurring in zonal lamellae and as fine dust tracks or traces. 30X.

Fig. 4. Flaky inclusions of an unknown nature lying in one or several parallel planes. 50X.

Fig. 5. Sequence of transparent and milky bands originating from zoned growth. 10X.

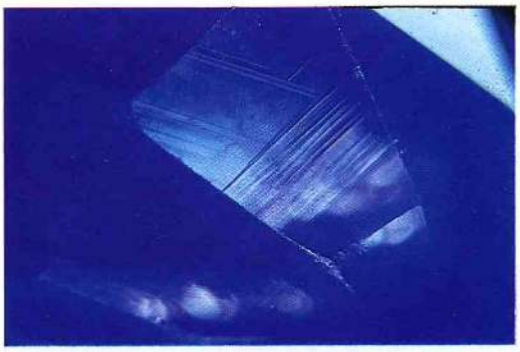

Fig. 6. Reflecting zoned growth in the form of various crystallographic planes and blocks. 20X.

Fig. 7. Very small intercalated twin lamellae. 15X.

Fig. 10. Healed fissure with flat, strongly recrystallised cavities (negative crystals), a few containing opaque crystallites. 50X.

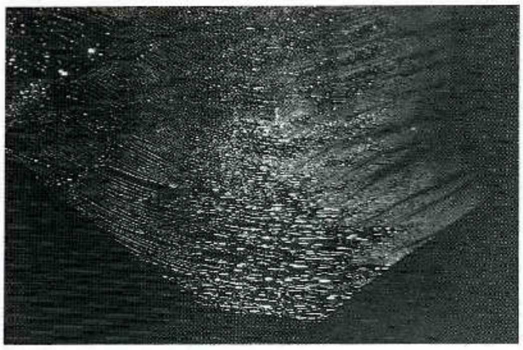

Fig. 8. Graded healed fissure with short tubes and residual droplets. 30X.

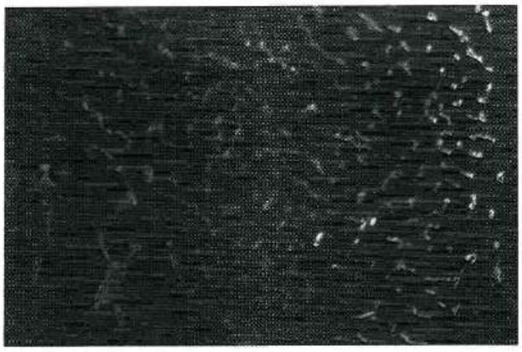

Fig. 9. Healing fissure with a more or less disintegrated network of canal structures. 30X.

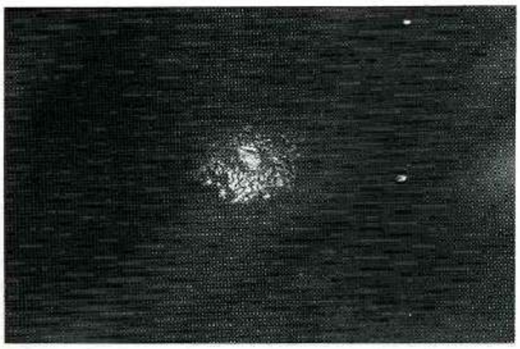

Fig. 11. Apparently burst negative crystal with healed fissure plane containing minute cavities. 50X.

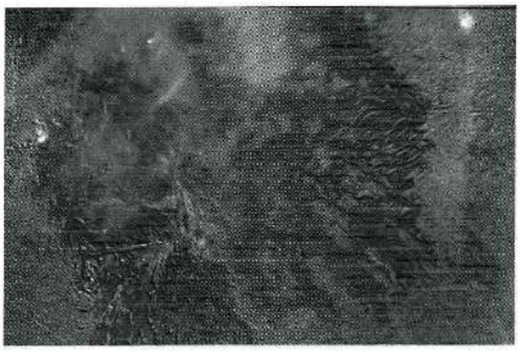

Fig. 12. Incompletely healed fissure with a frost pattern. 30X.

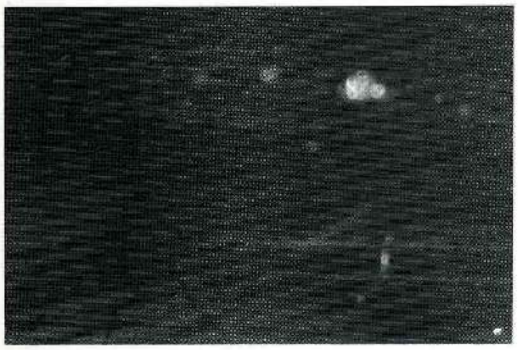

Fig. 13. Lines of dust-like tracks or trails, which cross at acute angles and exhibit fine diagonal striations. 25X.

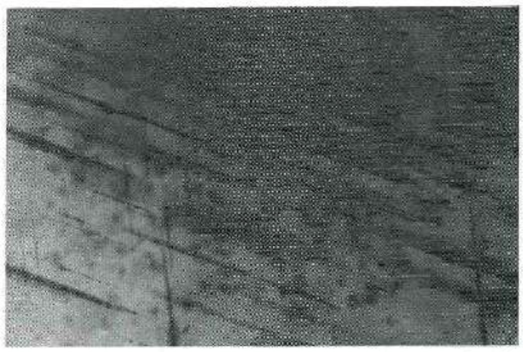

Fig. 14. Intersecting long and shorter dust lines (running in three directions). 25X.

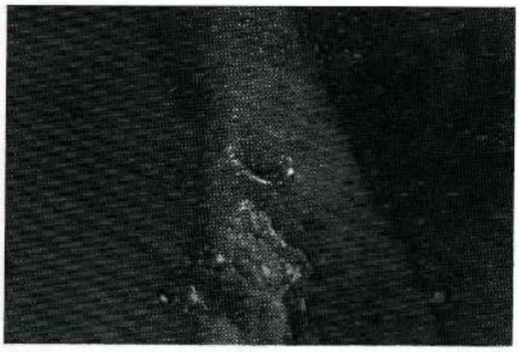

Fig. 15. Green inclusions of tourmaline crystals in Kashmir sapphire, mainly corroded and broken, seldom idiomorphic. 30X.

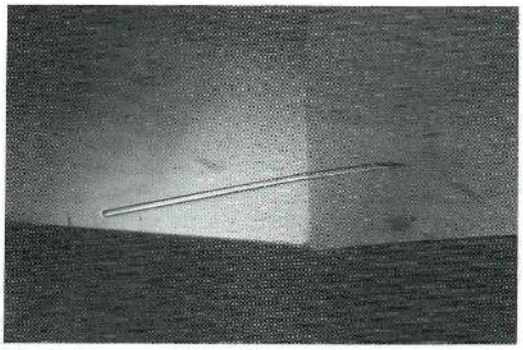

Fig. 16. Long pargasite needle exposed on surface and analysed by SEM/EDS. 45X.

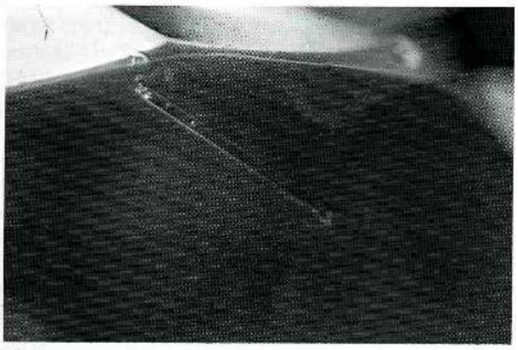

Fig. 17. Long zircon needle exposed on surface and analysed by SEM/EDS. 40X.

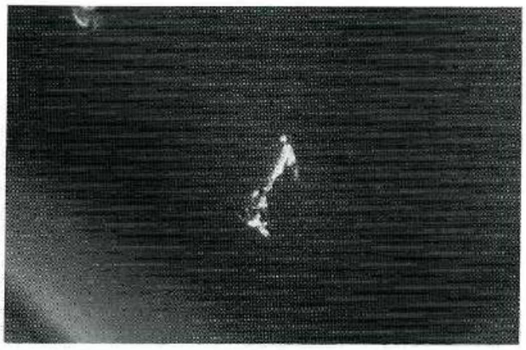

Fig. 18. Corroded zircon crystal inclusion. 60X.

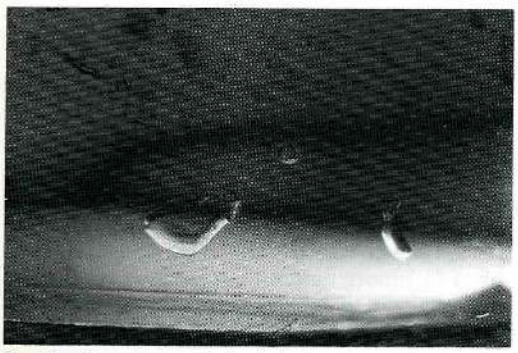

Fig. 19. Strongly corroded plagioclase inclusion exhibiting rounding and indentation. 50X.

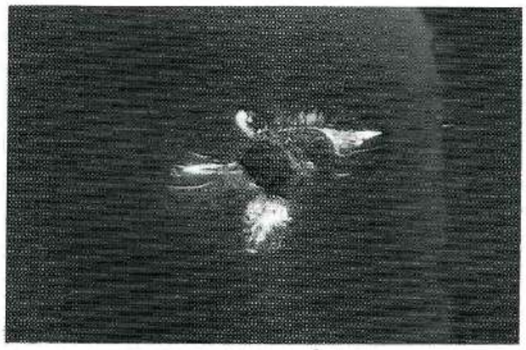

Fig. 20. Opaque cube of uraninite with stress fissures. A number of such crystallites reach the surface and could, therefore, be analysed (SEM/EDS). 40X.

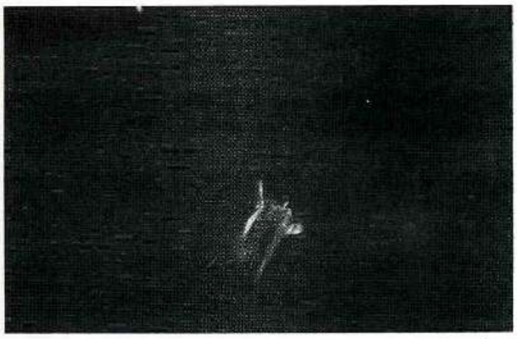

Fig. 21. Allanite (orthite) inclusions occur rarely in Kashmir sapphire. 30X.

Solid inclusions

Rutile (LM) could not be analytically confirmed. Kashmir sapphire can contain few short rutile needles, and it is assumed that the very fine dust particles occurring in zones may be developing rutile crystallites. The formation of rutile needles normally has not taken place. It is assumed that the frequent lamellar turbidity is also due to the presence of extremely fine rutile dust in layers (Figures 3-5). Compare: P1. The segregation of rutile needles from the corundum may have been prevented during fairly rapid cooling, and only dust-like particles were formed and are observed as turbid zones in most of the Kashmir sapphire. The nature of the very fine particles which usually form indistinct, more or less linear white trails is still unclear. Such lines traverse the sapphire roughly perpendicular to possible crystal faces, forming acute angles with each other (Gübelin and Koivula, 1986, p.342). They are constructed of short traverse lines (Figure 13) and could also represent minute rutile features. Compare: P2, G2, G3.

A further form of such minute white structure are the small, cruciform bodies, also shown by Gübelin and Koivula (1986). They seem to be composed of three intersecting planes of dust concentrations, also crystallographically oriented (Figure 14). Compare: G1.

Mineral inclusions in Kashmir sapphire were already observed in the last century (Mallet, 1882). Tourmaline and pargasite are considered to be the classical mineral inclusions specific to the deposit. Zircon has also been mentioned in earlier publications (Phukan, 1966; Schubnel, 1972; Gübelin and Koivula, 1986).

Tourmaline (dravite, SEM) occurs as short greenish crystals occasionally forming groups of inclusions. The stout crystals seldom possess any clear crystallographic forms and could represent partly dissolved crystals (Figure 15). Compare: S1, G6.

Pargasite (EMP, alumino-pargasite to aluminotschermakitic hornblende) forms fine long needles. These needles are so thin, that they are either colourless or pale green (Figure 16). Pargasite occurring as inclusion in corundum has been described in ruby from Burma (Schubnel, 1972) and in ruby from Tanzania (Schubnel, 1972; Eppler, 1973). Compare: S2, G5.

Zircon (SEM) has been found with varying length:width ratios. A ratio of 3:1 is common. A particularly long zircon needle (SEM) displayed a ratio of 18:1 (Fig 17). Stress fissures are nearly always found around the shorter zircons. They contain traces of uranium which explains the occurrence of the fissures, caused by an increase in volume. Some of the zircons are indented perpendicular to the long axis and occasionally contain small opaque inclusions (Figure 18). Compare: P3, G4.

Plagioclase (SEM, Ca-rich) was often observed, but could seldom be analysed. Plagioclase occurs in small, strongly resorbed crystals, sometimes in groups. Twinning is sometimes present. The colourless plagioclase is most easily identified by its habit – rounded form and often containing indentations (Figure 19). Compare: S3.

Uraninite (SEM) occurs as cubic black crystals, from which stress fissures usually radiate (Figure 20). The crystals often possess the same width as growth lamellae into which they are arranged. Rarely, uraninite can form inclusion groups with zircon.

Allanite (SEM, with traces of U and Th) was identified in one case. Again, stress fissures radiate from the colourless to pale reddish brown crystals into the hosting sapphire, presumably due to its content of radioactive elements (Figure 21).

Significance of determination of origin of Kashmir sapphire

Kashmir sapphire is considered by laymen to be unrivalled, but such a judgement cannot be justified as each deposit can produce high and low grade material. The question arises why sapphire from this region is so highly regarded. The fantasy is, of course, affected by the idea of gemstones originating in the past from legendary regions of the inaccessible East! The mines in question, however, are considered to have been exhausted for the last fifty years, and most of the valuable stones of the productive period may lie in the depths of the treasuries of the Maharajahs. Thus, the few Kashmir sapphires on the free market are avidly sought.

The determination of origin of Kashmir sapphire is of particular importance. Often, large price differences are noted on the market between sapphire from Kashmir, accompanied by a credible original report, and from other sources, despite being otherwise visually similar. The nondesirability of 'documents of origin' for gems is discussed by Hughes (1990). Obviously, a definite geographical origin is not a guarantee of high quality, and value should be determined by the beauty of a stone, governed by its colour, size, transparency and cut.

The origin of many stones cannot be stated with certainty, and even localities well-known for their production of quality material also produce inferior stones (Hänni, 1988[b]). In no respect should a 'superior' origin be used as an excuse to increase the value of a poor stone.

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References

Atkinson, D., Kothavala, R.Z., 1983. Kashmir Sapphires *Gems & Gemology*, **XIX**, Summer, 64-76.

Bosshart, G., 1981. Distinction of synthetic and natural rubies by ultra-violet spectrophotometry. *J. Gemm.*, **XVIII**, 145-60.

Bauer, M., 1896. *Edelsteinkunde*. C.H. Tauchnitz, Leipzig, 326-8.

Deer, W.A., Howie, R.A. Zussman, J., 1980. *An Introduction to the rock-forming minerals*. Longman, London.

Eppler, W.F., 1973. *Praktische Gemmologie*. Rühle-Diebener Verlag, Stuttgart.

Goldschmidt, V., 1918. *Atlas der Krystallformen*, Carl Winters Universitätsbuchhandlung. Band V.-Heidelberg.

Gübelin, E.J., Koivula, J.I., 1986. *Photoatlas of inclusions in gemstones*. ABC Edition, Zürich, 342-3.

Hänni, H.A., 1987. On corundum from Umba Valley, Tanzania. *J. Gemm.*, **XX**, 5, 278-84.

Hänni, H.A., 1988[a]. Certitude de la détermination de l'origine des gemmes. *Revue de Gemmologie a.f.g.*, décembre, 4-5.

Hänni, H.A., 1988[b]. An oil well in your garden? *Swiss Watch and Jewelry Journal*, **3**, 461-4.

Hughes, R.W., 1990. A question of origin. *Gemological Digest*.

Hughes, R.W., (in press). *Corundum*. Butterworths, London.

Kiefert, L., 1988. *Mineralogische Untersuchungen zur Charakterisierung und Unterscheidung naturlicher und synthetischer Sapphire*. Diplomarbeit, Universität Heidelberg.

La Touche, T.D., 1890. The sapphire mines of Kashmir. *Rec.Geol.Surv.India*, **22**, 59-69.

Mallet, F.R., 1882. On sapphires recently discovered in the north-west Himalayas. *Rec.Geol.Surv.India*, **XV**, 140.

Middlemiss, C.S., 1931. *Precious and semi-precious gemstones of Jammu and Kashmir*. Mineral Survey Report IX, Jammu and Kashmir Government.

Peretti, A., 1989. Personal communication.

Phukan, S., 1960. Studies on inclusions in some Indian gemstones. *J.Gemm.*, **X**, 1-7.

Roedder, E., 1982. Fluid inclusions in gemstones valuable defects in *Gemmological Symp. Proceedings 1982*, G.I.A. Santa Monica, 479-502.

Roy, B.C., 1949. Corundum. *Indian Minerals*, **3**, 3, 109-74.

Schmetzer, K., Bank, H., 1980. Explanations of the absorption spectra of natural and synthetic Fe- and Ti-containing corundums. *N.Jb.Miner.Abh.*, **139**, 216-25.

Schmetzer, K., Bank, H., 1981. Die Farbursachen und Farben der Mineralart Korund. *Z.Dt.Gemmolo.Ges.*, **31**, 265-80.

Schmetzer, K., 1985. Ein verbesserter Probenhalter und seine Anwendung auf Probleme der Unterscheidung natürlicher und synthetischer Rubine sowie natürlicher und synthetischer Amethyste. *Z.Dt.Gemmol.Ges.*, **34**, 29-46.

Schmetzer, K., 1986. *Natürliche und synthetische Rubine*. Eigenschaften und Bestimmung. E.Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart.

Schmetzer, K., 1989. Personal communication.

Schubnel, H.J., 1972. *Pierres précieuses dans le monde*. Horizons de France.

Stern, W.B. Hänni, H.A., 1982. Energy-dispersive X-ray spectrometry: a non-destructive tool in gemmology. *J.Gemm.*, **XVIII**, 285-96.